Pioneer-Sarah Creek Subwatershed Total Maximum Daily Load

wq-iw8-55e

Minnesota Pollution Control Agency

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Cover photo of Little Long Lake in Pioneer-Sarah Creek Watershed (by Three Rivers Parks District)

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Location	Located within western Hennepin County in the Pioneer-Sarah Creek Watershed in the Upper Mississippi River Basin.		2
303(d) Listing Information	Table 1.1 in Section 1.2		3
Applicable Water Quality Standards/ Numeric Targets	Criteria are set forth in Minn. R. 7050.0150 (Total Phosphorus and *E. coli*)		5 - 6
	Waterbody	**Numeric Target**	
	Bacteria Impairments	No more than 126 organisms per 100 ml as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 1,260 organisms per 100 ml. The standard applies only between April 1 and October 31.	
	Nutrient Impairments	Growing season (June-September) means of total phosphorus of 40 µg/l or less for deep lakes, 60 µg/l or less for shallow lakes	
Loading Capacity (expressed as daily load)	Nutrients: See Section 4.2.1 Bacteria: See Section 4.3.1		28 38
Wasteload Allocation	Nutrients: See Section 4.2.3 Bacteria: See Section 4.3.3		30 40
Load Allocation	Nutrients: See Section 4.2.2 Bacteria: See Section 4.3.2		29 40
Margin of Safety	Lake Nutrients: Explicit MOS of 5% of the loading capacity of each lake. See Section 4.2.4 Bacteria: An explicit figure of 5% of the loading capacity for each flow regime was used to represent the MOS. See Section 4.3.4		32 41
Seasonal Variation	Nutrients: See Section 4.2.5 Bacteria: Load duration curve methodology accounts for seasonal variations. See Section 4.3.5		32 41

Reasonable Assurance	TMDL implementation will be carried out on an iterative basis so that implementation course corrections based on periodic monitoring can be made to adjust the strategy to meet the applicable standard. See Section 6.	48
Monitoring	Progress in implementing the TMDL will be measured through regular monitoring efforts of water quality and total BMPs completed and estimates of the load reduction associated with those BMPs where appropriate. This will be accomplished through the efforts of several cooperating organizations. See Section 7.	51
Implementation	This report sets forth an implementation framework to achieve the TMDL. See Section 8.1. The cost of compliance with the TMDL is included for the one permitted point source affected, and an estimated cost range for the overall effort to meet the TMDL based on various assumptions is also included. See Section 8.5.	53
Public Participation	See Section 9 Public comment period: May 1, 2017 through May 31, 2017	60

Acronyms

ac-ft/yr	acre feet per year
AU	animal unit
AUID	Assessment Unit ID
BMP	Best Management Practice
BOD	biochemical oxygen demand
Chl-*a*	Chlorophyll-*a*
CLPW	curly-leaf pondweed
CWP	Clean Water Partnership
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
GW	Groundwater
HUC	Hydrologic Unit Code
IMW	Intensive Watershed Monitoring
ITPHS	imminent threat to public health and safety
in/yr	inches per year
km^2	square kilometer
LA	Load Allocation
Lb.	pound
lb/day	pounds per day
lb/yr	pounds per year
LGU	Local Government Unit
m	meter
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day
mL	milliliter
MnDOT	Minnesota Department of Transportation
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
MUSA	Metropolitan Urban Service Area
NCHF	North Central Hardwood Forests
NPDES	National Pollutant Discharge Elimination System
PSCWMC	Pioneer-Sarah Creek Watershed Management Commission
RC	Reserve Capacity
SDS	State Disposal System
SOD	sediment oxygen demand
SSTS	Subsurface Sewage Treatment Systems
TDLC	Total Daily Loading Capacity
TMDL	Total Maximum Daily Load
TP	Total phosphorus

UAL	Unit-area Load
µg/L	microgram per liter
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategies
WWTP	Wastewater Treatment Plant

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses 10 impairments in the Pioneer-Sarah Creek Subwatershed of the North Fork Crow River (Hydrologic Unit Code (HUC) 07010204) and South Fork Crow River Watersheds (HUC 07010205), located in the Upper Mississippi River Basin. These include nutrient impairments in Lake Ardmore, Peter Lake, Spurzem Lake, Half Moon Lake, North Whaletail Lake, and South Whaletail Lake, and *Escherichia coli (E. coli)* bacteria impairments in Sarah Creek, Pioneer Creek, Unnamed Creek, and Deer Creek.

All impaired water bodies addressed in this study, with the exception of Unnamed Creek, lie within the jurisdictional boundaries of the Pioneer-Sarah Creek Watershed Management Commission (PSCWMC). The area within the jurisdictional boundaries of the PSCWMC is about 45,000 acres and is located in western Hennepin County, Minnesota. The PSCWMC was formed in 1984 through a joint powers agreement among six municipalities (Greenfield, Independence, Loretto, Maple Plain, Medina, and Minnetrista), whose primary purpose is to protect and improve surface water quality and aquatic habitat.

The goal of this TMDL study is to quantify the pollutant reductions needed to meet state water quality standards for nutrients in lakes and *E. coli* for the four impaired stream reaches. This TMDL was established in accordance with Section 303(d) of the Clean Water Act and provides wasteload allocations (WLAs) for point sources (permitted sources), load allocations (LAs) for nonpoint sources (non-permitted sources), natural background assessment, and a margin of safety (MOS) aimed to restore aquatic recreation designated uses for the water bodies included.

Lakes

The TMDL study includes six lakes that are not meeting lake eutrophication standards for the North Central Hardwood Forests (NCHF) ecoregion. Nutrient budgets were developed for all six lakes, along with lake response models to determine the TMDLs. The primary sources of phosphorus to the lakes include manure, agricultural runoff from cropland areas, internal loading (from sediment release of phosphorus and/or curly-leaf pondweed (CLPW)), and urban and rural watershed runoff. Total nutrient reductions required to meet the lake water quality standards range from less than 30% for Peter Lake and South Whaletail Lake to over 90% for Lake Ardmore. Nutrient reduction implementation strategies for the lakes include application of stringent stormwater management standards to new and re-development activities, improving manure and pasture management, reducing nutrient and sediment loss from cropland, inspection and replacement of non-compliant septic systems, and reducing internal loading from enriched sediments, CLPW, and/or roughfish.

Bacteria

Flow and bacteria monitoring data in Sarah Creek, Pioneer Creek, Unnamed Creek, and Deer Creek were used to establish load duration curves to define the reductions necessary to meet the *E. coli* standard. A bacteria source inventory was conducted to estimate the potential sources of bacteria in the watershed of each impaired reach. This analysis indicated that wildlife is the primary source in Sarah Creek, while horses and livestock are the primary sources in Pioneer, Unnamed, and Deer Creeks. Bacteria reductions up to 66% are required to meet *E. coli* water quality standards, depending on flow conditions. Recommended implementation activities include manure and pasture management initiatives, limiting livestock access to streams, inspection and replacement of non-compliant septic systems, and pet waste management.

Findings of this TMDL were used for development of the implementation activities included in the Pioneer-Sarah Creek Watershed Restoration and Protection Strategy (WRAPS) Report. The intent of the WRAPS report was to develop scientifically based restoration and protection strategies for the Pioneer-Sarah Creek Subwatershed.

1. Project Overview

1.1 Purpose

The goal of this TMDL report is to quantify the pollutant load reductions needed to meet the Minnesota Pollution Control Agency's (MPCA's) water quality standards for nutrients in six lakes and bacteria in four stream reaches in the Pioneer-Sarah Creek Subwatershed. This TMDL was established in accordance with Section 303(d) of the Clean Water Act and provides the WLAs and LAs for the impaired water resources. This TMDL study is one component of the Pioneer-Sarah Creek WRAPS report designed to protect and restore key water resources within the Pioneer-Sarah Creek Subwatershed.

Figure 1-A shows the hydrologic boundary of the Pioneer-Sarah Creek Subwatershed, the jurisdictional limits of the PSCWMC, key water features that will be addressed in this document, and the municipalities that are included within the project area. The Pioneer-Sarah Creek Subwatershed covers an area of approximately 55.2 square miles (35,305 acres) and is located in the western part of the Minneapolis-St. Paul Metropolitan Area in Hennepin County. The subwatershed is drained by Pioneer Creek, Sarah Creek, and several minor tributaries to the Crow River. Water movement in the watershed is generally from east to west, with Sarah Creek discharging to the Crow River near the city of Rockford in Wright County, and Pioneer Creek discharging to the South Fork Crow River south of the city of Delano in Hennepin County. The subwatershed includes all or part of the cities of Minnetrista, Independence, Maple Plain, Medina, Greenfield, Loretto and a very small portion of Corcoran. The Pioneer-Sarah Creek Subwatershed is located entirely within the NCHF ecoregion.

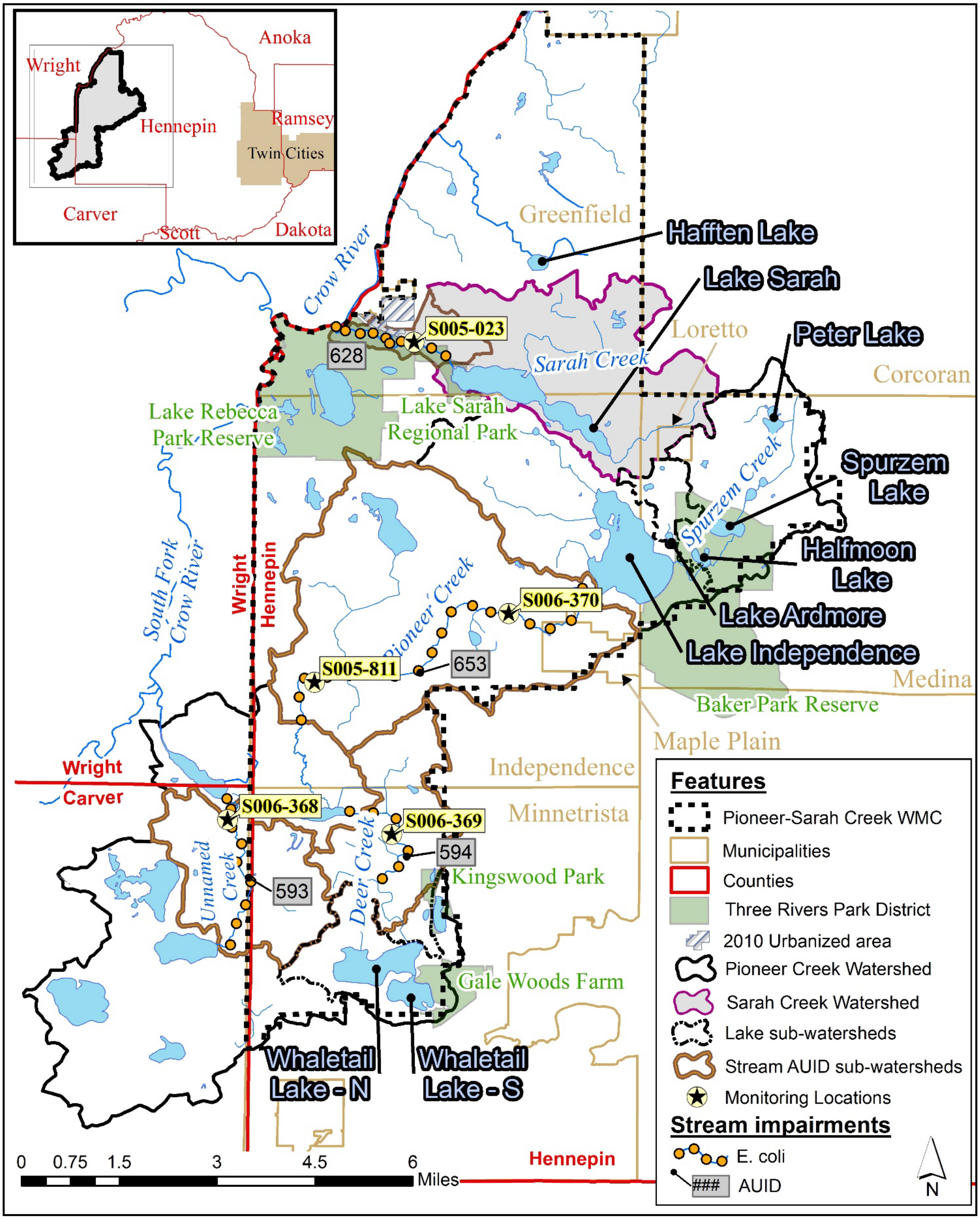


Figure 1-A - Pioneer-Sarah Creek Watershed Location and Key Features.

1.2 Identification of Waterbodies

Numerous impairments have been identified based on monitoring data collected by MPCA, PSCWMC, Three Rivers Park District, and others during the 10-year period between 2006 and 2015. Table 1.1 summarizes the current and proposed impairment listings included in this report.

Table 1.1 - Impairments addressed in this TMDL report

Stream (Reach Description) or Lake Name	Assessment Unit ID	Affected Use	Pollutant	Designated Use Class	Year Listed	TMDL Target Start/Completion
Sarah Creek	07010204-628	Aquatic recreation	*E. coli*	2B, 3C	2012	2014/2019
Pioneer Creek	07010205-653			2C	Proposed 2016*	2012/2017
Unnamed Creek	07010205-593			2B, 3C		
Deer Creek	07010205-594					
Peter Lake – North Bay	27-0147-02	Aquatic Recreation	Nutrients	2B, 3C	Proposed 2016*	2012/2017
Spurzem Lake	27-0149				2008	2013/2018
Half Moon Lake	27-0152				Proposed 2016*	2012/2017
Lake Ardmore	27-0153				Proposed 2016*	2012/2017
South Whaletail Lake	27-0184-02				2006	2013/2018
North Whaletail Lake	27-0184-01				2008	2013/2018

* Listed on the 2016 Draft 303(d) Impaired Waters List.

1.3 Previously Completed TMDLs and Other Impairments

TMDLs have already been completed for three lakes in the project area: Lake Independence (851 acres), Lake Sarah (552 acres), and Hafften Lake (43 acres). The Lake Independence Phosphorus TMDL was approved in 2007 and calls for an overall estimated phosphorus load reduction of 1,081 lbs/yr, which equates to a 45% reduction in the phosphorus loading affecting the lake at the time the TMDL was prepared. Lake Ardmore and the chain of lakes on Spurzem Creek (Peter, Spurzem, and Half Moon) all discharge water that reaches Lake Independence and assuring that these lakes meet water quality standards will help achieve the load reduction goal for Lake Independence. The Lake Sarah Nutrient TMDL was approved in 2011 and requires a phosphorus load reduction of 4,330 lbs/yr, or about 79% of the load affecting the lake at the time the TMDL was prepared. About 26% of the load reduction was targeted to come from watershed sources, and 74% from control of internal sources (CLPW and releases of phosphorus from enriched lake bottom sediments). Finally, the TMDL for Hafften Lake was included in the North Fork Crow River TMDL: Bacteria, Nutrients, and Turbidity report, which was approved in 2015. The TMDL calls for a 34% reduction of the phosphorus load affecting the lake.

In addition to the *E. coli* impairments, Pioneer Creek, Unnamed Creek, and Deer Creek are also on the 2016 Draft 303(d) Impaired Waters List as impaired by low dissolved oxygen (DO). These impairments are based on historic DO data collected by Three Rivers Park District, which includes periodic site visits as well as data sonde deployments to continuously monitor DO throughout the summer period. Synoptic surveys for each DO impaired reach conducted in July and August 2013 included longitudinal measurements of DO and biochemical oxygen demand (BOD) at several locations throughout each impaired reach. The synoptic survey data were used to construct and calibrate River and Stream Water Quality Models (QUAL2K) for each reach to determine and quantify the sources of low DO.

Results of the surveys and modeling suggest that low DO levels are primarily driven by BOD (algae) loading from upstream impaired lakes (Lake Independence, Whaletail Lake, and Mud Lake) and in-channel sediment oxygen demand (SOD) in reaches that flow through large wetland complexes. Since the drivers of low DO appear to be a combination of natural background conditions (wetlands) and upstream lake loading, DO TMDLs were not developed at this time. Instead, the WRAPS Report includes some general strategies to address the DO impaired reaches, as well as strategies aimed at decreasing phosphorus loading from the upstream impaired lakes and investigating potential channel alterations/restorations after the lakes have been restored. The synoptic survey and modeling efforts are summarized in a series of technical memorandums available on the Pioneer-Sarah Creek WRAPS: TMDL Project webpage.

1.4 Priority Ranking

The MPCA's schedule for TMDL completions, as indicated on the 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned our TMDL priorities with the watershed approach and our WRAPS cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on the 10-year cycle. The MPCA developed a state plan Minnesota's TMDL Priority Framework Report to meet the needs of EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments, which will be addressed by TMDLs by 2022. The Pioneer-Sarah Creek Watershed waters addressed by this TMDL are part of that MPCA prioritization plan to meet the EPA's national measure.

2 Applicable Water Quality Standards and Numeric Water Quality Targets

2.1 State of Minnesota Designated Uses

Most of the impaired waters included in Table 1.1 are classified as Class 2B (warm water/cool water) and Class 3C waters, which indicates industrial use. Pioneer Creek is classified as a Class 2C water (indigenous fish and associated aquatic life and habitat). These waters are protected for aquatic life and recreation uses by [Minn. R. 7050.0140, subp. 3](#).

2.2 State of Minnesota Standards and Criteria for Listing

Following is a brief summary of the numerical water quality standards adopted by the state of Minnesota for the impairments that are addressed in this document.

2.2.1 Excess Nutrients

Minnesota's standards for nutrients limit the concentration of nutrients, which may be found in surface waters. Minnesota's standards at the time of listing (Minn. R. 7050.0150(3)) also stated that in all Class 2 waters of the state ". . . *there shall be no material increase in undesirable slime growths or aquatic plants including algae*." In accordance with Minn. R. 7050.0150(5), to evaluate whether a water body is in an impaired condition, the MPCA has developed "numeric translators" for the narrative standard for purposes of determining which lakes should be included in the Section 303(d) list as being impaired by nutrients. The translators established numeric thresholds for phosphorus, chlorophyll–*a*, and water clarity as measured by Secchi depth.

Minnesota adopted lake water quality standards in 2008 that differentiate between "deep" lakes and "shallow" lakes. Shallow lakes are defined as lakes with a maximum depth of 15 feet or less or with 80% or more of the lake area shallow enough to support emergent or submergent rooted aquatic plants (littoral zone). Conversely, deep lakes are defined as those with maximum depths over 15 feet and as having less than 80% of the lake area as littoral zone. This TMDL addresses impairments for both deep and shallow lakes. The numeric eutrophication standards that apply to each type of lake for the NCHF ecoregion are presented in Table 2.1. In addition to meeting phosphorus limits, chlorophyll-*a* (Chl-*a)* and Secchi transparency standards must be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (MPCA 2005). Clear relationships were established between the causal factor total phosphorus (TP) and the response variables Chl-*a* and Secchi transparency. Based on these relationships, it is expected that by meeting the phosphorus target in each lake, the Chl-*a* and Secchi standards will likewise be met.

Table 2.1 - Numeric eutrophication standards for shallow and deep Lakes within the NCHF Ecoregion.

Parameters	Shallow[1]	Deep[1]
Total Phosphorus (µg/L)	<60	<40
Chlorophyll-*a* (µg/L)	<20	<14
Secchi disk (meters)	>1.0	>1.4

[1] Numeric standards are June 1 – September 30 mean values

2.2.2 Bacteria *(E. coli)*

The narrative standard for Class 2B (also applicable to Class 2C waters) is defined in Minn. R. 7050.0222:

> *The quality of Class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. (underline emphasis added)*

The numeric standard for Class 2B (also applicable to Class 2C) for *E. coli*:

> *Not to exceed 126 organisms per 100 milliliters (cfu/100ml) as a geometric mean of not less than five samples representative of conditions within any given calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 1,260 cfu/100 ml. The standard applies only between April 1 and October 31.*

2.3 Analysis of Impairment

The criteria used for determining impairments are outlined in the MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) list (2016). The MPCA guidance manual includes information on how the MPCA monitors and assesses surface waters to determine if they are considered impaired based on their designated uses. Section VII- Protection of Aquatic Resources, includes an overview of aquatic recreation-based standards, including *E. coli* bacteria for streams and rivers and excessive nutrient loads for lakes. Section VII outlines the data requirements needed for determination of an impaired condition, and also includes information on the determination of lake classification (shallow/deep) and ecoregion.

3 Watershed and Waterbody Characterization

3.1 Overview of Pioneer-Sarah Creek Subwatershed

The Pioneer-Sarah Creek Subwatershed is located in the northwest portion of the Minneapolis-St. Paul metropolitan area, in portions of the North and South Fork Crow River Watersheds of the Upper Mississippi River Basin. The subwatershed covers just over 70 square miles (44,980 acres) and includes all or portions of the cities of Minnetrista, Independence, Maple Plain, Medina, Greenfield, Loretto and a very small portion of Corcoran. Based on 2010 data from the Metropolitan Council, about 36% of the land within the subwatershed is classified as undeveloped, a category that includes undevelopable wetlands and grasslands, in addition to lands that are currently vacant and developable. Nearly 38% of the subwatershed is classified as agricultural, and less than 10% was classified as developed land uses.

3.2 Lakes

Table 3.1 shows basin morphometric data and watershed information for each of the six lakes that are addressed in this document. For purposes of assigning appropriate water quality standards, North Whaletail Lake is considered a shallow lake, while the other five lakes are considered deep lakes.

Table 3.1 - Summary data for Pioneer-Sarah Creek Watershed Impaired Lakes.

Characteristic	Peter Lake (N. Bay)	Spurzem Lake	Half Moon Lake	Lake Ardmore	South Whaletail Lake	North Whaletail Lake
Surface Area (ac)	55.8	78.6	31.1	13.5	156.1	369.9
Max Depth (ft)	69.1	37.4	30.3	24.4	23.3	10.3
Mean depth (ft)	15.1	11.1	13.4	9.5	12.1	5.2
Volume (ac-ft)	840.3	873.1	416.2	127.9	1,895	1,904
Residence Time (yrs)	3.8	0.50	0.20	0.48	2.37	1.05
Littoral area (ac)	32.5	55.3	18.3	10.1	102.8	369.9
Littoral area (%)	58	70	59	75	66	100
Watershed area (ac)[1]	301	2,915	3,430	507	673	1,256
Watershed Area : Lake Area Ratio	5.3 : 1	37 : 1	110 : 1	38 : 1	4.3 : 1	3.4 : 1
Municipalities in Watershed	Medina, Corcoran	Medina, Loretto, Corcoran	Medina, Loretto, Corcoran	Medina, Independence	Minnetrista	Minnetrista

[1] Does not include area of subject lake but does include area of upstream lakes

3.3 Streams

The Sarah Creek *E. coli* impaired reach (628) is approximately 2.4 miles long and is completely contained in Hennepin County in the Pioneer-Sarah Creek Subwatershed within the larger South Fork Crow River Watershed (Figure 1-A, Table 3.2). The watershed of the impaired reach, including land upstream of the reach headwaters, covers approximately 5,831 acres. The predominant land use types throughout the subwatershed are agriculture (40%), park/reserve/recreation (35%), and undeveloped land (25%), which includes wetlands and other vacant undevelopable land (Table 3.4 in Section 3.5).

The Pioneer Creek *E. coli* impaired reach (593) is approximately 7.1 miles long and is completely contained in Hennepin County in the Pioneer-Sarah Creek Subwatershed (Figure 1-A, Table 3.2). The watershed of the impaired reach, including land upstream of the reach headwaters, covers approximately 17,573 acres. The predominant land use types throughout the watershed are undeveloped land (41%) and agriculture (40%; Table 3.4).

The Unnamed Creek *E. coli* impaired reach (593) is approximately 3.1 miles long in the Pioneer-Sarah Creek Subwatershed (Figure 1-A, Table 3.2). The watershed of the impaired reach, including land upstream of the reach headwaters, covers approximately 6,715 acres in Carver and Hennepin Counties. Only a small fraction of the watershed land cover is urbanized or roads. Over half the watershed is in agricultural use (58%), while undeveloped land is the other primary land use (31%; Table 3.4).

The Deer Creek *E. coli* impaired reach (594) is approximately 2.1 miles long, located in the city of Minnetrista in the Pioneer-Sarah Creek Subwatershed (Figure 1-A, Table 3.2). The watershed of the impaired reach, including land upstream of the reach headwaters, covers approximately 4,936 acres. The predominant land use types in the watershed are undeveloped (46%), agriculture (39%), and single family residential (11%; Table 3.4).

Table 3.2 - Key information for Pioneer Sarah Creek Watershed Stream Reaches Listed as Impaired.

Characteristic	Sarah Creek	Pioneer Creek	Unnamed Creek	Deer Creek
Reach Length (mi)	2.4	7.1	3.1	2.1
Upstream Boundary Condition(s)	Lake Sarah	Lake Independence	Oak Lake and Mud Lake	North Whaletail Lake
Direct Watershed Area[1] (acres)	760	9,178	2,952	2,603
Total Watershed Area[2] (acres)	5,831	17,573	6,714	4,936
Municipalities in Direct Watershed	Greenfield	Independence, Maple Plain	None	None

[1] Only includes are draining directly to impaired reach. Does not include watershed area draining to upstream lakes that were identified as boundary conditions

[2] Total area of the impaired reach watershed – includes upstream boundary conditions.

3.4 Lake Land Use and Subwatersheds

Figure 3-A shows the 2010 Met Council land cover for the Pioneer-Sarah Creek Watershed project area based on Metropolitan Council data. Table 3.3 summarizes the land cover for each of the six lake watersheds (inclusive of the watersheds of upstream lakes and of the lakes themselves) by major land cover category.

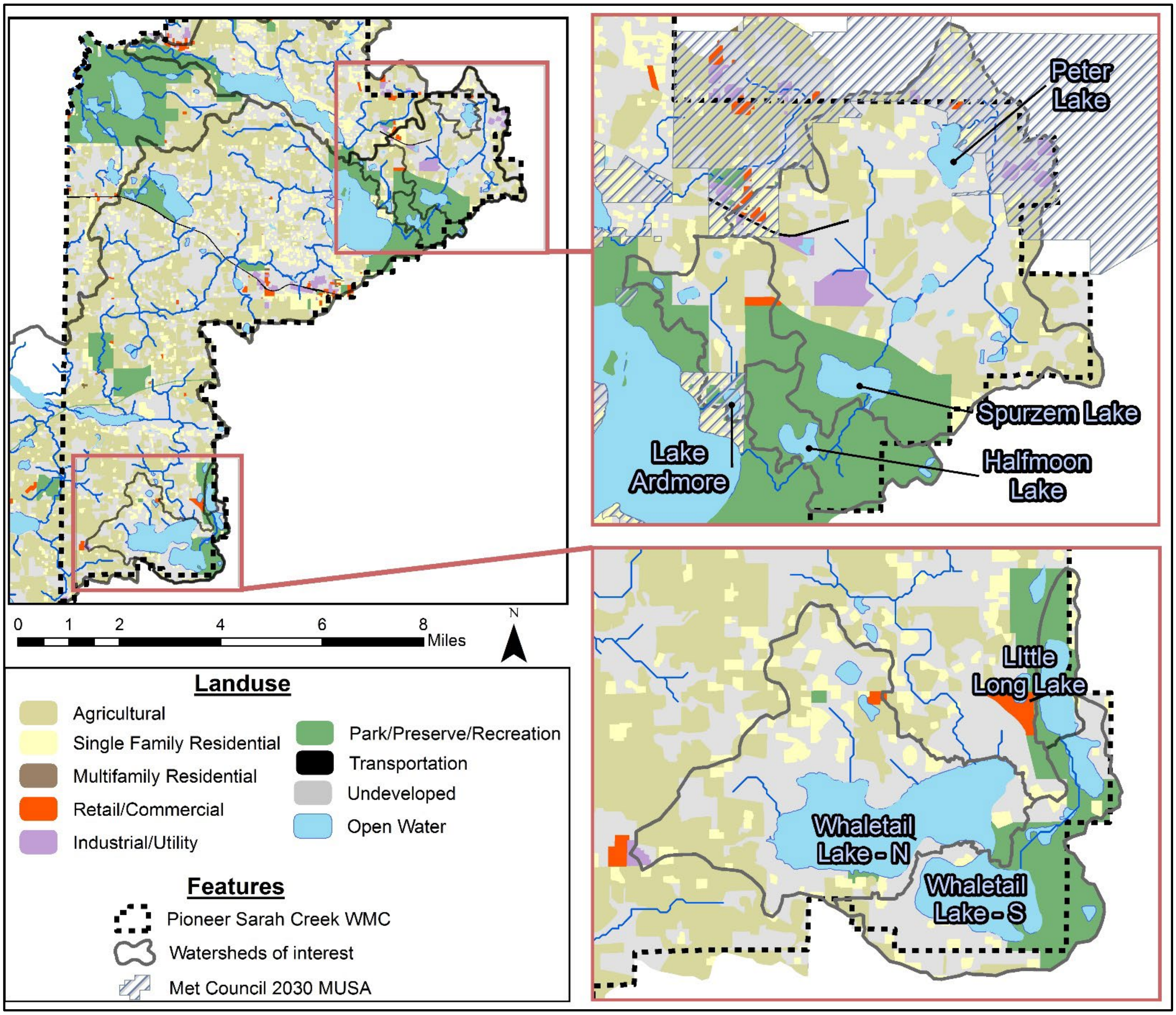


Figure 3-A - 2010 Met Council Land Cover and Planned 2030 MUSA Coverage for Project Area Lake Watersheds.

Table 3.3 - Summary of Met Council 2010 Land Cover for the Project Area Lakes.

	Peter Lake watershed		Spurzem Lake watershed[1]		Half Moon Lake watershed[2]		Lake Ardmore watershed		South Whaletail Lake watershed		North Whaletail Lake watershed[3]	
Met Council 2010 Land Use Classification	Area (ac.)	%	Area (ac.)	%	Area (ac.)	%	Area (ac.)	%	Area (ac.)	%	Area (ac.)	%
Agricultural	71	19.9	823	27.5	823	23.8	156	29.9	30	3.6	316	15.1
Undeveloped	191	53.5	1,241	41.5	1,241	35.9	124	23.8	212	25.5	667	32.0
Park/Preserve/Recreation	0	0.0	372	12.4	802	23.2	185	35.6	284	34.3	310	14.9
Single Family Residence	35	9.9	237	7.9	237	6.8	23	4.5	50	6.1	153	7.3
Open water	55	15.4	178	5.9	215	6.2	23	4.4	253	30.6	631	30.3
Retail/Commercial	0.5	0.1	13	0.4	13	0.4	9	1.8	0	0.0	4	0.2
Multifamily Residence	0	0.0	2	0.1	2	0.0	0	0.0	0	0.0	0	0.0
Industrial/Utility	4	1.2	119	4.0	119	3.4	0	0.0	0	0.0	5	0.2
Transportation	0	0.0	11	0.4	11	0.3	0	0.0	0	0.0	0	0.0
Totals	357		2,996		3,463		520		829		2,086	

1 Includes Peter Lake watershed

2 Includes Peter Lake and Spurzem Lake watersheds

3 Includes Whaletail-S Lake watershed

Only about 658 acres (17%) of the Peter Lake, Spurzem Lake, Half Moon Lake and Lake Ardmore Watersheds are within the 2030 Metropolitan Urban Service Area (MUSA). There are no areas in the North Whaletail Lake or South Whaletail Lake Watersheds in the 2030 MUSA. Future MUSA coverage reflects the anticipation by regional and local governments to convert current land uses to urban and suburban land uses in the future.

Based on a review of the comprehensive land use plans prepared by each community within the project area, approximately 2,350 acres (about 60%) of the Peter Lake, Spurzem Lake, Half Moon Lake and Lake Ardmore hydrologic watersheds are expected to change land use between 2010 and 2030. For the North Whaletail and South Whaletail Lake Watersheds, the expected change is about 890 acres, which is about 43% of the total land area of the combined watersheds of these two lakes. Most of the future land use is expected to involve conversion of undeveloped or agricultural land to low density/rural residential land uses.

3.5 Stream Land Use and Subwatersheds

Figure 3-B shows the Metropolitan Council 2010 land cover for the subwatersheds of the impaired stream reaches. Table 3.4 summarizes the land cover for each of the stream AUID watersheds by major land cover category.

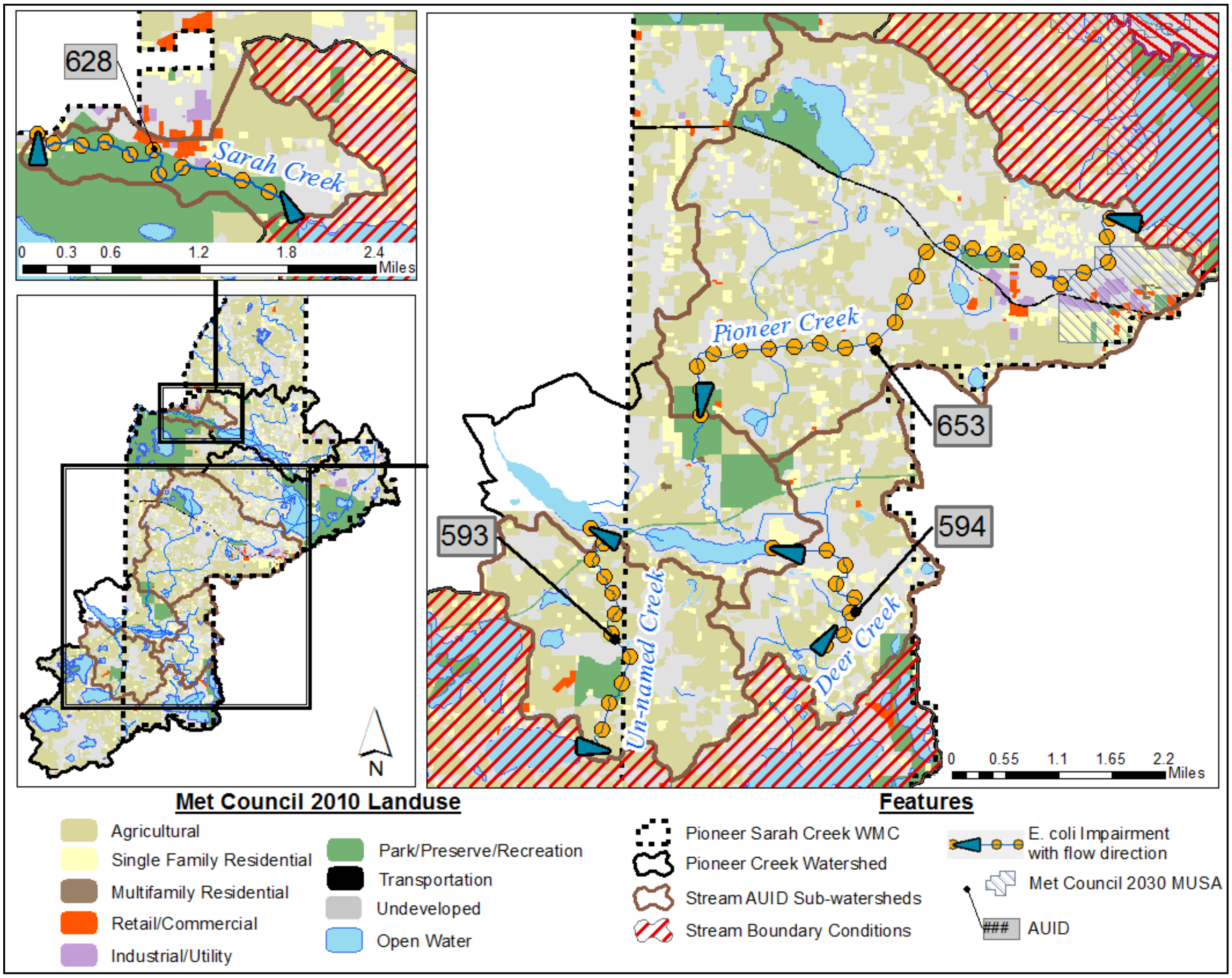


Figure 3-B - 2010 Met Council Land Cover and Planned 2030 MUSA Coverage for Project Area Stream Reach Watersheds.

Table 3.4 - Summary of 2010 Met Council land use for the stream AUID direct watersheds (not including the upstream watershed above the AUID reach boundaries).

Met Council 2010 Land Use Classification	Sarah Creek Watershed (AUID 628) Area (ac.)	%	Unnamed Creek Watershed (AUID 593) Area (ac.)	%	Deer Creek Watershed (AUID 594) Area (ac.)	%	Pioneer Creek Watershed (AUID 653) Area (ac.)	%
Agricultural	230	30.3	1,719	58.2	1,009	38.8	3,633	39.6
Undeveloped	187	24.7	925	31.3	1,198	46.0	3,728	40.6
Park/Preserve/Recreation	267	35.2	142	4.8	80	3.1	419	4.6
Single Family Residence	40	5.3	99	3.4	290	11.2	774	8.4
Open water	0	0.0	48	1.6	20	0.8	345	3.8
Retail/Commercial	27	3.6	19	0.6	5	0.2	81	0.9
Multifamily Residence	0	0.0	0	0.0	0	0.0	11	0.1
Industrial/Utility	7	1.0	0	0.0	0	0.0	120	1.3
Transportation	0	0.0	0	0.0	0	0.0	67	0.7
Totals	758		2,952		2,602		9,178	

The dominant land use for land directly adjacent to the impaired stream reaches is agricultural (averaging 46% of all land use across the Pioneer Creek Stream Subwatersheds and 30% of the Sarah Creek Stream Subwatershed). About 166 acres (22%) of the Sarah Creek Stream Subwatershed and 701 acres (8%) of the Pioneer Creek Stream Subwatershed are within the 2030 MUSA. There are no areas of Unnamed Creek and Deer Creek direct subwatersheds in the 2030 MUSA. As noted above, future MUSA coverage reflects the anticipation by regional and local governments to convert current land uses to urban and suburban land uses in the future.

Based on a review of the comprehensive land use plans prepared by each community within the project area, approximately 3,670 acres (about 40%) of the Pioneer Creek Subwatershed, 1,200 acres (about 46%) of the Deer Creek Subwatershed, and 321 acres (about 42%) of the Sarah Creek Subwatershed are expected to change land use between 2010 and 2030. Most of the future land use is expected to involve conversion of undeveloped or agricultural land to low density/rural residential land uses. There are no major expected land use changes for the Unnamed Creek subwatershed between 2010 and 2030.

3.6 Water Quality

3.6.1 Nutrients

Historical surface water quality data for TP, chlorophyll–*a*, and secchi disk transparency for all six lakes addressed in this report are summarized in Figure 3-C through Figure 3-H. Where data are available, the data presented in the figures extend back to the mid-1990s, though the focus for this TMDL is the 10-year period between 2006 and 2015. The data presented are mean values over the growing season (June through September) each year.

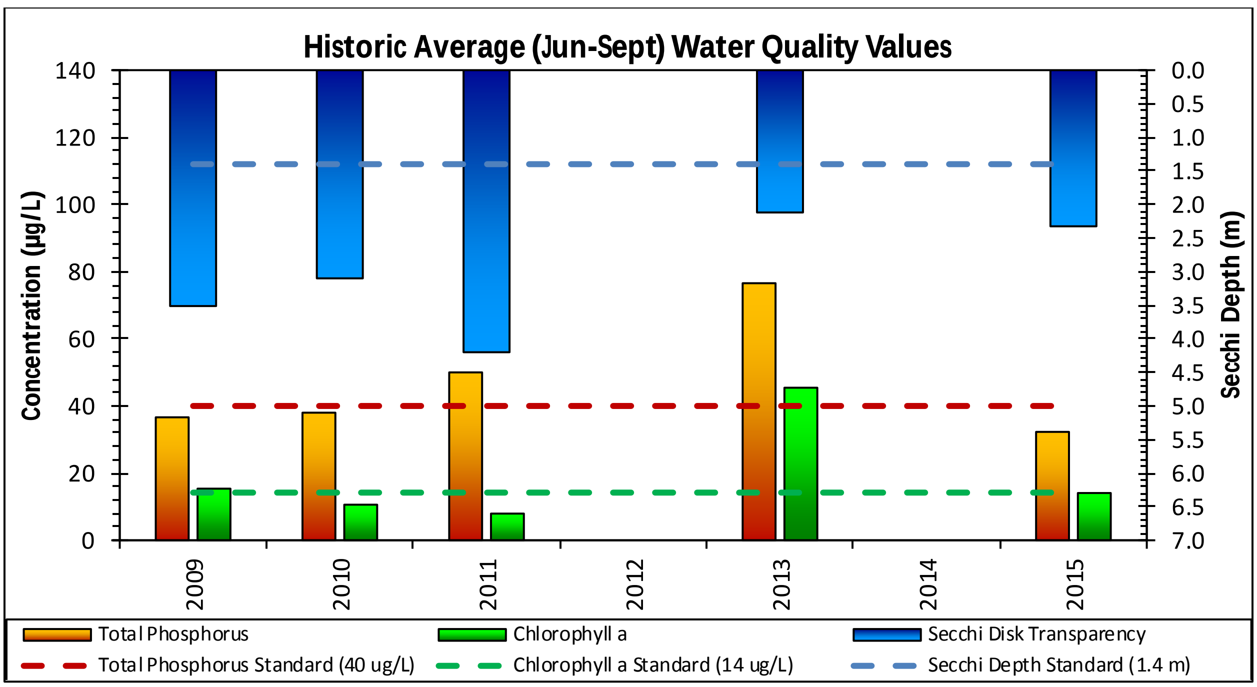


Figure 3-C - Peter Lake (North Bay) Growing Season (June – September) Mean Water Quality Data

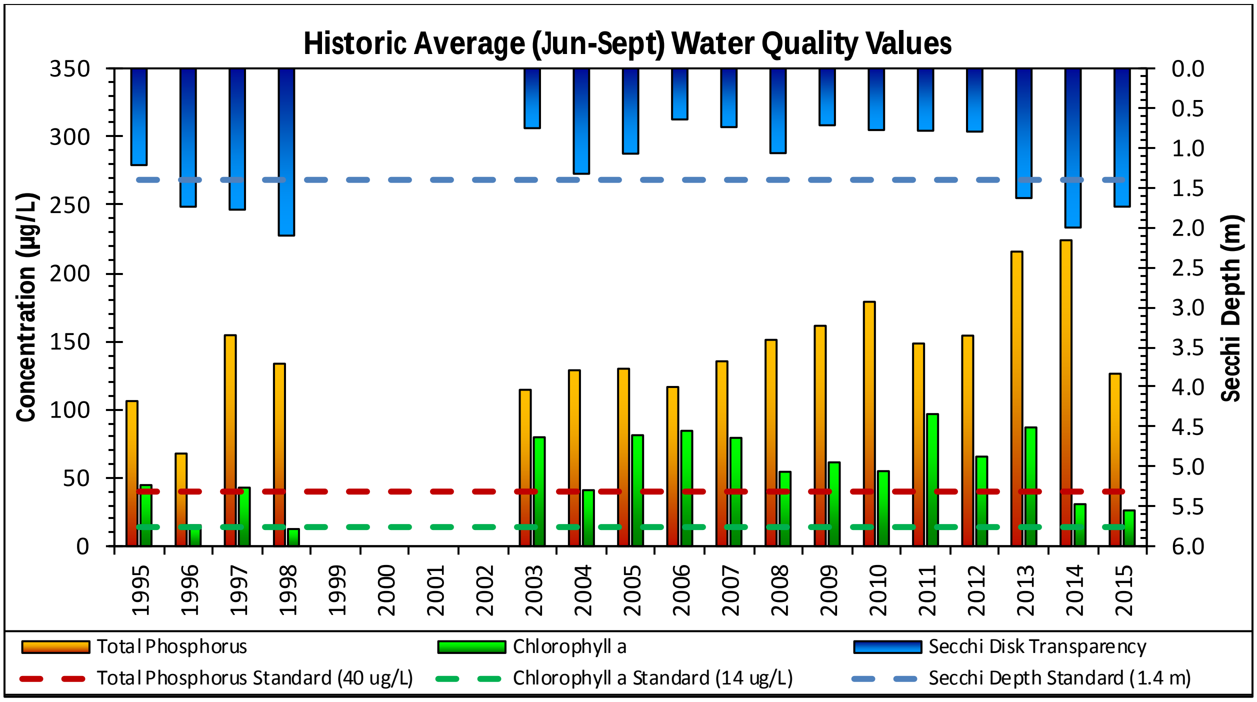


Figure 3-D - Spurzem Lake Growing Season (June-September) Mean Water Quality Data.

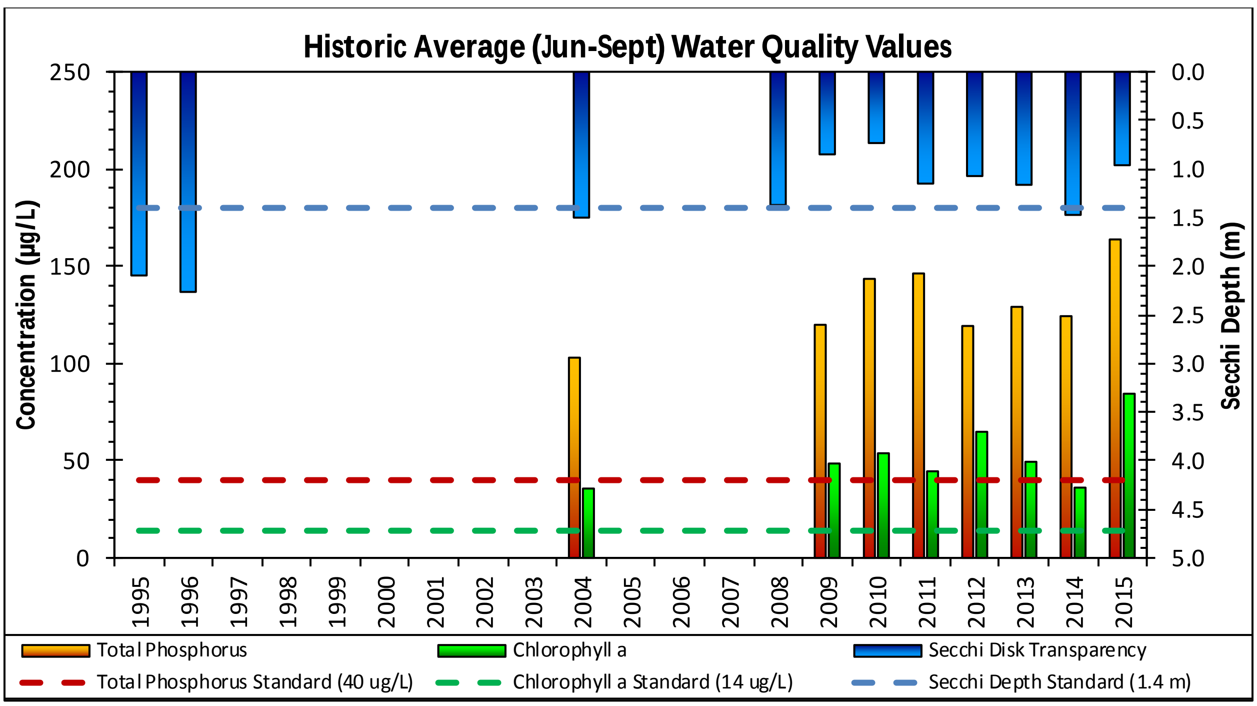


Figure 3-E - Half Moon Lake Growing Season (June – September) Mean Water Quality Data.

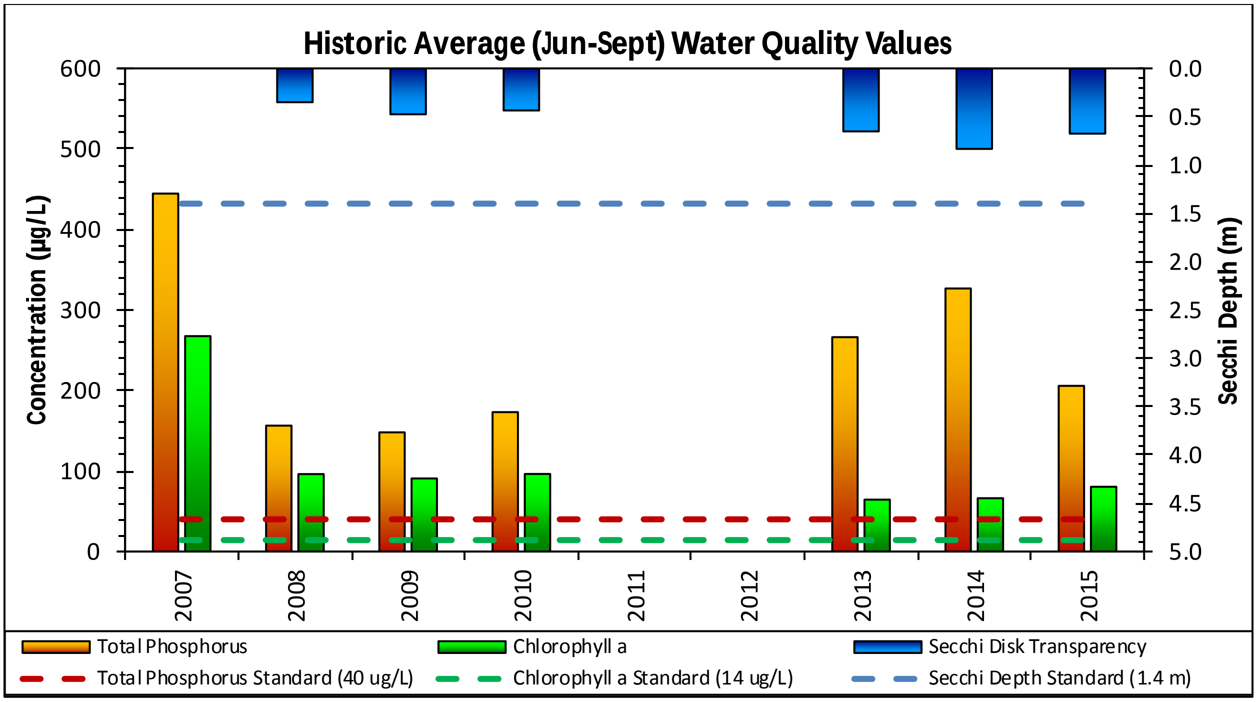


Figure 3-F – Lake Ardmore Growing Season (June – September) Mean Water Quality Data.

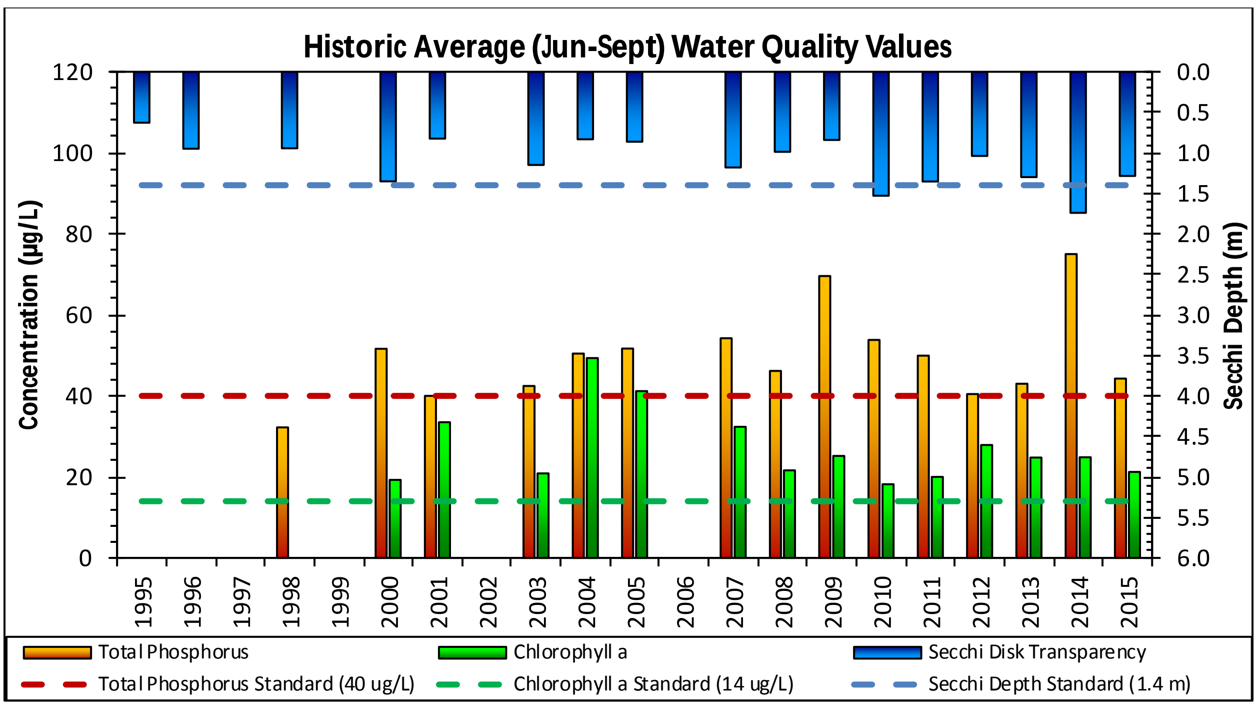


Figure 3-G - South Whaletail Lake Growing Season (June – September) Mean Water Quality Data.

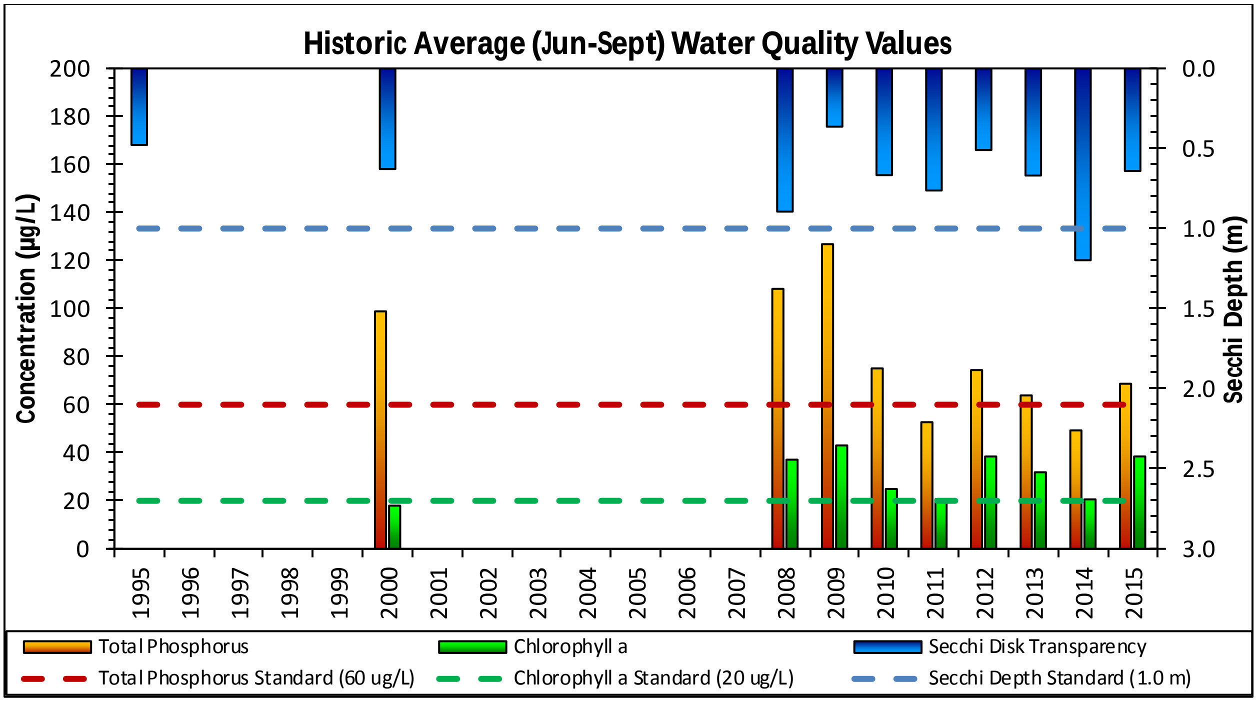


Figure 3-H - North Whaletail Lake Growing Season (June – September) Mean Water Quality Data.

3.6.2 Bacteria *(E. coli)*

Water quality data for the *E. coli* impaired reaches were collected by Three Rivers Park District between 2009 and 2013. Figure 1-A shows the monitoring locations for each impaired reach. Table 3.5 shows April through October monthly *E. coli* geometric means for the *E. coli* impaired reaches addressed in this TMDL study. Results indicate each reach exceeded the 126 cfu/100 ml chronic *E. coli* standard for at least one month during the April through October period. Table 3.5 also shows acute exceedances for the sampling stations located within each impaired reach. Individual samples exceed the 1,260 cfu/100 ml acute standard at least 5% of the time in each reach during the April through October.

Continuous flow data for each impaired reach were collected by Three Rivers Park District between 2008 and 2014. Flow data gaps for these stations were filled using regression relationships with the Minnesota Department of Natural Resources (DNR) continuous flow monitoring station (S001-255) on the South Fork Crow River in Delano. This station operates year around and therefore makes it possible to simulate complete flow records for each station from 2008 through 2014. The 2008 through 2014 continuous flow records for each reach were used to construct the flow duration curves described in Section 4.3.

Table 3.5 - Monthly *E. coli* Summary.

Reach ID	EQuIS ID	Data Years	April			May			June			July			August			September			October		
			n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260
Sarah Creek (628)	S005-023	2009-2012	--	--	--	7	21.0	0%	10	66.2	10%	9	26.4	0	10	90.6	0	8	**298**	25%	6	**303**	0%
Pioneer Creek (653)	S005-811; S006-368; S006-369; S006-370	2009-2011	--	--	--	13	**135**	0%	45	75	0%	41	**127**	7%	49	**247**	6%	13	**258**	23%	5	**161**	0
Unnamed Creek (593)	S006-368	2010-2013	4	12.2	0%	6	33.4	0%	15	86.5	0%	14	104	7%	14	**195**	14%	3	**258**	33%	2	**307**	0%
Deer Creek (594)	S006-369	2010-2013	4	**596**	25%	6	110	17%	15	**194**	27%	14	120	0%	15	70.5	0%	3	51.9	0%	2	84.8	0%

Notes: Red values = monthly geomean values greater than 126 cfu/100ml
n = number of samples
Geo = Geometric mean in cfu/100 ml
%n > 1,260 = Percent of samples greater than 1,260 cfu/100 ml
-- no available data

3.7 Pollutant Source Summary

3.7.1 Nutrients

There are six lakes impaired by nutrients that are addressed in this TMDL report. Nutrients, mainly nitrogen and phosphorus, from human-driven activities contribute 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. In Minnesota, the primary focus in managing nutrient enrichment of lakes has been to emphasize the control of phosphorus because of its role as a limiting nutrient in lake productivity.

There are three primary sources of phosphorus loading to lakes: watershed (external) loading, internal loading, and atmospheric deposition. Each is described in more detail below to address both permitted and non-permitted sources.

3.7.1.1 Permitted Sources

Municipal Separate Storm Sewer Systems (MS4s)

Permitted sources include discharges from MS4 conveyance systems that serve the stormwater drainage needs of a community. With the exception of Greenfield, all of the communities within the TMDL project area are permitted MS4s, though the area of each community that is served by their regulated MS4 conveyance system is generally very limited. The MS4 conveyance system provides the mechanism to transport vegetative material (such as grass clippings, leaves, and seeds), dust and dirt, car washing wastewater, improperly disposed of pet waste, and other phosphorus-containing material to a receiving water.

Feedlots

There are currently no National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permitted feedlot operations in the bacteria impaired reach watersheds. There are several smaller, registered feedlot operations throughout the impaired lake watersheds. While these feedlots are not required to meet the zero discharge standard for NPDES or SDS permitted facilities, the requirements under Minnesota Rule Chapters 7020, 7050 and 7060 still apply.

Municipal/Industrial Wastewater

Permitted sources also include discharges from municipal and industrial wastewater treatment plants (WWTPs) that receive permits under the NPDES/SDS program administered by the MPCA. The only known pollutant source of this type in the project area is the Loretto WWTP (Permit MN0023990), which discharges treated municipal effluent to a wetland just upstream of Spurzem Lake.

Construction/Industrial Stormwater

Other permitted sources include certain construction as well as industrial stormwater discharges. Construction Stormwater Permits are required for any construction activities that disturb:

- One acre or more of soil

- Less than one acre of soil if that activity is part of a "larger common plan of development or sale", or
- Less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources

Phosphorus loading from construction sites is mostly associated with movement of soil off the site due to erosion.

Industrial Stormwater Discharge Permits are required for facilities with Standard Industrial Classification (SIC) codes in 10 categories of industrial activity with significant materials and activities exposed to stormwater. These include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried off-site. Currently, there are several Industrial Stormwater Discharge permitted facilities in the Pioneer-Sarah Creek Subwatershed.

3.7.1.2 Non-Permitted Sources

Non-permitted generally include runoff-driven pollutant loads from land (in most cases rural) that does not pass through a regulated MS4 conveyance system. Examples include nutrients from manure, eroded soil, subsurface treatment systems (SSTS), and other material that may be deposited in, or conveyed to, a receiving water without entering a regulated MS4 conveyance system.

Livestock: Animal Feeding Operations

Animal waste containing phosphorus and other nutrients can be transported in watershed runoff to surface waters. The MPCA regulates animal feedlots in Minnesota though counties may be delegated by the MPCA to administer the program for feedlots that are not under federal regulation. The primary goal of the state program for animal feeding operations is to ensure that surface waters are not contaminated by the runoff from feeding facilities, manure storage or stockpiles, and cropland with improperly applied manure.

Livestock also occur at hobby farms, small-scale farms that are not large enough to require registration but may have small-scale feeding operations and associated manure application or stockpiles. Although the number of horses in the Pioneer-Sarah Creek Subwatershed (a possible reflection of hobby farm activity) stayed roughly the same from 2006 to 2011 at just over 1,000 animals, it is anticipated that these numbers could well increase as rural residential development replaces traditional agriculture land uses.

Appendix A shows the general location and number of cattle and horses in each of the stream and lake subwatersheds addressed in this TMDL. The information was developed using high resolution imagery taken at low altitude that captures multiple images of the same area to allow viewing of the area from different angles. The imagery was obtained from Hennepin County, who obtained it from a private vendor. Two sets of images were available for 2011 for the project area, one in April and the second in May. Typically, there were 5 and 15 images of each parcel and the images were at a scale of 1:1,500. If animals were found when reviewing the images, that area was viewed at a higher magnification and from different angles, and the number and type of animals recorded. The highest number of animals observed between the two sets of images was used in the inventory. It should be noted that there was no way to account for animals that may have been housed in barns at the time the images were taken.

Livestock: Land Application of Manure

Livestock manure is often either surface applied or incorporated into farm fields as a fertilizer and soil amendment. This land application of manure has the potential to be a substantial source of phosphorus loading, entering waterways from overland runoff and drain tile intakes.

Minn. R. ch. 7020 contains manure application setback requirements (Table 3.6). These setback requirements are largely based on research related to phosphorus transport, and not bacterial transport, and the effectiveness of these current setbacks on bacterial transport to surface waters is not known. For minimum setbacks near waters, counties can be more restrictive than Minn. R. ch. 7020.

Table 3.6. Manure application setback distances for Minnesota[1]

Waterbody Type	Surface Application	Incorporation within 24 hrs.
Lake, stream	300'*	25'**
Wetlands (10+ ac.)	300'*	24'**
Ditches (without berms)	300'*	25'**
Open tile intakes	300'	0
Well, quarry	50'	50'
Sinkhole (w/o berms)		
Downslope	50'	50'
Upslope	300'	50'

[1] Table adapted from "Fecal Coliform TMDL Assessment for 21 Impaired Streams in the Blue Earth River Basin" (Minnesota State University, Mankato, Water Resources Center, June 2007)
*100' vegetated buffer can be used instead of 300' setback for non-winter applications (50' buffer for wetlands/ditches).
**No long-term phosphorus build-up within 300'

Livestock: Grazing

Pastured areas are those where grass or other growing plants are used for grazing, and where the concentration of animals allows a vegetative cover to be maintained during the growing season. Pastures are neither permitted nor registered with the state.

Internal Sources

Internal nutrient loading in a lake is also considered a non-permitted source. It is usually the result of enriched bottom sediments releasing phosphorus into the water column. In most cases, lakes retain a large percentage of the pollutant load that is discharged to them. Much of the incoming phosphorus to a lake can end up in its bottom sediments, and a percentage of this accumulated phosphorus can be available for release. The actual amount released depends on a number of factors, including the magnitude of past phosphorus loading to the lake, the type and degree of enrichment of the sediments, the lake's bathymetric (depth) profile, and the area of and length of time a lake's bottom sediments are exposed to low or no oxygen conditions. Internal release of phosphorus can be a major component of the overall phosphorus load affecting the quality of a lake in areas where human disturbance of the contributing watershed has been ongoing for decades or longer, and/or there have been historic wastewater discharges. It should be noted that the overabundance of carp or other roughfish, as well as some invasive aquatic plants (notably CLPW), can also contribute to the internal phosphorus.

Atmospheric Deposition

Another non-permitted source is atmospheric deposition. Atmospheric deposition is caused by precipitation and dryfall (i.e. dust particles suspended by wind) that fall directly on the lake surface.

Non-compliant subsurface sewage treatment systems (SSTS)

In rural areas not served by sanitary sewer systems, non-compliant SSTS on lakeshore properties and in other locations in the watershed can contribute to nutrient impairments. See Section 3.7.2.2 for more information.

3.7.2 Bacteria *(E. coli)*

3.7.2.1 Permitted

MS4s

There are only two MS4s that have at least a portion of their boundary within the Pioneer Creek impaired reach watershed, the cities of Independence and Maple Plain. The primary sources of bacteria within the MS4 areas include improperly managed pet waste and wildlife inputs (i.e. waterfowl and other birds) directly to impervious surfaces and water features (wetlands, stormwater ponds, etc.). However, bacteria loading from these cities is believed to be minimal since their boundaries cover a small portion of the watershed (2.7%), and given their location relative to the main-stem of the impaired reach. There are no permitted MS4s located in the Sarah Creek, Unnamed Creek, and Deer Creek impaired reach watersheds.

Municipal/Industrial Wastewater

Permitted sources of bacteria can include industrial wastewater effluent and municipal WWTP effluent. Review of the impaired reaches indicates that there are no active permitted wastewater dischargers in the impaired reach watersheds.

Feedlots

There are currently no NPDES or SDS permitted feedlot operations in the bacteria impaired reach watersheds. There are several smaller, registered feedlot operations throughout the bacteria impaired reach watersheds. While these feedlots are not required to meet the zero discharge standard for NPDES or SDS permitted facilities, the requirements under Minn. R. chs. 7020, 7050, and 7060 still apply. Livestock grazing and land application of manure are the primary sources of bacteria loading from livestock operations in the Pioneer-Sarah Creek Watershed. These are discussed in more detail in Section 3.7.1.2.

3.7.2.2 Non-Permitted

Non-permitted sources of bacteria include runoff from rural homesteads, agricultural land, pastureland, and other areas that have the potential to transport bacteria from livestock animals and/or wildlife.

Non-compliant SSTS

Failing or nonconforming septic systems, or SSTS near waterways can also be a source of bacteria to streams, especially during low flow periods when these sources continue to discharge and runoff driven sources are not active.

Currently, the exact number and status of SSTSs in the bacteria impaired reach watersheds is unknown. The MPCA's 10 Recommendations and Planning for Statewide Inventories, Inspections of SSTS (MPCA 2011) includes some general information, by county, regarding the performance of SSTSs in the Pioneer-Sarah Creek Watershed (Table 3.7). The report differentiates between systems that are generally failing and those that are an imminent threat to public health and safety (ITPHS). Generally, failing systems are those that do not provide adequate treatment and may contaminate groundwater. For example, a generally failing system may have a functioning, intact tank and soil absorption system, but fails to protect ground water by providing a less than sufficient amount of unsaturated soil between where the sewage is discharged and the ground water or bedrock. Systems considered ITPHS are severely failing or were never designed to provide adequate raw sewage treatment. Examples include ISTSs that discharge directly to surface water bodies such as ditches, streams or lakes.

Table 3.7. SSTS failure rates by county.

County	Generally Failing SSTSs	ITPHS SSTSs
Carver	26%	14%
Hennepin	29%	1%
Wright	30%	2%

Source: MPCA 2011.

3.7.2.3 Bacteria Source Inventory

The total amount of bacteria produced within the direct drainage area of each impaired reach was estimated to aid in focusing implementation activities (Table 3.8 through Table 3.11). The bacteria accounting used available livestock information, geographic information systems (GIS) data, human and pet populations, wildlife population, septic system data and literature rates from various studies/sources.

Table 3.8 - Estimate of bacteria production in the Sarah Creek Watershed.

Major Category	Source	Animal Units* or Individuals in Subwatershed	*E. coli* Organisms Produced Per Unit Per Day [Billions of Org.] (8)	Total *E. coli* Organisms Produced Per Day [Billions of Org.]	Total *E. coli* Organisms Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) (1)	Horses (Animal Units)	0	58	0	0	0%
	Cattle (Animal Units)	0	89	0		
	Chicken/Turkeys (Animal Units)	0	21	0		
Wildlife	Deer (3)	13	0.5	6.4	11	58%
	Waterfowl (4)	12	0.4	4.7		
Human	Failing Septic Systems (5)	1	5.7	5.7	5.7	30%
	WWTP effluent (6)	--	--	--		
Domestic Animals (2)	Improperly Managed Pet Waste (7)	0.5	4.5	2.3	2.3	12%

General note: Bacteria production estimates only include water area downstream of the Lake Sarah boundary condition.
* One Animal Unit (AU) represents one 1,000-pound animal, the typical weight of a beef steer, stock cow, or horse
(1) Livestock animal counts based on Three River Park District Aerial photo survey
(2) Calculated based on # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA, 2002)
(3) Assumes average deer density of 6 deer/mi^2 (DNR Willmar Office, personal communication)
(4) Estimated from the DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (DNR, 2011)
(5) Based on county SSTS inventory failure rates (MPCA, 2011) and rural population estimates
(6) Based on WWTP effluent data from facility discharge monitoring reports (DMRs)
(7) Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)
(8) Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits

Table 3.9 - Bacteria production in the Pioneer Creek Watershed.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] (8)	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) (1)	Horses (Animal Units)	75	58	13,211	17,221	96%
	Cattle (Animal Units)	15	89	4,010		
	Chicken/Turkeys (Animal Units)	0	21	0		
Wildlife	Deer (3)	158	0.5	79	136	<1%
	Waterfowl (4)	144	0.4	57		
Human	Failing Septic Systems (5)	5	5.7	28	28	<1%
	WWTP effluent (6)	--	--	--		
Domestic Animals (2)	Improperly Managed Pet Waste (7)	111	4.5	500	500	3%

General note: Bacteria production estimates only include water area downstream of the Lake Independence boundary condition.

* One AU represents one 1,000-pound animal, the typical weight of a beef steer, stock cow, or horse

(1) Livestock animal counts based on Three River Park District Aerial photo survey

(2) Calculated based on # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA, 2002)

(3) Assumes average deer density of 6 deer/mi^2 (DNR Willmar Office, personal communication)

(4) Estimated from the DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011)

(5) Based on county SSTS inventory failure rates (MPCA, 2011) and rural population estimates

(6) Based on WWTP effluent data from facility discharge monitoring reports (DMRs)

(7) Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (Center for Watershed Protection, 1999)

(8) Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

Table 3.10 - Bacteria production in the Unnamed Creek bacteria impaired reach (593) watershed.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] (8)	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) (1)	Horses (Animal Units)	23	58	1,343	4,387	96%
	Cattle (Animal Units)	50	89	3,044		
	Chicken/Turkeys (Animal Units)	0	21	0		
Wildlife	Deer (3)	101	0.5	50	87	2%
	Waterfowl (4)	92	0.4	37		
Human	Failing Septic Systems (5)	8	5.7	45	45	1%
	WWTP effluent (6)	--	--	--		
Domestic Animals (2)	Improperly Managed Pet Waste (7)	8	4.5	34	34	<1%

General note: Bacteria production estimates only include water area downstream of the Oak and Mud Lake boundary conditions.

* One AU represents one 1,000-pound animal, the typical weight of a beef steer, stock cow, or horse

(1) Livestock animal counts based on Three River Park District Aerial photo survey

(2) Calculated based on # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA, 2002)

(3) Assumes average deer density of 6 deer/mi^2 (DNR Willmar Office, personal communication)

(4) Estimated from the DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011)

(5) Based on county SSTS inventory failure rates (MPCA, 2011) and rural population estimates

(6) Based on WWTP effluent data from facility discharge monitoring reports (DMRs)

(7) Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

(8) Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

Table 3.11 - Bacteria production in the Deer Creek bacteria impaired reach (594) watershed.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] (8)	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) (1)	Horses (Animal Units)	92	58	5,354	6,245	99%
	Cattle (Animal Units)	10	89	891		
	Chicken/Turkeys (Animal Units)	0	21	0		
Wildlife	Deer (3)	41	0.5	20	35	<1%
	Waterfowl (4)	37	0.4	15		
Human	Failing Septic Systems (5)	2	5.7	11	11	<1%
	WWTP effluent (6)	--	--	--		
Domestic Animals (2)	Improperly Managed Pet Waste (7)	2	4.5	8.7	9	<1%

General note: Bacteria production estimates only include water area downstream of the Whaletail Lake boundary condition.

* One AU represents one 1,000-pound animal, the typical weight of a beef steer, stock cow, or horse

(1) Livestock animal counts based on Three River Park District Aerial photo survey

(2) Calculated based on # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA, 2002)

(3) Assumes average deer density of 6 deer/mi^2 (DNR Willmar Office, personal communication)

(4) Estimated from the DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011)

(5) Based on county SSTS inventory failure rates (MPCA, 2011) and rural population estimates

(6) Based on WWTP effluent data from facility discharge monitoring reports (DMRs)

(7) Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

(8) Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

4. TMDL Development

4.1 General description of TMDL

A TMDL represents the total mass of a pollutant that can be assimilated by the receiving water without causing that receiving water to violate water quality standards. The TMDL is defined by the loading capacity for a given pollutant that is distributed among its components as follows:

$$TMDL = \Sigma\ WLA + \Sigma\ LA + MOS + Reserve\ Capacity$$

The WLA represents the allowable pollutant loading from permitted sources, such as stormwater discharges from regulated MS4s, municipal or industrial wastewater facility discharges, and construction and industrial stormwater site discharges. The LA represents the loading from non-permitted sources, such as storm drainage systems that are not regulated under the MS4 permit system, atmospheric deposition, SSTS, and internal loading (in the case of lakes). A portion of the TMDL is allocated to the MOS to account for uncertainty associated with modeling and other analytical techniques, environmental variation, and other variables. The reserve capacity (RC) is the load set aside for future allocations from growth or changes. However, Minnesota does not include a RC for lake nutrient TMDLs.

4.2 Nutrients

4.2.1 Loading Capacity Methodology

The initial step in developing an excess nutrient TMDL for lakes is to determine the nutrient loading capacity for the lake, defined as the maximum nutrient load it can receive and still meet water quality standards. To determine the loading capacity for each lake addressed in this report, the average annual nutrient and water budgets were coupled with a lake response model, and calibrated to a monitored in-lake condition for a specified time period (generally a 1 to 3-year time period and always within the 10-year period between 2006 and 2015). The lake response model used for this project was the BATHTUB suite of models (Walker 1999). This modeling package uses lake-specific characteristics such as annual phosphorus loading, mean lake depth, and hydraulic flushing time to predict in-lake phosphorus concentrations. Once a lake-specific calibrated BATHTUB model was developed, it was used to define a load response curve that reflected the relationship between total nutrient loading and in-lake water quality. The curve was used to determine the total load required to meet the June through September in-lake phosphorus standard for that lake (60 µg/l for a shallow lake, 40 µg/l for a deep lake). The total load at which the in-lake water quality goal is met is the loading capacity for the lake.

Three types of loading needed to be accounted for in modeling each lake system. The first was atmospheric loading. Atmospheric phosphorus loads were set to the default value of 0.27 lbs/yr/acre of lake surface, similar to values reported in a technical memorandum to the MPCA (Barr Engineering 2007). The second was loads from watershed runoff. The Generalized Watershed Loading Function (GWLF) model (Evans 2011) was used to estimate watershed-driven loads of phosphorus and water to each of the lakes for which TMDLs were prepared. The GWLF model is a continuous simulation model for runoff, sediment and nutrients. The basic model framework for a given receiving water is created using GIS layers and various non-spatial model parameters. The required GIS layers include digital elevation model (DEM) information, land use, weather, hydrologic basins, streams and soils layers. Annualized watershed phosphorus and water loads were derived by a GWLF model that was calibrated to monitored loads using data generated at four stream sites within the project area. For each lake, the annual phosphorus and water loads generated by the GWLF watershed model were then used as input to the BATHTUB model for that lake, to represent watershed contributions and support the BATHTUB model calibration process.

The third major type of loading is internal loading. An internal load estimate for each lake was developed by determining the "residual" load that would need to be added to the BATHTUB model to get the modeled in-lake phosphorus concentration to exactly match the observed in-lake phosphorus concentration, after atmospheric and watershed inputs were accounted for. The internal load estimate derived using the "residual" method was then compared with another estimate developed using a field-based approach outlined in Nurnberg (1988 and 2005). The Nurnberg approach relies on the collection and incubation of intact sediment cores from a lake to estimate in-situ rates of phosphorus release from the lake's bottom sediments under oxic and anoxic conditions. Where aquatic vegetation surveys supported it, a component that accounted for the load driven by CLPW growth and senescence was added to the Nurnberg sediment-driven internal load estimate. This generated a range of annual internal load estimates for the lake in question, depending mostly on the extent and duration of low DO periods affecting the lake sediments. In each case, the model "residual"-derived internal load estimates were within 20% of the mid-point of the range of values produced by the Nurnberg-based method, confirming the validity of the "residual" estimate for internal load estimation to support the final TMDL model.

Some of the lakes in this TMDL have upstream lakes, which are also addressed in this TMDL. In certain cases, meeting water quality standards in the downstream lake is contingent on water quality improvements in one or more impaired upstream lakes. For these situations, lake outflow loads from the upstream lake were routed directly into the downstream lake as part of the modeling process, using monitoring data for the existing condition and calculated values based on the appropriate in-lake standard for the TMDL.

See the following appendices for more detailed information on the technical methods used to develop TMDLs for the lakes addressed in this report information:

- Appendix A: Livestock Inventory for Pioneer-Sarah Creek Watershed Project Subwatersheds
- Appendix B: Watershed Modeling – GWLF-E Model Description, Inputs, and Outputs for Lakes
- Appendix C: BATHTUB Model Methods, Inputs, and Outputs for Lakes
- Appendix D: Point-Intercept Aquatic Vegetation Survey Data
- Appendix E: Sediment Phosphorus Fractionation Reports for Internal Loading Estimation

4.2.2 Load Allocations

LAs for the lake TMDLs include:

- Atmospheric loading
- Internal loading from release of phosphorus by lake bottom sediments, CLPW senescence, etc.

- Watershed loads from the following areas:
  - Areas in each community that are not expected to be within the MUSA, even if identified in the comprehensive land use plan for expected development after 2030
  - Existing and future residential development where lots are two acres or greater (generally considered rural residential), as they are not expected to be served by a regulated conveyance system
  - Any areas owned by Hennepin County or Minnesota Department of Transportation (MnDOT) that are outside the 2010 Urban Census Area
  - All areas classified as wetlands by the National Wetland Inventory (2014)
  - Phosphorus loading from non-compliant SSTSs

Peter Lake, North Whaletail Lake, and South Whaletail Lake were assessed for SSTSs. The other lakes either are expected to be sewered or are surrounded by park area. To determine the number of septic systems around the lakes, light detection and ranging (LiDAR) imagery with buildings was visually inspected within a 200-m buffer around the lakes of interest. If there were multiple buildings per parcel, only one building was counted. Minimal information was available with regard to system failure rates, so a failure rate of 29% was applied to the estimated number of septic systems (MPCA 2011). The annual load per septic system was calculated by assuming 2.8 people per system with a loading rate of 2.7 grams TP/person/day (EPA Manual 2002). Discharges of phosphorus to surface waters from SSTS are illegal; therefore, the LA for SSTS is zero.

4.2.3 Wasteload Allocation Methodology

The WLAs were divided into NPDES permitted wastewater dischargers, MS4 permittees, and NPDES-permitted construction and industrial stormwater. Following is a description of how each of these allocations was assigned.

4.2.3.1 Permitted wastewater dischargers

The WWTP operated by the city of Loretto (MN0023990) is the only permitted wastewater point source discharger affected by this TMDL. The WWTP seasonally discharges treated sewage effluent into a wetland complex that flows to Spurzem Lake. In recent years, the Loretto WWTP has been applying alum to their treatment ponds prior to discharge. This management measure has reduced the concentration of phosphorus in their discharge to under 0.2 mg/l, or 200 ppb. This represents a phosphorus concentration reduction of over 95% compared to influent concentrations, and any further significant reductions are neither reasonable nor cost-effective. For 2013 and 2014, the facility's discharge averaged 24.6 lb/yr Thus, a WLA of 24.6 lb/yr has been assigned to this facility for the Spurzem Lake TMDL. This facility was assigned a WLA of zero in the Lake Independence TMDL (PSCWMC and Three Rivers Park District 2007). However, action to eliminate this discharger has been delayed due to the lack of success in securing agreements with the Metropolitan Council and neighboring communities to access the regional wastewater collection system. A target date for this connection was previously set at December 31, 2020. The Spurzem Lake TMDL includes a non-zero WLA for this facility because the city of Loretto cannot guarantee that the discharge will be terminated. By setting the WLA at the existing load level, the Spurzem Lake WLA will require the City to maintain very high levels of treatment while the discharge remains active. If the discharge from the facility is terminated at some point in the future, it is anticipated that the WLA assigned the WWTP would be split proportionately among the permitted MS4s in that watershed.

4.2.3.2 Permitted MS4s

There are five MS4s that are completely within or have a portion of their municipal boundary in at least one of the impaired lake watersheds: city of Corcoran (Peter Lake and Spurzem Lake), city of Independence (Lake Ardmore), city of Loretto (Lake Ardmore and Spurzem Lake), city of Medina (Lake Ardmore, Spurzem Lake, Half Moon Lake), and city of Minnetrista (North Whaletail Lake and South Whaletail Lake). Because none of the project area is within the 2010 Urban Census Area, no county or state road authorities were assigned WLAs in the TMDLs.

WLAs assigned to MS4 jurisdiction were determined as follows. First, the area of the community that was expected to be included in the MUSA boundary by 2030 was determined based on each community's comprehensive plan as approved by the Metropolitan Council. This is an indication of where each community expects land use conversion to residential, commercial, industrial, and other land cover to occur at high enough densities that utility infrastructure (including a stormwater conveyance system) will be needed to service the area. It is assumed that the needed stormwater conveyance system would become part of a city's regulated MS4 once it was installed. The WLA for each MS4 was assigned proportionate to the acreage of the 2030 MUSA service area within the subwatershed of a given impaired lake. Individual MS4 allocations were calculated by multiplying each MS4s percent watershed coverage (determined in GIS) by the total watershed loading capacity after subtracting the MOS, atmospheric load, internal load and construction/industrial stormwater WLAs. It should be noted that much of the area within many of the MS4 communities is expected to be converted from agricultural/undeveloped land uses to low density rural residential land uses that will not be served by the MUSA. In addition, the immediate watersheds of Half Moon Lake, North Whaletail Lake, and South Whaletail Lake do not have any areas that are expected to be served by the MUSA between now and 2030. All these areas were therefore included in the LA as described in the previous section. Table 4.1 summarizes the area of each MS4 that was used to establish the WLA for that community by impaired lake watershed.

Table 4.1- Summary of Permitted MS4s in the nutrient impaired lake watersheds.

Impaired Lake	Permitted MS4	Permit #	MUSA Area within Watershed (ac)[1]	Percent of Watershed (%)
Peter Lake	City of Corcoran	MS400081	39	13.0
	City of Medina	MS400105	18	6.0
Spurzem Lake	City of Corcoran	MS400081	16	0.6
	City of Loretto	MS400030	64	2.5
	City of Medina	MS400081	198	7.7
Lake Ardmore	City of Loretto	MS400030	1	0.2
	City of Medina	MS400105	31	6.1

[1] Values in this column are the anticipated regulated area of the community that will drain to the subject lake, exclusive of those areas in the community draining to an upstream impaired lake.

4.2.3.3 Construction and Industrial Stormwater

To account for construction activity and possible industrial stormwater in the watersheds of the impaired lakes, as well as future growth in the watersheds, WLAs equal to 1.0% of the loading capacity for each lake were assigned to cover both of these categories. The best management practices (BMPs) and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or facility-specific Individual Wastewater Permit.

4.2.4 Margin of Safety

The MOS is intended to ensure achievement of the water quality goals despite scientific uncertainty. Most lakes addressed in this TMDL have a reasonably robust data set, including in-lake monitoring data over multiple years and at a frequency of bi-weekly to monthly. In addition, there were three tributary monitoring sites that were used to estimate loads, and all of the lakes have lab-measured sediment phosphorus release rates. An explicit margin of 5% of the loading capacity was set aside in each lake TMDL. The 5% MOS was considered adequate given each lake's reasonably robust data set and the lake response model performance.

4.2.5 Seasonal Variation and Critical Conditions

Seasonal variation was taken into account in the TMDL by using the eutrophication standards, which are based on growing season averages. The eutrophication standards were set with seasonal variability in mind. The load reductions are established so that the receiving water will meet the water quality standard over the course of the growing season (June through September). Critical conditions in the impaired lakes occur during the growing season when the lakes are used most intensively for direct and indirect contact aquatic recreation. Since the TMDL is based on growing season averages, the critical period is covered by the TMDL.

4.2.6 TMDL Summary

TMDLs for each lake were calculated as the sum of the WLA, the LA, and the MOS expressed as a phosphorus mass per unit time. Table 4.2 through Table 4.7 present the TMDL equations for each lake. The sections below summarize the primary findings under existing conditions and management of each lake as it pertains to achieving the applicable in-lake water quality standard. The TMDL for each lake is then presented in tabular form, including the loading capacity of the lake and the reductions in nutrient loading needed by permitted or non-permitted source to reach the in-lake standard. The total load reduction shown in the first line of each table is the sum of all of the individual load reductions in the column below. Because the load reductions must accommodate the MOS, their total is greater than the difference between the total existing and total allowable loads.

4.2.6.1 Peter Lake

Key findings pertaining to Peter Lake are as follows:

- Peter Lake (AUID: 27-0147-00) is approximately 55.8 acres in surface area and has a maximum depth of 69.1 feet. About 58% of the lake is less than 15 feet deep. Peter Lake is classified as a deep lake. The contributing watershed area to the lake is 301 acres.
- The lake is on the raft 2016 303(d) Impaired Waters List. It has met all water quality standards for three of the five years it was monitored. In the five years it was monitored, it met the secchi depth standard every year. In 2013, neither the TP nor Chl-*a* standard were met and in 2009, the Chl-*a* levels were just over the standard.
- The lake's watershed has very little development with only about 10% in single family residential. About 73% of the watershed is in agriculture or undeveloped land uses.
- Based in part on incubation of sediment cores and estimation of phosphorus release rates under both anoxic and oxic conditions, about 62% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while about 35% comes from watershed sources and 3.2% comes from atmospheric deposition.

Table 4.2 presents the phosphorus TMDL and allocations for Peter Lake. To meet the TMDL, the needed reduction in the TP load is 96 lbs/yr, or 20% of the current total load. This load reduction can be achieved through reducing the existing internal load by 33% and the SSTS load by 100%.

Table 4.2 - Peter Lake Phosphorus TMDL and Allocations.

Load Category	Load Component	Existing Load (lbs/yr)	Allowable Load (lbs/yr)	Estimated Load Reduction[1] (lbs/yr)	Estimated Load Reduction[1] %	TMDL (lbs/day)
TOTAL LOAD		**472.7**	**396.9**	**95.6**	**20%**	**1.087**
Wasteload Allocation	**Total WLA**	**34.6**	**34.6**	**0.0**	**0%**	**0.095**
	Construction/Industrial Stormwater	4.0	4.0	0.0	0%	0.011
	Corcoran MS4	21.0	21.0	0.0	0%	0.057
	Medina MS4	9.6	9.6	0.0	0%	0.027
Load Allocation	**Total LA**	**438.1**	**342.4**	**95.6**	**22%**	**0.938**
	Non-MS4 Runoff	131.1	131.1	0.0	0%	0.359
	Atmospheric deposition	15.2	15.2	0.0	0%	0.042
	Internal load	291.7	196.1	95.5	33%	0.537
	SSTS	0.1	0.0	0.1	100%	0.000
Margin of Safety		**0.0**	**19.8**	**--**	**--**	**0.054**

[1] Existing TP load is an average for the years 2009-2015

4.2.6.2 Spurzem Lake

Key findings pertaining to Spurzem Lake are as follows:

- Spurzem Lake (AUID: 27-0149-00) is approximately 78.6 acres in surface area and has a maximum depth of 37.4 feet. About 70% of the lake is less than 15 feet deep. The lake is classified as a deep lake. The contributing watershed area to the lake is about 2,915 acres.
- Not including the watershed area to Peter Lake upstream, the Spurzem Lake Watershed has very little development with only about 13% developed area and 14% in park preserve or recreation. About 68% of the watershed is in agriculture or undeveloped land uses.

- The lake monitoring data extends back to 1995. The water quality data indicates the lake is severely degraded.
- Both CLPW and common carp are present in the lake at nuisance levels.
- About 37% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while about 62% comes from watershed sources. Release of phosphorus by bottom sediments is the largest source of internal loading, followed by growth and senescence of CLPW.

Table 4.3 presents the phosphorus TMDL and allocations for Spurzem Lake. To meet the TMDL, the needed reduction in the TP load is 1,868 lbs/yr, equal to an 85% reduction of the existing total load. This load reduction can be achieved through:

- Watershed load reductions of 88% and holding the Loretto WWTP load discharge to no higher than 24.6 lbs/yr.
- Internal load reductions of 88%, aimed at reducing CLPW to non-nuisance conditions, a reduction in releases from bottom sediments and a reduction in common carp.

Table 4.3 - Spurzem Lake Phosphorus TMDL and Allocations.

Load Category	Load Component	Existing Load (lbs/yr)	Allowable Load (lbs/yr)	Estimated Load Reduction[1] (lbs/yr)	%	TMDL (lbs/day)
TOTAL LOAD		**2,188.7**	**337.2**	**1,868.4**	**85%**	**0.924**
Wasteload Allocation	**Total WLA**	**175.1**	**45.2**	**129.9**	**74%**	**0.124**
	Construction/Industrial Stormwater	3.4	3.4	0.0	0%	0.009
	Loretto WWTP	24.6	24.6	0.0	0%	0.067
	Corcoran MS4	8.5	1.0	7.5	88%	0.003
	Loretto MS4	33.9	4.0	29.9	88%	0.011
	Medina MS4	104.7	12.2	92.5	88%	0.034
Load Allocation	**Total LA**	**2,013.6**	**275.2**	**1,738.4**	**86%**	**0.754**
	Upstream lake (Peter Lake)	26.9	24.3	2.6	10%	0.067
	Non-MS4 Runoff	1,156.4	135.1	1,021.3	88%	0.370
	Atmospheric deposition	21.2	21.2	0.0	0%	0.058
	Internal load	809.1	94.6	714.5	88%	0.259
Margin of Safety		**0.0**	**16.9**	**--**	**--**	**0.046**

[1] Existing TP load is an average for the years 2009-2015

4.2.6.3 Half Moon Lake

Key findings pertaining to Half Moon Lake are as follows:

- Half Moon Lake (AUID: 27-0152-00) is approximately 31.1 acres in surface area and has a maximum depth of 30.3 feet. About 59% of the lake is less than 15 feet deep. The lake is classified as a deep lake. The contributing watershed area to the lake is about 3,430 acres.
- Not including the watershed area to Spurzem Lake upstream, the Half Moon Lake Watershed is all park preserve or recreational area or water.

- There is lake-monitoring data back to 2004 with Secchi disk readings back to 1995. The water quality data indicates the lake is severely degraded.
- Both CLPW and common carp are present in the lake.
- Based in part on incubation of sediment cores and estimation of phosphorus release rates under both anoxic and oxic conditions, only about 22% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while about 78% comes from watershed sources. Most of the internal load is due to the release of phosphorus by bottom sediments.

Table 4.4 presents the phosphorus TMDL and allocations for Half Moon Lake. To meet the TMDL, the needed reduction in the TP load is 1,373 lbs/yr. This is equal to an 80% reduction of the existing total load of 1,713 lbs/yr. This load reduction can be achieved through:

- Achieving water quality standards for Spurzem Lake, which require reducing the incoming watershed load to Half Moon Lake by 580 lbs/yr (about 42% of the total load reduction required to meet the TMDL),
- Watershed load reductions of 85% for that part of the Half Moon Watershed downstream of the Spurzem Lake outlet, and
- Internal load reductions of 85%, aimed at reducing CLPW to non-nuisance conditions, a reduction in releases from bottom sediments, and a reduction in common carp.

Table 4.4 - Half Moon Lake Phosphorus TMDL and Allocations.

Load Category	Load Component	Existing Load	Allowable Load	Estimated Load Reduction[1]		TMDL
		(lbs/yr)	(lbs/yr)	(lbs/yr)	%	(lbs/day)
TOTAL LOAD		**1,712.8**	**357.6**	**1,373.1**	**80%**	**0.980**
Wasteload Allocation	**Total WLA**	**3.6**	**3.6**	**0.0**	**0%**	**0.010**
	Construction/Industrial Stormwater	**3.6**	**3.6**	**0.0**	**0%**	0.010
Load Allocation	**Total LA**	**1,709.2**	**336.1**	**1,373.1**	**80%**	**0.921**
	Upstream lake (Spurzem Lake)	**771.0**	**190.8**	**580.2**	**75%**	0.523
	Non-MS4 Runoff	**555.9**	**81.7**	**474.2**	**85%**	0.224
	Atmospheric deposition	**8.6**	**8.6**	**0.0**	**0%**	0.024
	Internal load	**373.7**	**55.0**	**318.7**	**85%**	0.151
Margin of Safety		**0.0**	**17.9**	**--**	**--**	**0.049**

[1] Existing TP load is an average for the years 2009-2015

4.2.6.4 Lake Ardmore

Key findings pertaining to Lake Ardmore are as follows:

- Lake Ardmore (AUID: 27-0153-00) is approximately 13.5 acres in surface area and has a maximum depth of 24.4 feet. About 75% of the lake is less than 15 feet deep. The lake is classified as a "deep lake". The contributing watershed area to the lake is about 507 acres.
- The land use in the lake's watershed is only about 6% developed. About 54% of the watershed is in agriculture or undeveloped land uses and 36% of the watershed is in park/preserve or recreation.

- There is lake-monitoring data back to 2007. The water quality data indicates the lake is severely degraded. The lake is proposed for listing as impaired by nutrients in 2016.
- Common carp are present in the lake, periodically at nuisance levels. An aquatic plant survey conducted in 2015 showed no significant rooted aquatic plant community.
- Based in part on incubation of sediment cores and estimation of phosphorus release rates under both anoxic and oxic conditions, about 49% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while about 50% comes from watershed sources. Most of the internal load is due to the release of phosphorus by bottom sediments.

Table 4.5 presents the phosphorus TMDL and allocations for Lake Ardmore. To meet the TMDL, the needed reduction in the TP load is 490 lbs/yr. This is equal to a 91% reduction of the existing total load of 538 lbs/yr. This load reduction can be achieved through:

- Watershed load reductions of 92%, and
- Internal load reductions of 92%, aimed at a reduction in releases from bottom sediments and a reduction in common carp.

Table 4.5 - Lake Ardmore Phosphorus TMDL and Allocations.

Load Category	Load Component	Existing Load	Allowable Load	Estimated Load Reduction[1]		TMDL
		(lbs/yr)	(lbs/yr)	(lbs/yr)	%	(lbs/day)
TOTAL LOAD		**537.90**	**50.14**	**490.26**	**91%**	**0.1371**
Wasteload Allocation	**Total WLA**	**17.50**	**1.84**	**15.66**	**89%**	**0.0051**
	Construction/Industrial Stormwater	**0.50**	**0.50**	**0.00**	**0%**	0.0010
	Loretto MS4	**0.50**	**0.04**	**0.46**	**92%**	0.0001
	Medina MS4	**16.50**	**1.30**	**15.20**	**92%**	0.0040
Load Allocation	**Total LA**	**520.40**	**45.80**	**474.50**	**91%**	**0.1250**
	Non-MS4 Runoff	**251.70**	**20.50**	**231.10**	**92%**	0.0560
	Atmospheric deposition	**3.70**	**3.70**	**0.00**	**0%**	0.0100
	Internal load	**265.00**	**21.60**	**243.40**	**92%**	0.0590
Margin of Safety		**0.00**	**2.50**	**--**	**--**	**0.0070**

[1] Existing TP load is an average for the years 2009-2015

4.2.6.5 South Whaletail Lake

Key findings pertaining to South Whaletail Lake are as follows:

- South Whaletail Lake (AUID: 27-0184-02) is approximately 156.1 acres in surface area and has a maximum depth of 23.3 feet. About 66% of the lake is less than 15 feet deep. The lake is classified as a "deep lake." The contributing watershed area to the lake is about 507 acres.
- The land use in the lake's watershed is only about 6% developed with single family residential. About 29% of the watershed is in agriculture or undeveloped land uses and 34% of the watershed is in park/preserve or recreation. The lake has a very low watershed-to-lake ratio of 4.2:1.

- There are in-lake monitoring data extending back to 1995. The water quality data indicates the lake is moderately degraded, but met or was close to meeting TP standards in 2012, 2013, and 2015.
- Based in part on incubation of sediment cores and estimation of phosphorus release rates under both anoxic and oxic conditions, about 80% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while only about 12% comes from watershed sources and 8% comes from atmospheric deposition. Most of the internal load is due to the release of phosphorus by bottom sediments.

Table 4.6 presents the phosphorus TMDL and allocations for South Whaletail Lake. To meet the TMDL, the needed reduction in the TP load is 180 lbs/yr. This is equal to a 34% reduction of the existing total load of 529 lbs/yr. This load reduction can be achieved through:

- Internal load reductions of 43%, aimed at a reduction in releases from bottom sediments.
- Elimination of discharges from poorly functioning SSTSs.

Table 4.6 - South Whaletail Lake Phosphorus TMDL and Allocations.

Load Category	Load Component	Existing Load (lbs/yr)	Allowable Load (lbs/yr)	Estimated Load Reduction[1] (lbs/yr)	Estimated Load Reduction[1] %	TMDL (lbs/day)
TOTAL LOAD		**528.9**	**367.0**	**180.2**	**34%**	**1.005**
Wasteload Allocation	**Total WLA**	**3.7**	**3.7**	**0.0**	**0%**	**0.010**
	Construction/Industrial Stormwater	**3.7**	**3.7**	**0.0**	**0%**	0.010
Load Allocation	**Total LA**	**525.2**	**345.0**	**180.2**	**34%**	**0.945**
	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
Margin of Safety		**0.0**	**18.4**	**--**	**--**	**0.050**

[1] Existing TP load is an average for the years 2009-2015

4.2.6.6 North Whaletail Lake

Key findings pertaining to North Whaletail Lake are as follows:

- North Whaletail Lake (AUID: 27-0184-01) is approximately 369.9 acres in surface area and has a maximum depth of 10.3 feet. The entire lake is less than 15 feet deep. The lake is classified as a "shallow lake". The contributing watershed area to the lake is about 1,585 acres.
- Not including the watershed area to South Whaletail Lake, the land use in North Whaletail Lake's Watershed is about 9% developed (primarily single family residential). About 29% of the watershed is agricultural or undeveloped land uses and 34% of the watershed is park or preserve. The watershed-to-lake area ratio is small at 4.3:1.
- The lake is proposed for listing in 2016 for nutrient impairments. There are in-lake monitoring data back to 1995. The water quality data indicates the lake is somewhat degraded, but met or was close to meeting TP standards in 2011, 2013, and 2014.

- A vegetation survey conducted in 2015 indicated moderate to heavy growth of CLPW in about 100 acres of the northwest and western portion of the lake.
- Based in part on incubation of sediment cores and estimation of phosphorus release rates under both anoxic and oxic conditions, about 80% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while only about 12% comes from watershed sources and 8% comes from atmospheric deposition. Most of the internal load is due to the release of phosphorus by bottom sediments.

Table 4.7 presents the phosphorus TMDL and allocations for North Whaletail Lake. To meet the TMDL, the needed reduction in the TP load is 212 lbs/yr. This load reduction includes the MOS of 31 lbs/yr. This is equal to a 26% reduction of the existing total load of 801 lbs/year. This load reduction can be achieved through:

- Reducing the loading coming from South Whaletail Lake by 20%,
- Watershed load reductions of 32%, and
- Internal load reductions of 32%, aimed at a reduction in releases from bottom sediments and managing CLPW.

Table 4.7 - North Whaletail Lake Phosphorus TMDL and Allocations.

Load Category	Load Component	Existing Load (lbs/yr)	Allowable Load (lbs/yr)	Estimated Load Reduction[1] (lbs/yr)	Estimated Load Reduction[1] %	TMDL (lbs/day)
TOTAL LOAD		**801.4**	**620.2**	**212.2**	**26%**	**1.699**
Wasteload Allocation	**Total WLA**	**6.2**	**6.2**	**0.0**	**0%**	**0.017**
	Construction/Industrial Stormwater	**6.2**	**6.2**	**0.0**	**0%**	0.017
Load Allocation	**Total LA**	**795.2**	**583.0**	**212.2**	**27%**	**1.597**
	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	**0.06**	**0.00**	**0.06**	**100%**	0.000
Margin of Safety		**0.0**	**31.0**	**--**	**--**	**0.085**

[1] Existing TP load is an average for the years 2009-2015

4.3 Bacteria *(E. coli)*

The *E. coli* TMDLs presented in this report provide WLAs, LAs and the MOS needed to achieve the state standard for each bacteria impaired reach in the Pioneer-Sarah Creek Subwatershed. The following sections describe the approach used to develop the various components of the *E. coli* TMDLs.

4.3.1 Loading Capacity Methodology

Assimilative capacities for each impaired reach were developed from load duration curves (Cleland 2002). Load duration curves display flow and *E. coli* data across stream flow regimes, provide assimilative capacities, and set load reductions necessary to meet water quality standards.

Flow duration curves were developed using continuous flow data collected at each reach's monitoring station over a seven-year period (2008 through 2014). The curved line relates mean daily flow to the percent of time those values have been met or exceeded (Figure 4-A). For example, at the 50% exceedance value for Pioneer Creek, the stream was approximately 10 cfs or greater 50% of the time. The 50% exceedance is also the midpoint or median flow value. The curve is then divided into flow zones including very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%) and very low (90% to 100%) flow conditions. Subdividing all flow data over the past 10-years into these five categories ensures high-flow and low-flow critical conditions are accounted for in this TMDL study.

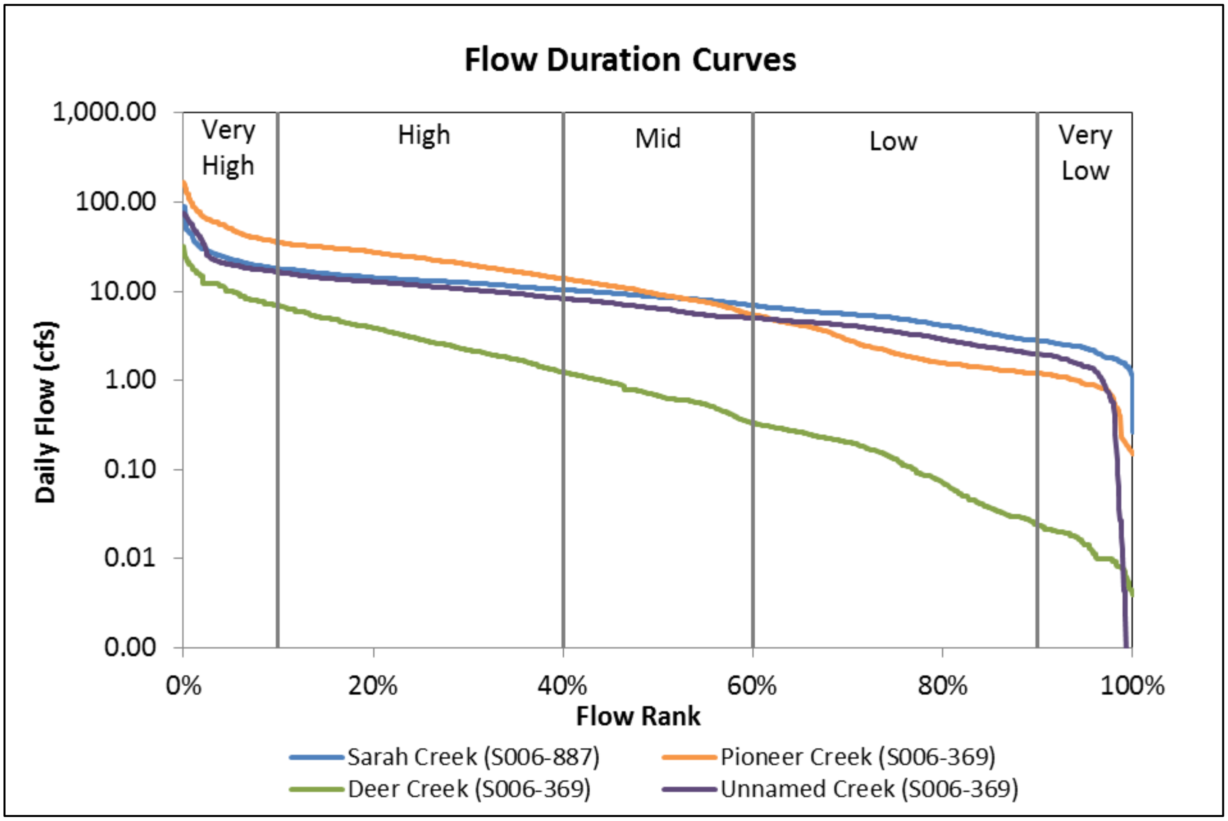


Figure 4-A – Flow duration curves for each *E. coli* impaired reaches.

To develop a load duration curve, all average daily flow values were multiplied by the 126 cfu/100 ml standard and converted to a daily bacteria load to create a "continuous" load duration curve (see Figure 4-B through Figure 4-E). The line represents the assimilative capacity of the stream for each daily flow. To develop the TMDL, the median load of each flow zone is used to represent the Total Daily Loading Capacity (TDLC) for that flow zone. The TDLC can also be compared to current conditions by plotting individual load measurements (open black circles in Figure 4-B through Figure 4-E) for each water quality sampling event. Each value that is above the TDLC line (red line) represents an exceedance of the 126 cfu/100 ml standard, while those below the line are below the water quality standard. Also plotted are the geomean *E. coli* concentrations for each flow regime (solid green circles). The difference between these two provides a general percent reduction in *E. coli* that will be needed to remove each reach from the impaired waters list.

Because the load duration curve method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report (Table 4.9 through Table 4.12) only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA.

4.3.2 Load Allocation Methodology

The LA, also referred to as the watershed LA, is the remaining load after the MOS and WLAs are subtracted from the total load capacity of each flow zone. The watershed LA includes all non-permitted sources such as outflow from lakes and wetlands in the watershed and runoff from agricultural land, forested land, non-compliant septic systems, and non-regulated MS4 residential areas. This category also includes any *E. coli* considered "natural background." Natural background is that contribution that occurs outside of human influence. This would generally be wildlife contributions that are directly loaded to the water body (as opposed to loaded via a stormwater conveyance). For this TMDL, the watershed LAs are primarily comprised of agricultural land outside the MS4 boundaries.

For the purposes of this study, outflow from upstream lake boundary conditions were included as separate line items in the LA. Lakes typically act as sinks of fecal bacteria and therefore are not believed to contribute to elevated *E. coli* levels in impaired reaches. Allocations for the upstream lakes were calculated by multiplying the lake watershed area to total impaired reach watershed ratio (determined in GIS) by the total impaired reach watershed loading capacity (determined by load duration curves) after the MOS was subtracted. Since the watershed loading capacity for the impaired reach was established using the 126 cfu/100 ml *E. coli* standard, this method assumes outflow from the lake boundary conditions are allocated to the *E. coli* standard.

The city of Greenfield is not currently a permitted MS4, however population growth estimates for the city indicate it may qualify as a MS4 in the future. Thus, the city of Greenfield was included as a separate line item in the LA for Sarah Creek in case this load needs to be transferred from the LA to the WLA in the future.

4.3.3 Wasteload Allocation Methodology

The WLAs for *E. coli* TMDLs are typically divided into three categories: permitted point source dischargers, permitted MS4s, and construction and industrial storm water. The following sections describe how each of these WLAs was estimated.

4.3.3.1 Permitted Wastewater Dischargers

There are currently no permitted wastewater dischargers located in the bacteria impaired reach watersheds.

4.3.3.2 Permitted MS4s

Two MS4s that are completely within or have a portion of their municipal boundary in the impaired reach watersheds (Table 4.8) and are therefore assigned WLAs. MS4 boundaries were defined according to the methodology presented in Section 4.2.3.2. Individual MS4 allocations were calculated by multiplying each MS4's percent watershed coverage (determined in GIS) by the total watershed loading capacity (determined by load duration curves) after the MOS was subtracted.

Table 4.8 - Summary of permitted MS4s in the bacteria impaired reach watersheds.

TMDL Reach	MS4	Permit #	MUSA Area within watershed (acres)	Percent of Watershed
Pioneer Creek	Independence City MS4	MS400095	94	0.5%
	Maple Plain City MS4	MS400103	384	2.2%

4.3.3.3 Construction and Industrial Stormwater

WLAs for regulated construction stormwater (MNR100001) were not developed, since *E. coli* is not a typical pollutant from construction sites. Industrial stormwater receives a WLA only if the pollutant is part of benchmark monitoring for an industrial site in the watershed of an impaired water body. There are no bacteria or *E. coli* benchmarks associated with any of the Industrial Stormwater Permits (MNR050000) in these watersheds and therefore no industrial stormwater *E. coli* WLAs were assigned.

4.3.4 Margin of Safety

The MOS accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload, monitored flows, and in-stream water quality to ensure the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 5% of the total load was applied whereby 5% of the loading capacity for each flow regime was subtracted before allocations were made among the waste load and watershed load. Five percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty. The LDC calculations are based on *E. coli* target concentrations and monitored flow data. Most of the uncertainty with this calculation is therefore associated with the monitoring data that were collected over a multiyear period.

4.3.5 Seasonal Variation

Geometric means for *E. coli* bacteria within the impaired reaches are often above the state chronic standard from April through October. Exceedances of the acute standard occur in these reaches during this time period. Fecal bacteria are most productive at temperatures similar to their origination environment in animal digestive tracts. Thus, these organisms are expected to be at their highest concentrations during warmer summer months when stream flow is low and water temperatures are high. High *E. coli* concentrations in many of the reaches continue into the fall, which may be attributed to constant sources of *E. coli* (such as failing septic systems and animal access to the stream) and less flow for dilution. However, some of the data may be skewed as more samples were collected in the summer months than in October. Seasonal and annual variations are accounted for by setting the TMDL across the entire flow record using the load duration method.

4.3.6 TMDL Summary

Table 4.9 through Table 4.12 summarize all TMDL components for each *E. coli* impaired reach. Allocations for these TMDLs were established using the 126 cfu/100 ml *E. coli* standard. All LAs are reported in billions of organisms/day and were rounded to two significant figures to prevent zero load values. Figure 4-B through Figure 4-E show the estimated load reduction for each flow zone. This reduction was calculated based on the difference between the monitored geometric mean *E. coli* concentration of each flow zone and the 126 cfu/100 ml standard. At this time, there is not enough information or data available to estimate or calculate the existing (current conditions) load contribution from each of the WLA and LA sources presented in Table 4.9 through Table 4.12. Thus, the estimated load reduction for each flow zone applies to all sources. The Pioneer-Sarah Creek WRAPS report further investigates which sources and geographical locations within the impaired reach watershed should be targeted for bacteria BMPs and restoration strategies.

For some flow regimes, calculated pollutant loads fell below the allowable pollutant load. In an effort to follow antidegradation requirements, the existing pollutant load was used for load and wasteload calculations rather than the allowable load. The difference between the existing and allowable load was classified as the "unallocated load."

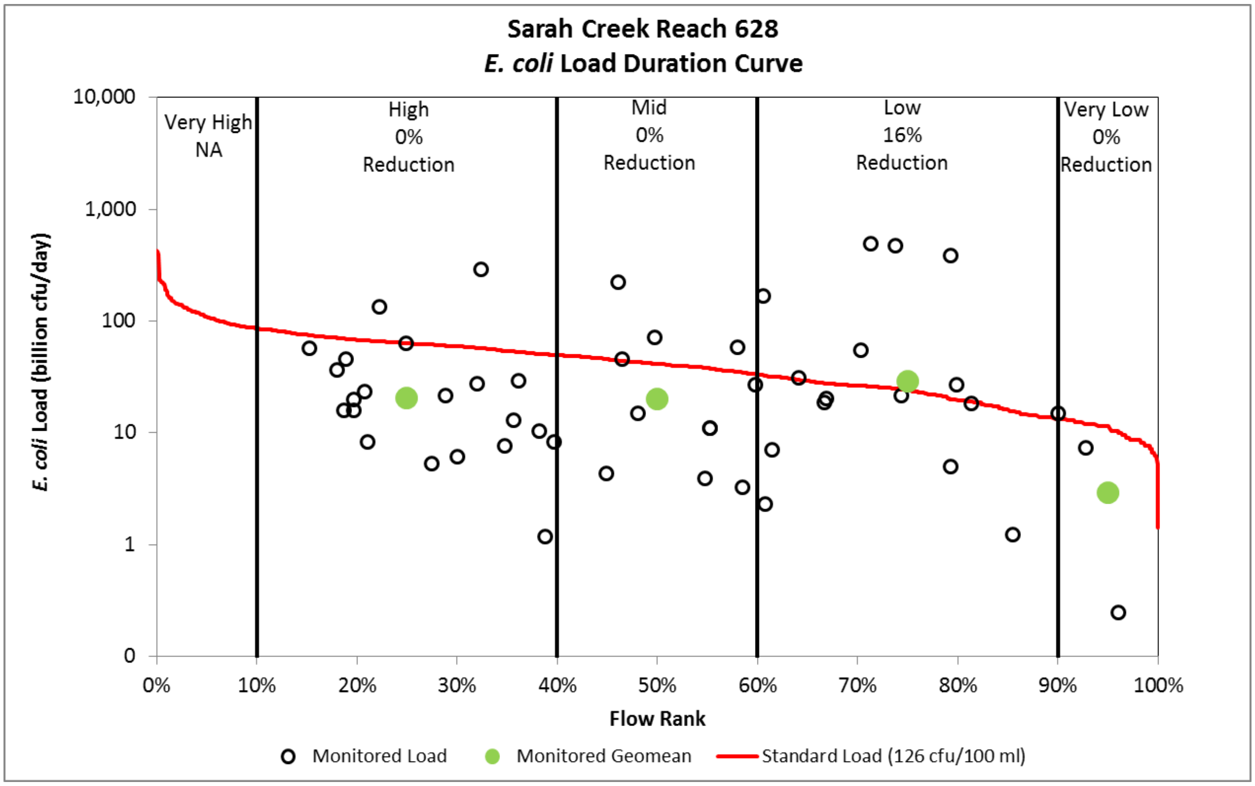


Figure 4-B - Sarah Creek *E. coli* load duration curve and TMDL reductions.

Table 4.9 - Sarah Creek *E.coli* TMDL summary.

		Flow Regime*				
		Very High	**High**	**Mid**	**Low**	**Very Low**
		***E. coli* Load (billions of organisms/day)**				
Wasteload	**Total WLA****	**--**	**--**	**--**	**--**	**--**
	Permitted Wastewater Dischargers	--	--	--	--	--
	Permitted MS4s	--	--	--	--	--
Load	**Total LA**	**103.34**	**17.33**	**18.03**	**22.95**	**2.33**
	Lake Sarah Boundary Condition	89.87	15.07	15.68	19.96	2.03
	Greenfield City	2.21	0.37	0.39	0.49	0.05
	Watershed LA	11.26	1.89	1.96	2.50	0.25
MOS		**5.44**	**3.17**	**2.07**	**1.21**	**0.56**
Unallocated Load		**0.00**	**42.92**	**21.25**	**0.00**	**8.31**
TOTAL LOAD (TMDL)		**108.78**	**63.42**	**41.35**	**24.16**	**11.20**
Existing Load (geomean of observed data)		NA***	20.50	20.10	28.76	2.90
Estimated Reduction (%)		NA***	0%	0%	16%	0%

* Data collected between 2008-2014 were used to develop the flow regimes and loading capacities for this reach

** There are no permitted point discharges from industries, municipalities, WWTP, or individually permitted sources within the Sarah Creek Watershed

*** Not enough data at this time to estimate a load reduction

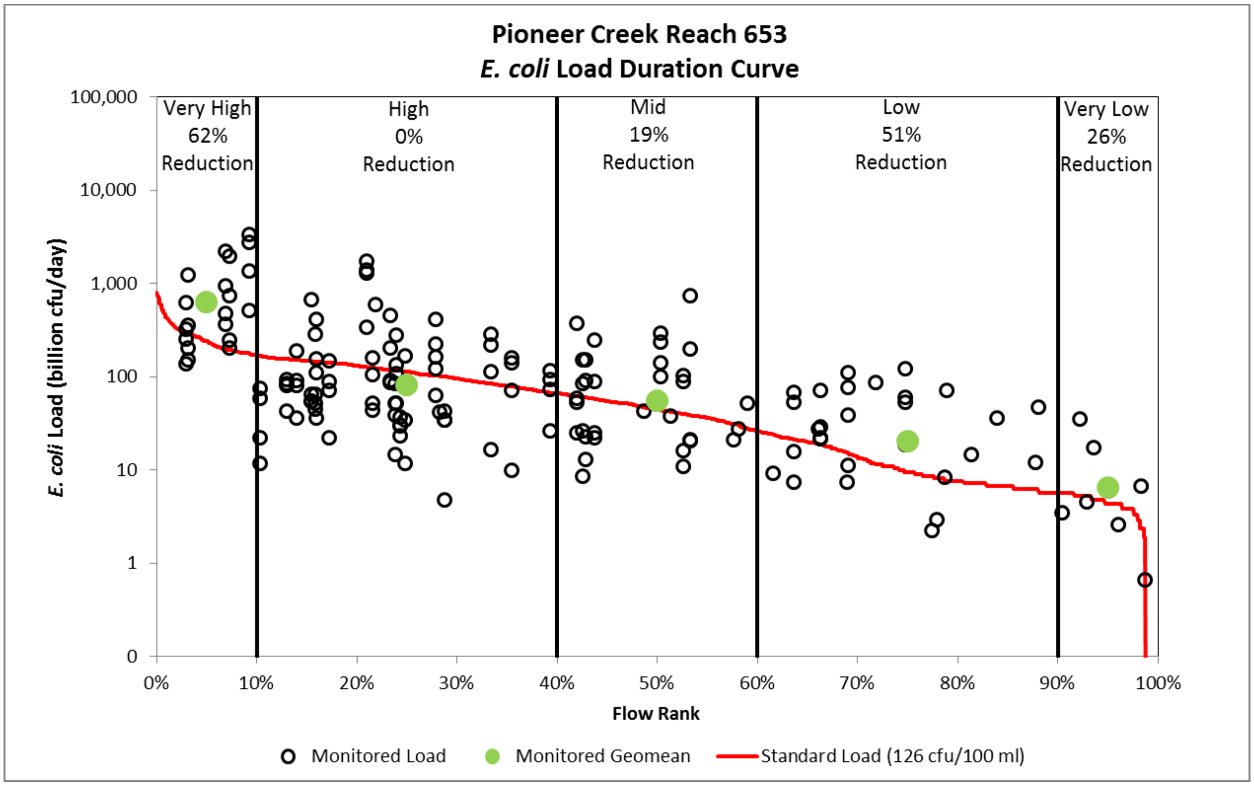


Figure 4-C - Pioneer Creek *E. coli* load duration curve and TMDL reductions.

Table 4.10 - Pioneer Creek *E.coli* TMDL summary.

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli Load (billions of organisms/day)				
Wasteload	**Total WLA****	**6.24**	**2.07**	**1.15**	**0.26**	**0.12**
	Permitted Wastewater Dischargers	--	--	--	--	--
	Independence City MS4	1.23	0.41	0.23	0.05	0.02
	Maple Plain City MS4	5.01	1.66	0.92	0.21	0.10
Load	**Total LA**	**222.62**	**73.75**	**40.91**	**9.26**	**4.32**
	Lake Independence Boundary Condition	109.33	36.22	20.09	4.55	2.12
	Watershed LA	113.29	37.53	20.82	4.71	2.20
MOS		**12.05**	**5.69**	**2.21**	**0.50**	**0.23**
Unallocated Load		**0.00**	**32.32**	**0.00**	**0.00**	**0.00**
TOTAL LOAD (TMDL)		**240.91**	**113.82**	**44.27**	**10.02**	**4.67**
Existing Load (geomean of observed data)		633.97	81.50	53.35	19.96	6.16
Estimated Reduction (%)		62%	0%	19%	51%	26%

* Data collected between 2008-2014 were used to develop the flow regimes and loading capacities for this reach.

** There are no permitted point discharges from industries, municipalities, WWTP, or individually permitted sources within the Sarah Creek Watershed

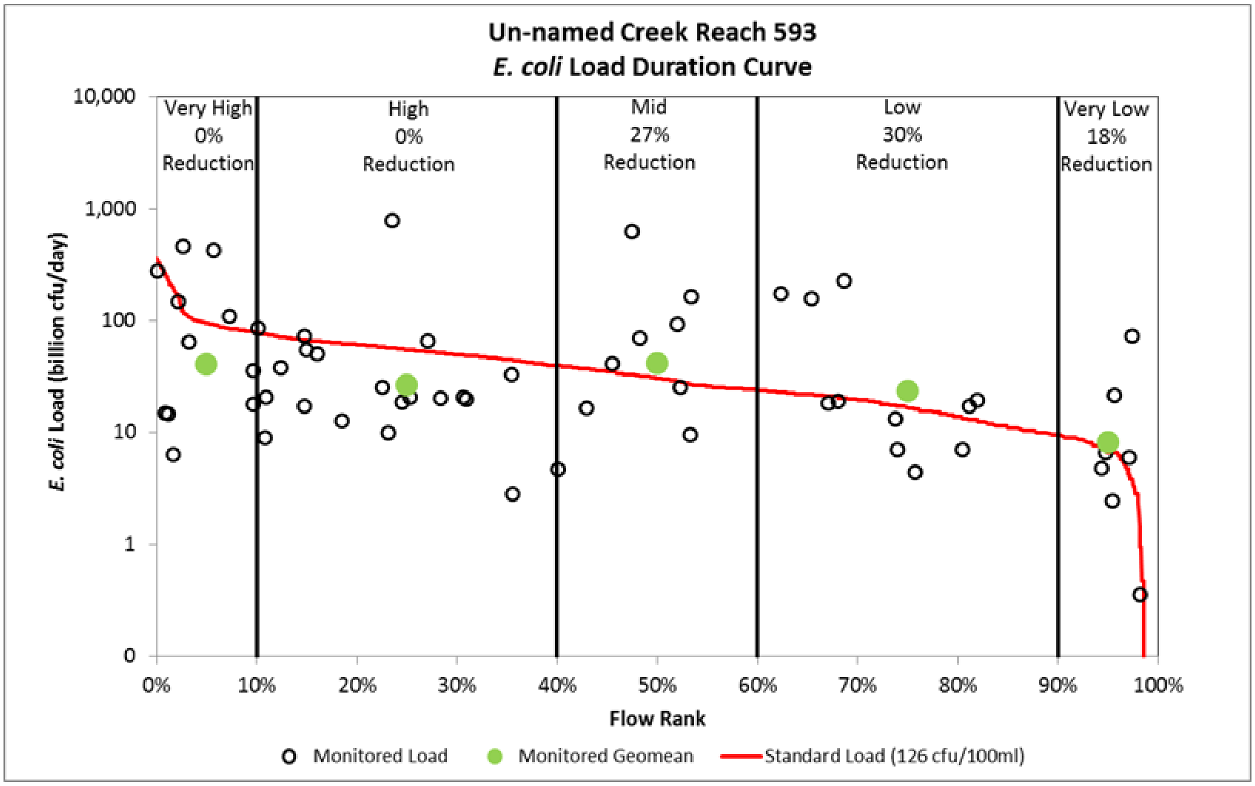


Figure 4-D - Unnamed Creek *E. coli* load duration curve and TMDL reductions.

Table 4.11 - Unnamed Creek *E.coli* TMDL summary.

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli Load (billions of organisms/day)				
Wasteload	**Total WLA****	**--**	**--**	**--**	**--**	**--**
	Permitted Wastewater Dischargers	--	--	--	--	--
	Permitted MS4s	--	--	--	--	--
Load	**Total LA**	**36.57**	**23.83**	**29.07**	**16.08**	**6.55**
	Oak & Mud Lake Boundary Conditions	25.40	16.55	20.19	11.17	4.55
	Watershed LA	11.17	7.28	8.88	4.91	2.00
MOS		**4.73**	**2.77**	**1.53**	**0.85**	**0.35**
Unallocated Load		**53.36**	**28.78**	**0.00**	**0.00**	**0.00**
TOTAL LOAD (TMDL)		**94.65**	**55.38**	**30.60**	**16.93**	**6.90**
Existing Load (geomean of observed data)		41.30	26.60	41.93	24.17	8.41
Estimated Reduction (%)		0%	0%	27%	30%	18%

* Data collected between 2008-2014 was used to develop the flow regimes and loading capacities for this reach.

** There are no permitted point discharges from industries, municipalities, WWTP, or individually permitted sources within the Unnamed Creek Watershed.

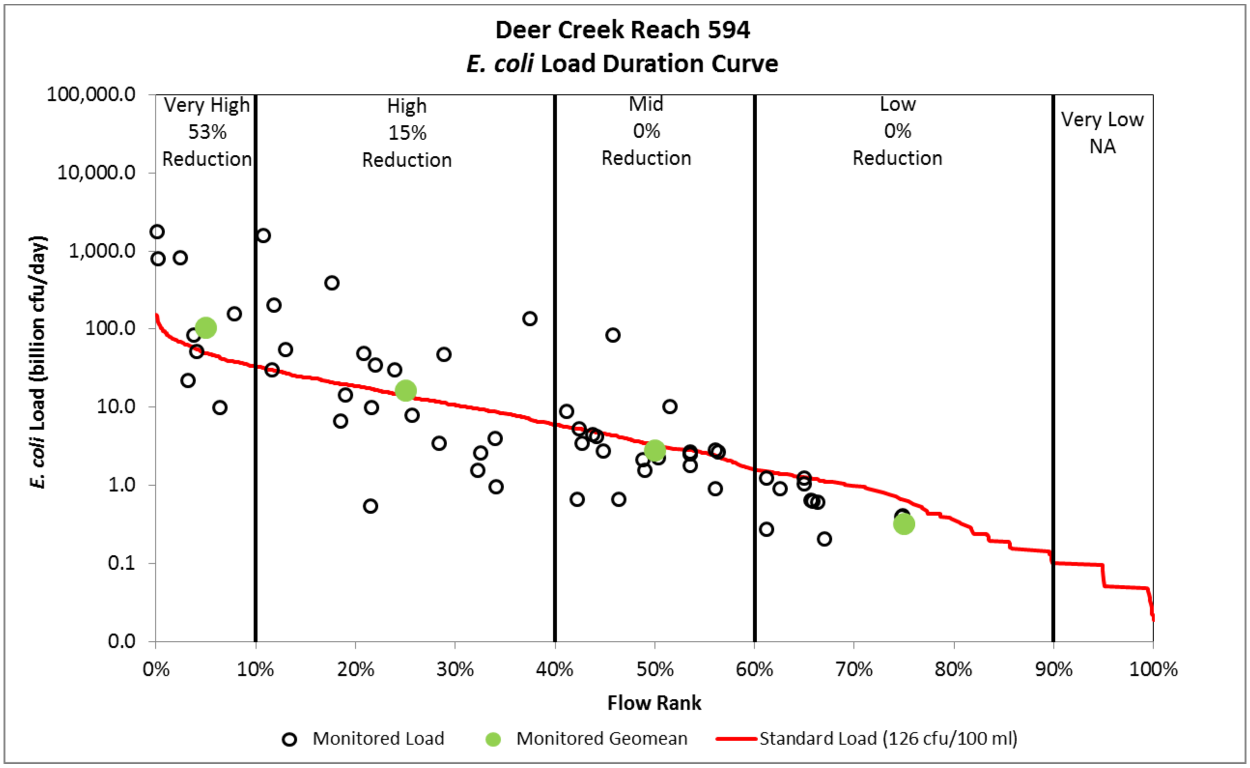


Figure 4-E - Deer Creek reach 594 *E. coli* load duration and TMDL reductions.

Table 4.12 - Deer Creek *E.coli* TMDL summary.

		Flow Regime*				
		Very High	**High**	**Mid**	**Low**	**Very Low**
		***E. coli* Load (billions of organisms/day)**				
Wasteload	**Total WLA****	**--**	**--**	**--**	**--**	**--**
	Permitted Wastewater Dischargers	--	--	--	--	--
	Permitted MS4s	--	--	--	--	--
Load	**Total LA**	**46.28**	**13.07**	**2.64**	**0.29**	**0.06**
	Whaletail Lake Boundary Condition	21.88	6.18	1.25	0.14	0.03
	Watershed LA	24.40	6.89	1.39	0.15	0.03
MOS		**2.44**	**0.69**	**0.16**	**0.03**	**0.003**
Unallocated Load		**0.00**	**0.00**	**0.48**	**0.31**	**0.00**
TOTAL LOAD (TMDL)		**48.72**	**13.76**	**3.28**	**0.63**	**0.07**
Existing Load (geomean of observed data)		103.66	16.20	2.80	0.32	NA***
Estimated Reduction (%)		53%	15%	0%	0%	NA***

* Data collected between 2008-2014 were used to develop the flow regimes and loading capacities for this reach.

** There are no permitted point discharges from industries, municipalities, WWTP, or individually permitted sources within the Deer Creek Watershed.

*** Not enough data at this time to estimate a load reduction.

5. Future Growth Considerations

5.1 New or Expanding Permitted MS4 WLA Transfer Process

Future transfer of watershed runoff loads in this TMDL may be necessary if any of the following scenarios occur within the project watershed boundaries:

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more non-regulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
4. Expansion of a U.S. Census Bureau Urban Area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL was completed, but are now inside a newly expanded Urban Area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
5. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES Permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment.

5.2 New or Expanding Wastewater

The MPCA, in coordination with the Environmental Protection Agency (EPA) Region 5, has developed a streamlined process for setting or revising WLAs for new or expanding wastewater discharges to waterbodies with an EPA approved TMDL (MPCA 2012). This procedure will be used to update WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are at or below the instream target, and will ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying all WLAs will be handled by the MPCA, with input and involvement by the EPA, once a permit request or reissuance is submitted. The overall process will use the permitting public notice process to allow for the public and EPA to comment on the permit changes based on the proposed WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made.

For more information on the overall process, visit the MPCA's TMDL Policy and Guidance webpage.

6. Reasonable Assurance

When establishing a TMDL, reasonable assurances must be provided, demonstrating the ability to reach and maintain the established water quality goals. Reasonable assurances typically include both regulatory and non-regulatory efforts at the state and local levels that will result in pollutant load reductions. The following should be considered reasonable assurance that implementation will occur and result in bacteria and nutrient load reductions to the waterbodies included in this TMDL study.

1. The BMPs and other actions outlined in Section 7 have all been demonstrated to be effective in reducing the generation and/or transport of pollutants to surface waters (MPCA 2014). Many of these actions are being promoted by state and local resource managers and have shown significant levels of adoption in both regulatory and non-regulatory environments.
2. The watershed and stakeholder groups that provided feedback and input for the project had broad representation from local government units (LGU) and agencies that are directly affected by the implementation recommendations. Citizens, including lake associations, who have a direct stake in the success of the implementation strategy were also informed about the process and provided input. Their interest and knowledge will help assure accountability in the implementation process. Finally, state and regional government representatives who will play a pivotal role in regulating and/or financially supporting many of the implementation elements were also involved in developing those elements.
3. The PSCWMC has developed and adopted its Third Generation Watershed Management Plan. The updated plan supports the implementation elements of this TMDL through regulatory requirements for new and re-development, a public education and outreach program, a capital projects selection and funding process, and a monitoring program. The application of updated stormwater mitigation requirements to new urban/suburban developments in the watershed provides a cost-effective opportunity to help decrease pollutant loads relative to current conditions. As part of the Third Generation Plan process, the Commission has revised their development requirements for stormwater management to reflect the Minimal Impact Designs (MIDs) standards recommended by the MPCA.
4. The issuance of an NPDES Permit provides reasonable assurance that the WLAs contained in a TMDL will be achieved. This is because 40 C.F.R. 122.44(d)(1)(vii)(B) requires that effluent limits in permits be consistent with "the assumptions and requirements of any available WLA" in an approved TMDL. All of the municipalities comprising the Pioneer-Sarah Creek Subwatershed project area, except Greenfield, are covered under updated MS4 General Permit and all lands are subject to the Construction Stormwater Permit, both of which became effective on August 1, 2013. Both permits mandate an increase in the volume of water that must be retained or abstracted on-site, as well as require measures to minimize/address soil compaction, control flow rates to protect the stability of downstream open channels, provide buffers adjacent to surface waters, etc. In addition, the next MS4 General Permit (expected to be issued in 2018) will trigger a regulatory requirement for all MS4s receiving WLAs under this TMDL to demonstrate annual progress meeting the required load reductions. The MS4 Permit therefore provides an important regulatory link between a permittee's

authorization to legally discharge stormwater to waters of the state and its progress in meeting its load reduction obligations under the TMDLs affecting it.

5. Monitoring will be conducted to track and document progress in meeting the TMDL and, if necessary, to provide a basis for adjusting the implementation approach outlined in this document consistent with the adaptive management philosophy for the project (see Section 8.6).
6. Additionally, all local units of government within the PSCWMC are required to prepare a local watershed management plan, capital improvement program, and official controls as necessary to bring local water management into conformance with the PSCWMC Watershed Management Plan. These local plans are reviewed and approved by the PSCWMC.
7. A WRAPS report was prepared as a companion document to this TMDL. The WRAPS report outlines key implementation elements for each water body, including specific management measures and expected implementation schedules. This information will support and facilitate planning of programs and capital projects, including securing funding from local, state, and federal sources.
8. The MPCA regulates the collection, transportation, storage, processing, and disposal of animal manure and other livestock operation wastes. The MPCA Feedlot Program implements rules governing these activities, and provides assistance to counties and the livestock industry. The feedlot rules apply to most aspects of livestock waste management including the location, design, construction, operation, and management of feedlots and manure handling facilities.

   There are two primary concerns about feedlots in protecting water:

   - Ensuring that manure on a feedlot or manure storage area does not run into water;
   - Ensuring that manure is applied to cropland at a rate, time and method that prevents bacteria and other possible contaminants from entering streams, lakes and ground water.
9. Subwatershed assessments, especially for rural agricultural portions of the project watersheds, will be especially important in identifying cost-effective opportunities for pollutant load reductions. The level of detail of analysis in this TMDL is not sufficient to identify the impact of specific parcels of land and how they are managed on downstream pollutant loads, nor is it sufficient to identify the most cost-effective individual projects. A subwatershed assessment that uses a combination of on-the-ground field observations, field-scale load estimation tools that account for the impacts of specific BMPs, and site-specific BMP cost information is essential in developing a list of prioritized projects and providing the basis to approach individual landowners to solicit cooperation. To facilitate both the subwatershed assessments themselves and help with landowner cooperation/agricultural project implementation, Hennepin County and the University of Minnesota Extension Service intends to jointly hire an agricultural specialist in 2017.
10. Historically, a variety of funding sources have been used for water resource projects within the TMDL study area and these sources are expected to continue into the foreseeable future.
    a. The PSCWMC funds its operations mostly through assessments to member cities, which raise those funds through either a tax levy imposed on residents or a special purpose stormwater utility fee. Revenue raised from these sources fund such PSCWMC activities as public education and outreach, monitoring, and preparation of annual activity reports.

b. Capital improvement projects undertaken by the PSCWMC can be funded through an ad valorem tax levy imposed through Hennepin County at the PSCWMC's request on residents anywhere within the PSCWMC jurisdictional limits. This annual tax levy is one of the main funding mechanisms available to support for capital-related implementation activities within the impaired subwatersheds of this study. Funds generated through the ad valorem process are used to fund projects outright, sponsor cost-share projects with municipal partners, as well as provide cash match to secure grants.

c. A third funding source available to the PSCWMC was made possible by Minnesota voters approving the Clean Water, Land, and Legacy (CWLA) amendment in 2008. This amendment increased the state sales and use tax rate by three-eighths of 1% on all taxable sales, starting July 1, 2009, and continuing through 2034. Of the funds generated, approximately one third have been dedicated to a Clean Water Fund to, "protect, enhance, and restore water quality is lakes, rivers, streams, and groundwater, with at least 5% of the fund targeted to protect drinking water sources." (MPCA 2014).

d. A fourth funding avenue available to support implementation of this TMDL study is the Clean Water Partnership (CWP) Program established by the Minnesota Legislature in 1987. The CWP program focuses on the control of nonpoint pollution sources and provides financial assistance through loans for activities like fixing failing septic systems, as well as technical assistance to LGUs.

e. The Federal Clean Water Act Section 319 Nonpoint Source (NPS) Management Program was established through amendment to the Clean Water Act in 1987 and is another source of potential funding. Section 319 NPS funds support BMPs for waters with TMDLs.

7. Monitoring Plan

Progress on TMDL implementation will be measured through regular periodic monitoring of water quality and tracking of the BMPs completed. This will be accomplished through the combined efforts of the organizations receiving LAs as well as the cooperating agencies (notably the PSCWMC, MPCA, and Three Rivers Park District). The Intensive Watershed Monitoring (IWM) program conducted by the MPCA is expected to provide a large-scale, longer-term picture of the degree to which conditions are changing in the Pioneer-Sarah Creek Subwatershed. Monitoring by the MPCA under this program was last conducted in 2007 and 2008 in the North Fork Crow Watershed and 2012 and 2013 in the South Fork Crow Watershed, and is expected to be undertaken again in 2017 and 2018, and 2022 and 2023 respectively as part of the 10-year monitoring cycle. As part of the Third Generation Watershed Management Plan, the Commission adopted and funded a rotating sampling program for streams and lakes designed in part to monitor progress in implementing the TMDL. A summary of the monitoring program to assess implementation progress is presented below.

7.1 Lake Monitoring

Spurzem Lake, Half Moon Lake, North Whaletail Lake and South Whaletail Lake will continue to be monitored by the Commission in partnership with Three Rivers Park District at least every two years because of their visibility and priority as public resources. Peter Lake and Ardmore Lake will be monitored at least once every three years by the Commission in partnership with Three Rivers Park District as access and resources are available, either through volunteers or under contract with professional staff. Lakes are generally monitored for Chl-*a*, TP, and Secchi disk transparency. The Commission has also regularly participated in the Metropolitan Council's Citizen Assisted Lake Monitoring Program (CAMP) since 2005. CAMP volunteers monitor surface water conditions and chemistry. They also judge the appearance of the lake, its odor, and its suitability for recreation.

Aquatic plant surveys should will be conducted on each lake at approximately three to five year intervals by the Commission in partnership with Three Rivers Park District. In-lake monitoring will continue as implementation activities are undertaken across the respective watersheds.

The DNR will continue to conduct fish surveys on lakes with public access (currently Spurzem Lake, Half Moon, and North Whaletail Lake) as allowed by their regular schedule. Currently, fish surveys are conducted approximately every five years.

7.2 Stream Monitoring

The Commission will continue to annually monitor flow and water quality at baseline sites on Sarah Creek and on Pioneer Creek, and at one additional site in the watershed per year on a rotating basis, so that each site is monitored every two to three years. These rotating sites include Dance Hall Creek, Loretto Creek, and Spurzem Creek. In addition, the Commission may periodically undertake special stream monitoring on other tributaries where necessary, for example to measure progress toward meeting a TMDL, calibrate models or refine source assessments.

7.3 Tracking of Best Management Practices

As part of their NPDES General Stormwater Permit, cities that are MS4s must annually track and report to the MPCA the number, type, location, and load reduction benefits of constructed BMPs (such as detention basins, filtration and infiltration basins, and swales) undertaken to achieve TMDL wasteload reductions. The PSCWMC will review member communities' annual reports to keep abreast of progress toward achieving the TMDLs. The Commission will also request that all its member cities track LA reduction BMPs and other WRAPS-related activities, and report them periodically so that the Commission can summarize this information annually and have it available for agencies and interested members of the public.

8. Implementation Strategy Summary

8.1 Implementation Framework

The strategies described in this section include potential actions to reduce nutrient and bacteria loads in the subject watersheds. NPDES Permit compliance includes being consistent with the assumptions and requirements of an approved TMDL and associated WLAs as they apply to the permittee. For both the lake and stream TMDLs, the baseline period is the mid-range year of the years used for the lake response modeling and development of the *E. coli* load duration curves, respectively (Table 8.1). Since the *E. coli* load duration curves were developed using monitored data, the baseline year will coincide with the mid-range monitoring period. Any load-reducing BMPs implemented during or after the baseline year will be able to "count" toward an MS4's load reductions. The lake models were calibrated to existing conditions using in-lake data, which implicitly takes into account BMPS that are already in the ground. The *E. coli* load duration curves were also determined using existing stream data. Therefore, if a load reducing BMP was implemented and fully functional prior to the baseline year it would already be incorporated into the estimated load reductions in the TMDLs. Any load-reducing BMPs implemented during or after the baseline year can be included in the permittees annual reporting of estimated cumulative load reductions to the MPCA stormwater program. See the MPCA MS4 TMDL Guidance for more information.

Table 8.1 - Implementation Baseline Years.

Water Body	Baseline Year
Peter Lake	2012
Spurzem Lake	
Half Moon Lake	
Lake Ardmore	
South Whaletail Lake	
North Whaletail Lake	
Sarah Creek	2011
Pioneer Creek	
Deer Creek	
Unnamed Creek	

Load reductions achieved for some implementation actions are creditable to the LAs in some cases and to WLAs in other cases. Examples of non-WLA creditable projects include strategies aimed at reducing in-lake loading (e.g., alum, aquatic plant management). For clarification on a particular project, the MPCA Stormwater Program staff should be contacted.

8.2 Permitted Sources

8.2.1 MS4

The MS4 General Permit requires permitees to address all WLAs in TMDLs approved prior to the effective date of the Permit. In doing so, they must determine if they are currently meeting their WLA(s). If the WLA is not being achieved at the time of application, a compliance schedule is required that includes interim milestones, expressed as BMPs, that will be implemented over the current five-year permit term to reduce loading of the pollutant of concern in the TMDL. Additionally, a long-term implementation strategy and target date for fully meeting the WLA must be included.

Many of the watersheds of the impaired waters identified in this report are expected to undergo land use changes between now and 2030. Table 8.2 shows the approximate total area of the watersheds draining to the impaired streams and lakes addressed in this report and the percentage of the area expected to change land uses by 2030.

Table 8.2 - Expected Land Use Change by Lake and Stream Reach Subwatershed.

Subwatershed	Approximate Total Drainage Area[1]	% of Drainage Area Expected to Change Land Use by 2030[2]
Peter Lake	300	85%
Spurzem Lake	2,800	73%
Half Moon Lake	3,250	64%
Lake Ardmore	500	56%
South Whaletail Lake	580	60%
North Whaletail Lake	1,450	53%
Sarah Creek (AUID-628)	760	42%
Pioneer Creek (AUID-653)	9,178	40%
Unnamed Creek (AUID-593)	2,952	0%
Deer Creek (AUID-594)	2,603	46%

[1] Total does not include area of subject lake, but does include area of other lakes and wetlands in the subject lake's watershed. For streams, area included is only for that draining to the stream reach below the upstream AUID boundary

[2] From 2010 Metropolitan Land Use Classification and planned 2030 Met Council land use.

To take advantage of the opportunity afforded by land use transition, aggressive stormwater management measures must be applied to new development everywhere in the watershed. Effective May 21, 2015, the PSCWMC adopted updated standards that govern stormwater management standards for quality, runoff volume and rate control for new development projects. Key provisions of those updated standards are the following:

- A decrease in the threshold for application of stormwater quality and quantity standards to one acre of disturbed surface, regardless of land use. This will result in more new developments subject to the updated stormwater management requirements of the Commission.
- Require infiltration of 1.1 inches of runoff volume off new impervious surfaces within 48 hours, based on the MPCAs MIDS and the NPDES General and Construction Permits. Where infiltration is not feasible, the new rules require that runoff be filtered before discharge from the site. The rules include several credits toward meeting the abstraction requirement, including

disconnection of impervious surface, conservation of existing native vegetation, and the use of de-compacted and amended soil as a BMP.

- A performance standard for stormwater quality to achieve a loading reduction as good as or better than that, which would be achieved by abstracting 1.1” of runoff depth from new impervious surfaces, or no-net increase in TP or total suspended solids (TSS), whichever is lower. Application of the 1.1-inch abstraction requirement equates to approximately a 76% reduction in TP compared to the post-development but non-mitigated phosphorus load from urban development (Wenck 2013), well above the 50% to 60% reduction typical of a wet detention pond based on Nationwide Urban Runoff Program (NURP) design standards. Compliance with this updated provision will require a calculation of the loading from the pre-development condition, then the load from the post-development condition assuming a 1.1-inch abstraction of impervious runoff from the post-development condition. The development must incorporate water quality BMPs to limit post-construction loading to the lesser of the two figures.

As permitted MS4s are expanded to serve new development, those MS4s may be able to take credit for working toward meeting their TMDL allocations based on net decreases in landscape loads associated with replacing high pollutant export non-urban uses with suburban/urban land uses that incorporate the stormwater controls identified. The PSCWMC should work with MPCA and the member communities to determine under what conditions this would be appropriate.

Other measures that should be considered by MS4s to meet their pollutant load reduction obligations under this TMDL include the following:

- Pursue stormwater treatment retrofit projects as opportunities arise (for example as part of road/street re-construction, residential/commercial/industrial re-development, etc.), with an emphasis on runoff infiltration/filtration as site conditions allow.
- Undertake intensified street cleaning activities in high priority areas, especially where opportunities for cost-effective implementation of structural BMPs is limited (Baker et. al. 2014).
- Enhance existing stormwater treatment features, such as by adding iron enhanced sand filters to existing stormwater ponds.

8.2.2 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs, and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

8.2.3 Industrial Stormwater

The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES Industrial Stormwater Permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000), or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

8.2.4 Wastewater

The wastewater treatment system operated by the city of Loretto (MN0023990) is the only permitted point source discharger affected by this TMDL. It is currently permitted to periodically discharge treated sewage effluent into a wetland complex that flows to Spurzem Lake. In recent years, the Loretto WWTP has been applying alum to its treatment ponds prior to discharge. This management measure has reduced the concentration of phosphorus in their discharge to under 0.2 mg/l, or 200 ppb. This represents a phosphorus concentration reduction of over 95% compared to influent concentrations, and any further significant reductions are neither reasonable nor cost-effective. Based on discharge monitoring data for the facility from 2013 and 2014, the annual load discharged from the facility over this time period average 24.6 lbs/yr. Thus, a WLA of 24.6 lbs/yr has been assigned to this facility for the Spurzem Lake TMDL.

8.3 Non-Permitted Sources

8.3.1 Manure Management

Based on the results of the livestock survey completed for this project, there were almost 800 head of livestock in the Pioneer Creek hydrologic watershed in 2011, including almost 260 beef and dairy cattle and about 540 horses. It was estimated that almost 16,000 pounds of manure-derived phosphorus was generated by livestock in the watershed in 2011, equal to just under 0.5 pounds per acre of watershed area. The amount of manure applied in the Pioneer Creek Subwatershed is likely substantial, and the way manure is managed is an important factor affecting how much of a risk it is to surface water quality. Routine soil testing would help determine where manure can be applied to satisfy nutrient needs for crops while minimizing potential nutrient loss to runoff. Manure spreading on frozen ground during the winter is a common practice, with many operations having no manure storage facilities. Much of the nutrient content and organic matter is likely lost to runoff when snowmelt events occur. Finally, livestock appear to have un-restricted access to streams in some reaches, which is likely to result in direct loading of bacteria and nutrients, and lead to bare or sparsely vegetated banks and riparian areas that foster streambank failures.

8.3.2 Rural Residential with Livestock Management

About 25% of the Pioneer Creek Subwatershed is expected to change from current land uses to rural residential land uses between 2010 and 2030, and “hobby” farms with livestock could be a significant component of that change. There are potentially significant benefits in terms of pollutant load reductions where intensive agricultural uses in sensitive areas are replaced with well-managed/mitigated rural residential uses. However, those load reduction benefits can easily be negated by poorly sited and/or managed “hobby” farm (especially horse) operations. Good siting and management of new hobby livestock operations will be important to minimize the export of pollutants from these operations to surface waters. Where applicable, the MS4 communities within the watershed (especially those with high hobby farm development potential such as Minnetrista and Independence) should adopt standards that address the following issues:

- Allowable locations of feedlots, pens, etc. relative to wetland edges, as well as stream and lake shorelines.
- Requirements for the design and siting of manure storage, containment, and composting areas, and schedules for the removal of manure or compost from the affected sites.
- Clean water diversions to divert upgradient runoff around feedlot and manure containment areas.
- Site runoff retention and vegetative filtration systems downslope from the feedlot and manure containments areas.
- Pasture management requirements, including allowable livestock densities in pasture areas based on the net area suitable to support pasturing (i.e., excluding wetlands, woodlots/woodland, areas occupied by buildings, driveways, parking areas, lawns, etc.) instead of the gross (total) area of the entire parcel.
- The MDA Agricultural BMP Handbook for Minnesota (MDA 2012) provides additional information on agricultural BMPs to improve and protect water quality.

8.3.3 Subsurface Sewage Treatment Systems (SSTSs) Management

According to MPCA (2011), there is an estimated 29% failure rate for septic systems in Hennepin County. The cities in the watershed are responsible for inspection of on-site septic systems and enforcement of standards, though some contract with the Hennepin County Department of Health to provide those services for them. In any case, the cities should continue to assure that systematic inspections are carried out and that septic system upgrades are ordered as necessary, with priority given to systems that are imminent threats to public health and safety, and failing systems near-or whose discharge can reach- streams, waterways, and lakes.

8.3.4 Internal Nutrient Loading

Internal nutrient loads will need to be reduced to meet the TMDL allocations for many of the lakes addressed in this document. One source of internal loading is CLPW. CLPW is present in a number of the lakes addressed in this report, and in some cases at extremely high densities. Senescence of CLPW in summer can be a significant source of internal phosphorus load that often results in mid- to late-summer water quality degradation. Vegetation management, such as successive years of chemical treatments that selectively targets CLPW but does not negatively impact native aquatic plants, may be required to reduce CLPW growths to non-nuisance levels.

Another source of internal load is release of accumulated phosphorus from enriched bottom sediments. While there are numerous options for internal load reduction, chemical inactivation of sediment phosphorus using an alum-based compound or another precipitant is likely to be most cost-effective. Ideally, most, if not all, of the watershed load reductions called for in the TMDL for a given lake should be achieved before sediment treatments occur. However, in lakes that are close to meeting water quality standards, it may be appropriate to implement an initial sediment treatment as part of a two to three phase sediment treatment sequence, once significant progress has been made in reducing watershed loads and/or CLPW generated loads. This approach can help generate a clear-water response that will improve the conditions for development of a robust rooted aquatic plant community and help stabilize the system in a clear water condition. This approach should only be taken with the understanding that fully achieving the targeted watershed load reductions will be important in extending the effective life of the internal load controls, and that the final internal load treatment in the sequence should be carried out only after substantial completion of the watershed load reduction effort.

8.4 Additional Strategies

The following measures will also be important elements of the implementation effort for this TMDL:

1. **Education**. Educational and outreach opportunities in the watershed should be pursued on such topics as fertilizer use, manure management, grazing management, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to lakes and streams. A high priority of these efforts should be to encourage the adoption of good individual property management practices across all land uses. Also included should be efforts to educate the public on the benefits of a healthy rooted aquatic plant community and the role it plays in a healthy lake or stream system, along with appropriate management expectations, objectives and tools to manage the aquatic plant community without destroying the benefits it offers.
2. **Installation and enhancement of buffers/shoreline restoration.** One of the larger potential sources of *E. coli* and nutrient loading in a number of the subwatersheds is associated with pasture use. Installation of new, or enhancement of existing, buffers to maintain native vegetation along stream banks will help stabilize the streambanks themselves as well as filter runoff from pastures near streams and waterways. Many riparian property owners in all parts of the watershed maintain turf to the shoreline. Property owners should be encouraged to restore a portion of their shoreline with native plants to reduce erosion, capture/filter direct runoff, and improve the near-shore riparian habitat that is so important to most of the desirable fish species found in lakes and streams. The Minnesota Board of Water and Soil Resources has guidelines for implementing Minnesota's recently enhanced Buffer Law for public waters and jurisdictional ditches. The PSCWMC, member cities, and the counties will evaluate their buffer requirements and enforcement programs and modify as necessary.
3. **Roughfish management**. Where appropriate, monitoring and management of the fish community should be undertaken to restore or maintain quality fish communities. Opportunities to assess roughfish populations (particularly common carp) should be undertaken where there is reason to

believe those populations are above the metrics conducive for clear water, native rooted aquatic plant-dominated in-lake condition and a healthy fish community. Control measures appropriate to the magnitude of the problem and the site-specific features of the situation should be undertaken to limit reproductive and recruitment success and roughfish migration.

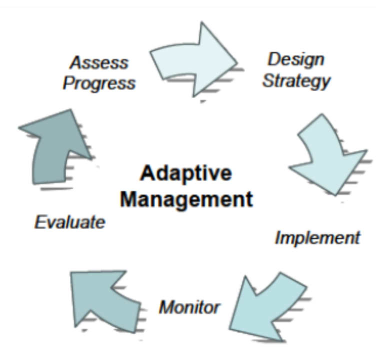
4. **Subwatershed assessments**. The level of detail of the analysis conducted for this TMDL is not generally sufficient to identify specific parcels of land or specific projects that are the most cost-effective for achieving load reductions to the water bodies identified. Additional effort to identify and evaluate potential projects will often be needed as a follow-up activity to this plan, especially for agricultural areas. These efforts should include on-the-ground field investigations to identify the highest priority areas for improvement, development of site-specific remedies, and development of project costs and load reduction benefits. An excellent example of a subwatershed assessment approach is an assessment completed by Hennepin County (2014) for the Dance Hall Creek Subwatershed Stormwater Retrofit Assessment of Lake Sarah in western Hennepin County. The outcome of the assessment effort can then be used as the basis to solicit cooperation from affected landowners, inform capital improvement project planning and implementation, and compile effective grant applications.

8.5 Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation of the cost to implement a TMDL [Minn. Stat. 2007, §114D.25]. The level of detail of the information provided in a large-scale, watershed-wide TMDL like this one is not sufficient to provide a good basis for accurately identifying these costs. This TMDL provides explicit guidance on the magnitude of pollutant reductions to meet the requisite standard. However, the implementation strategy for this TMDL recognizes as well that specific projects will be identified, and credible estimates of the costs and benefits of those projects developed, through the subwatershed assessments, feasibility studies, etc. as a follow-up to the TMDL. However, based on a review of the impairments and the scale at which restoration will be necessary in the watershed, it is estimated that a dollar range of $2,506,800 to $4,555,200 might be necessary. An identification of the types of projects and assumptions, as well as whether each type of project applies to permitted, non-permitted, or both sources, is included in Appendix F. Note that the cost range is an estimate and many aspects can cause the costs to rise or fall as implementation takes place across the watershed.

8.6 Adaptive Management

The implementation strategies and elements focus will be carried out in the context of adaptive management. Continued monitoring and "course corrections" in response to technically sound monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water bodies.



9. Public Participation

A stakeholder participation process was undertaken for this TMDL to obtain input from, review results with, and take comments from the public and interested/affected agencies and local partners regarding the development and conclusions of the TMDL. The process was led by the PSCWMC, the local partner for the TMDL effort. The following cities/agencies/organizations were invited to project meetings and/or received communications regarding the project:

City of Corcoran	Hennepin County Environmental Services
City of Greenfield	Board of Water and Soil Resources
City of Independence	Metropolitan Council Environmental Services
City of Loretto	Minnesota Department of Natural Resources
City of Maple Plain	Minnesota Department of Transportation
City of Medina	Minnesota Pollution Control Agency
City of Minnetrista	Minnesota Department of Agriculture
Lake Sarah Improvement Association	Lake Independence Citizen's Association

Knowledge, Attitudes, and Practices (KAP) Survey

As an initial step in the stakeholder/public involvement process, a Knowledge, Attitudes, and Practices (KAP) survey was conducted of watershed residents (Eckman 2013). While the relatively small sample size of returned surveys cannot be considered representative of all property owners in the watershed, study findings do provide some information on audience knowledge, constraints, information needs, attitudes, and current practices. Among the key findings are the following:

- There is a very high awareness of the connection between people's actions and water quality in local lakes.
- An overwhelming majority of all respondents felt that individuals degrading a public water body have the responsibility for clean-up.
- There is clearly very strong support and unmet demand for education and outreach programs on water quality issues.
- In terms of fostering BMP adoption, financial incentives and cost shares appear to be important to some respondents. Also important is a sense of leaving a legacy for future generations, which should factor into PSCWMC messaging.
- There is considerable scope to expand the role of PSCWMC as a source of information for both groups.

The survey results also offer suggestions for civic engagement, education, and outreach. These recommendations include stronger roles for the PSCWMC in:

- developing educational programming centered on the information needs and priorities expressed by the survey respondents

- leading a civic engagement effort that provides opportunities for individuals and families to become involved in clean water activities, and
- offering an incentive program for watershed residents including financial incentives and cost-shares to support the adoption of BMPs.

Technical Stakeholder Process

At the core of the public participation process were two processes. One involved meeting with a Technical Stakeholders Group (TSG) comprised primarily of technical experts of the communities affected by the TMDL project as well as agency technical experts. This TSG first met March 25, 2014, to receive information on why the project was being undertaken and how the outcome might affect their organizations. It met a second time in March 2, 2016, to review the preliminary results of the project, including the proposed allocations and the implications of those allocations for their organization.

Community Conversations

Another key component of the stakeholder review process was a series of “community conversations”. Three of these community conversations were held between November 2014 and November 2016 (specific meeting dates were November 20, 2014; November 16, 2015; and November 2, 2016), with a total attendance exceeding 100 people. Each session brought together a broad cross-section of people with a direct interest in water quality management, including persons representing production agriculture, horse farm operations, outdoor recreation, lake associations, elected local government leaders, and state and local agency staff. The meetings included opportunities to share information and perspectives in small group discussions, provide information on the condition of the water resources of interest through presentations by technical staff, publicize stories of local water quality improvement successes, and discuss what each group was willing to contribute to advancing pollution reduction efforts. Agendas for each meeting are available from the PSCWMC, and summaries of each meeting were prepared and distributed to PSCWMC members, as well as posted on the PSCWMC’s website to reach all other participants. All presentations given at the meetings are posted on the PSCWMC’s web site as well.

The official TMDL public comment period was held from May 1, 2017 through May 31, 2017. Two comment letters were received.

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Appendices

Appendix A – Livestock Inventory for Pioneer-Sarah Creek Watershed Project Subwatersheds

Appendix B – GWLF Watershed Model – Description, Inputs, and Outputs

Appendix C – BATHTUB Modeling Methods, Input, and Output for Lakes (including Lake Bathymetry)

Appendix D – Vegetation Surveys for Lakes

Appendix E – Internal Phosphorus Loading and Sediment Phosphorus Fractionation reports

Appendix F – Implementation Cost Estimate

Appendix A: Livestock Inventory for Pioneer-Sarah Creek Watershed Project Subwatersheds

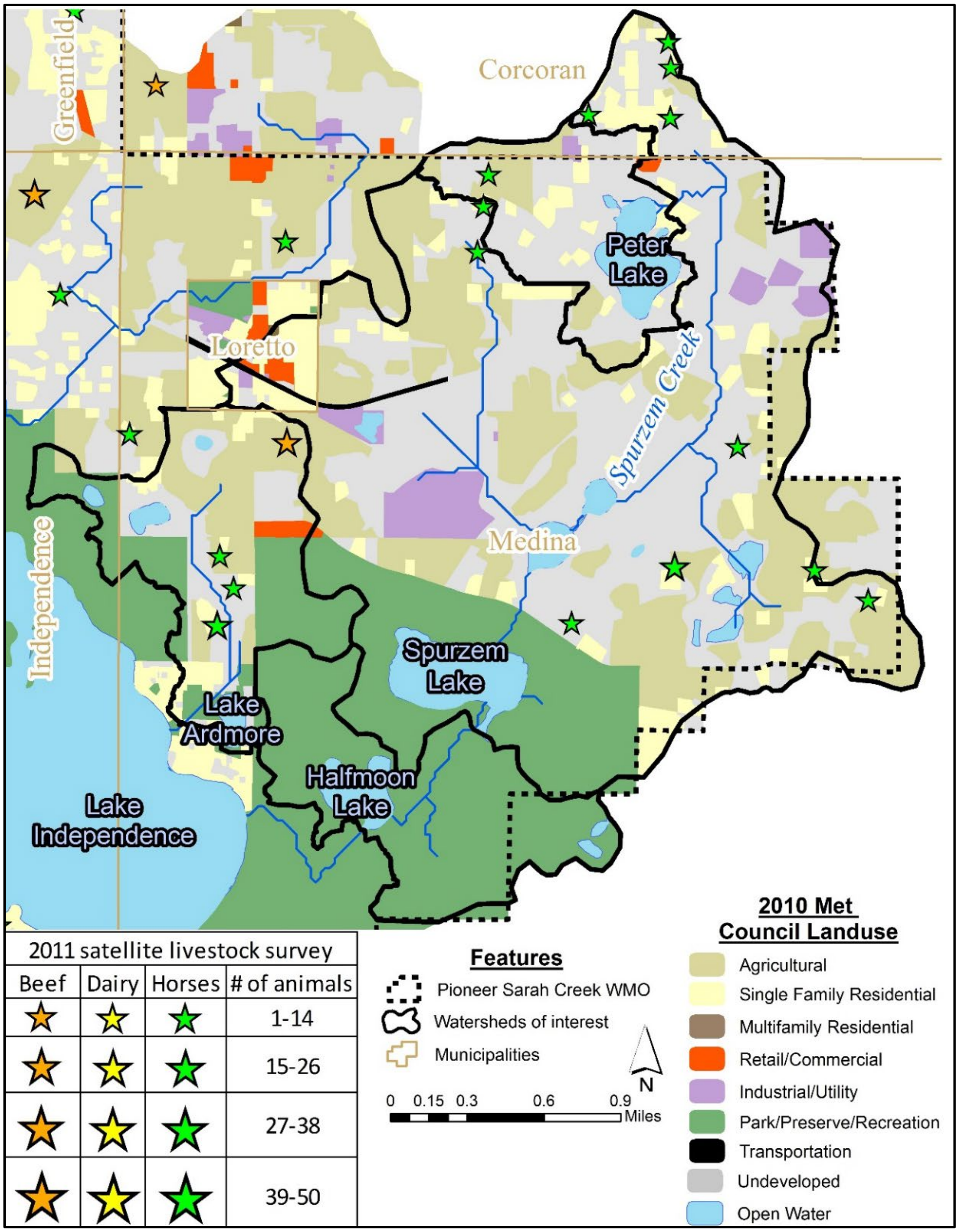


Figure A. 1 - 2011 Satellite imagery livestock inventory for Lake Ardmore, Half Moon Lake, Spurzem Lake and Peter Lake Watersheds

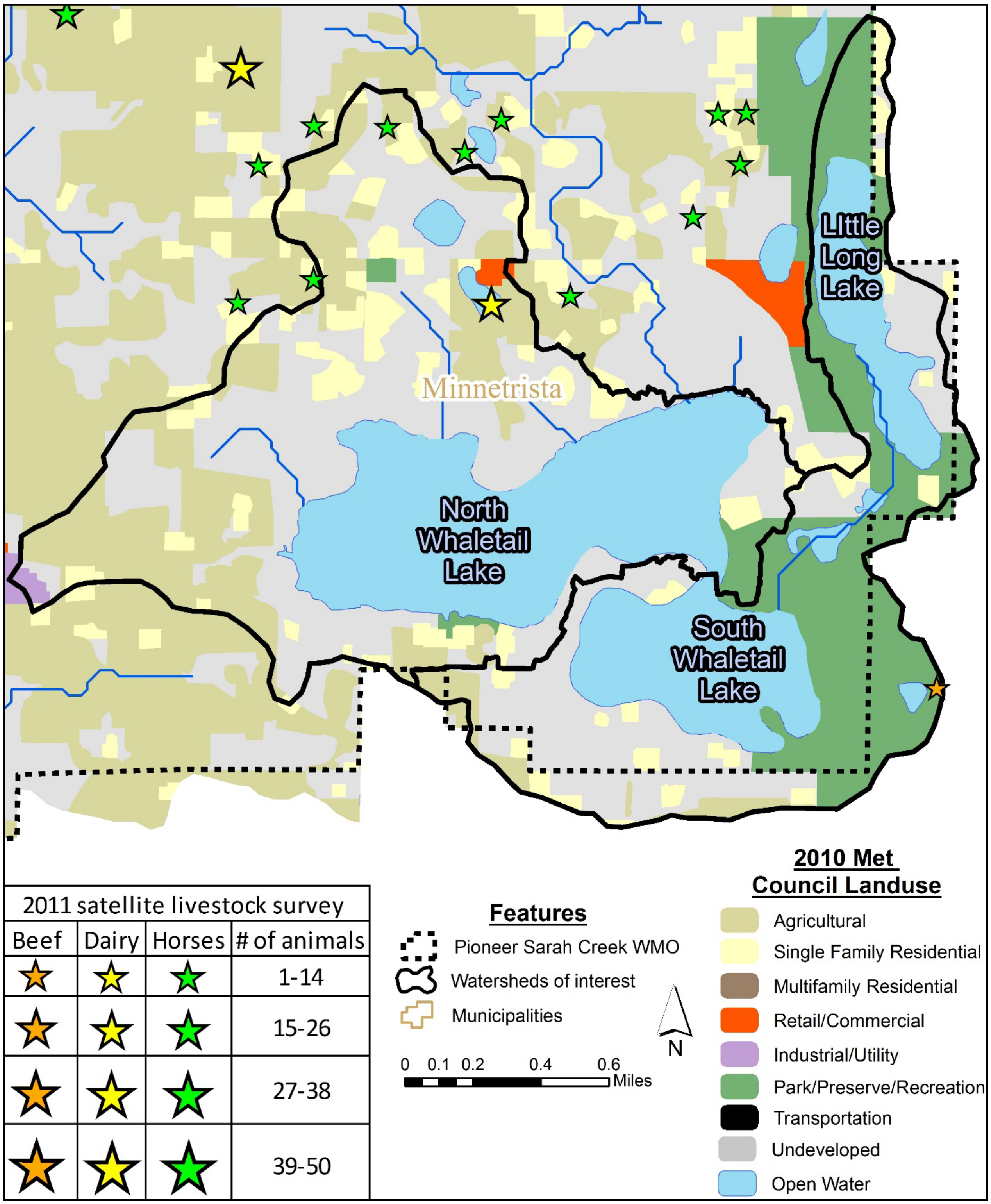


Figure A. 2 - 2011 Satellite imagery livestock inventory for South Whaletail Lake and North Whaletail Lake Watersheds

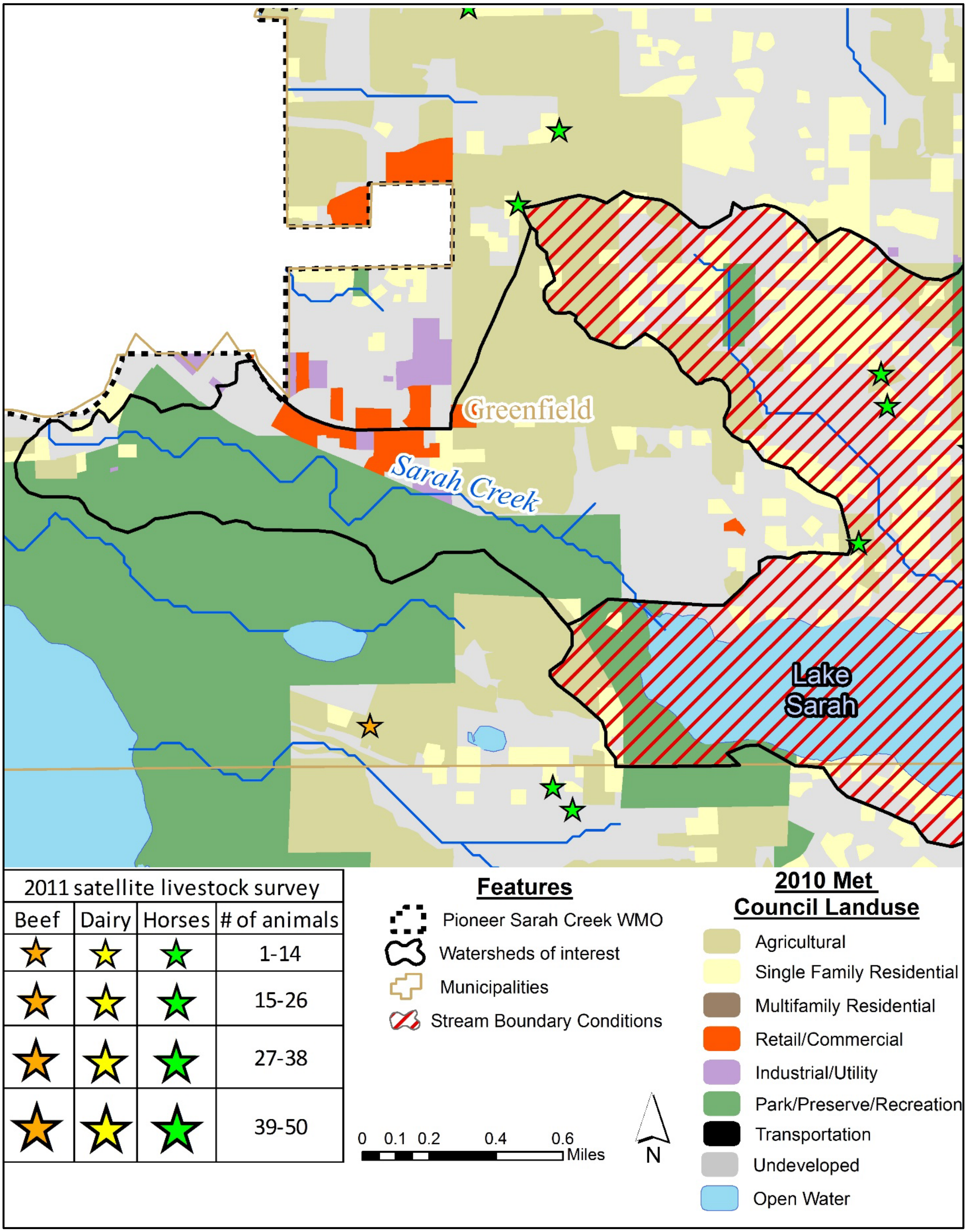


Figure A. 3 - 2011 Satellite imagery livestock inventory Sarah Creek (AUID 628)

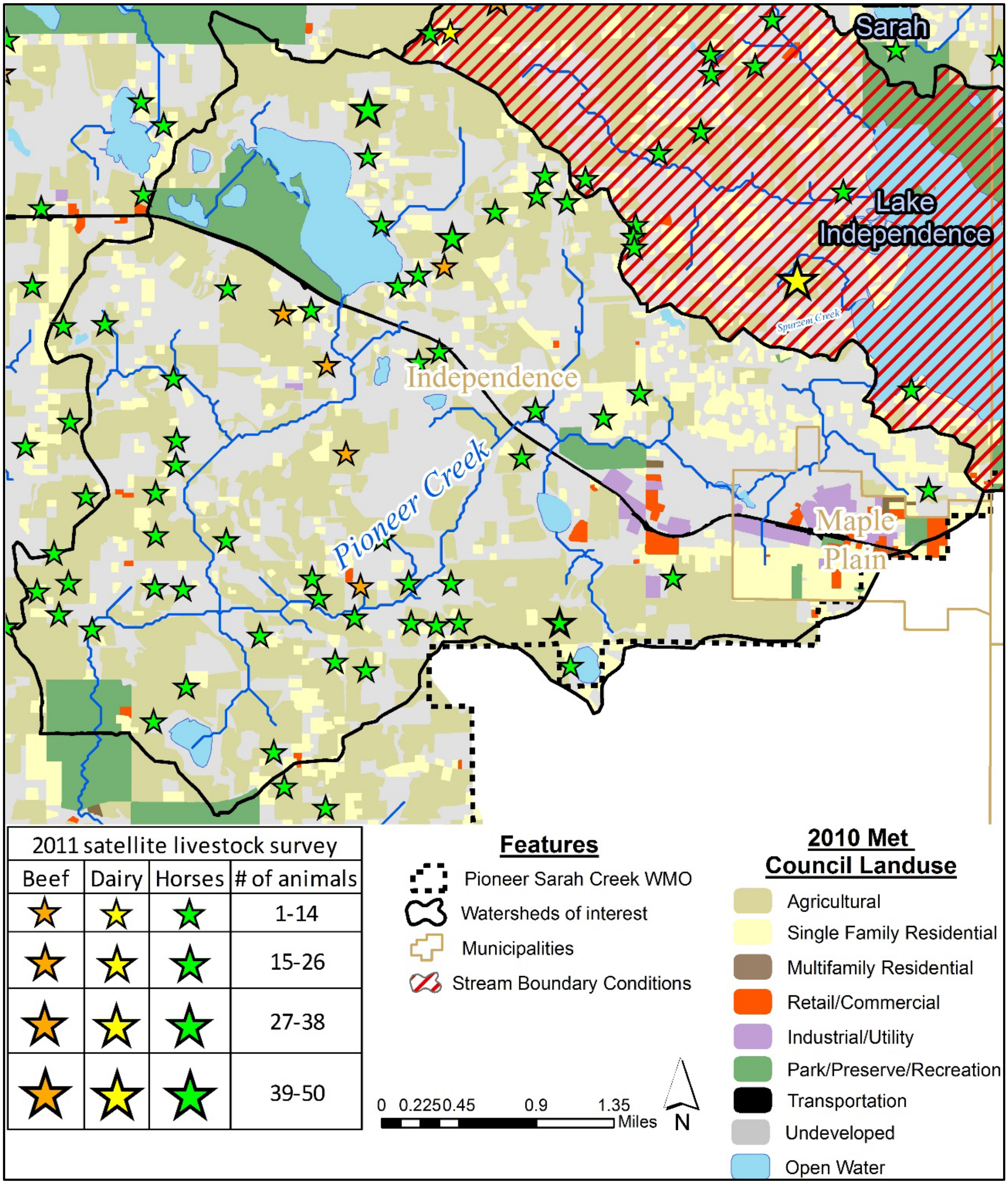


Figure A. 4 - 2011 Satellite imagery livestock inventory Pioneer Creek (AUID 653)

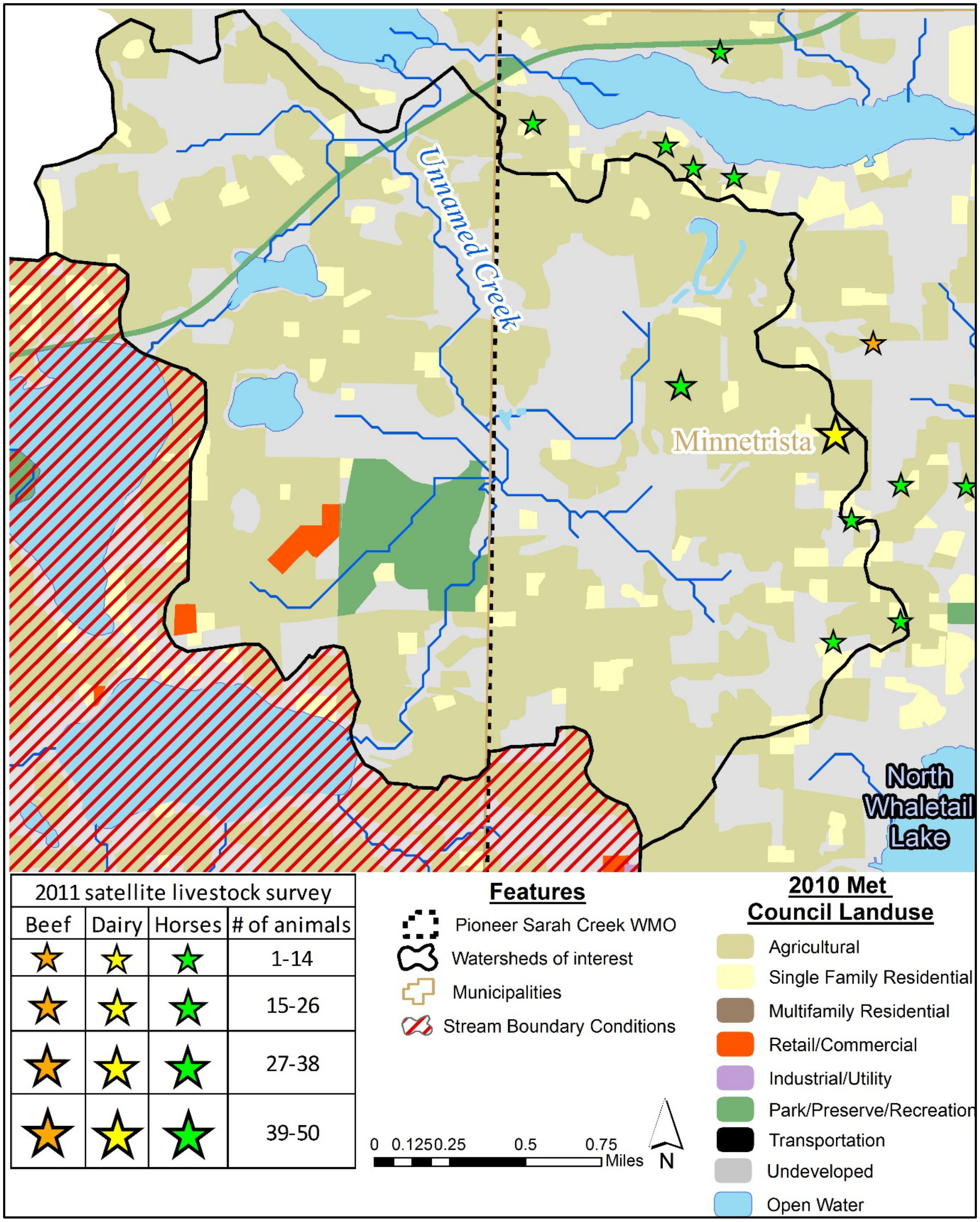


Figure A. 5 - 2011 Satellite imagery livestock inventory Unnamed Creek (AUID 593)

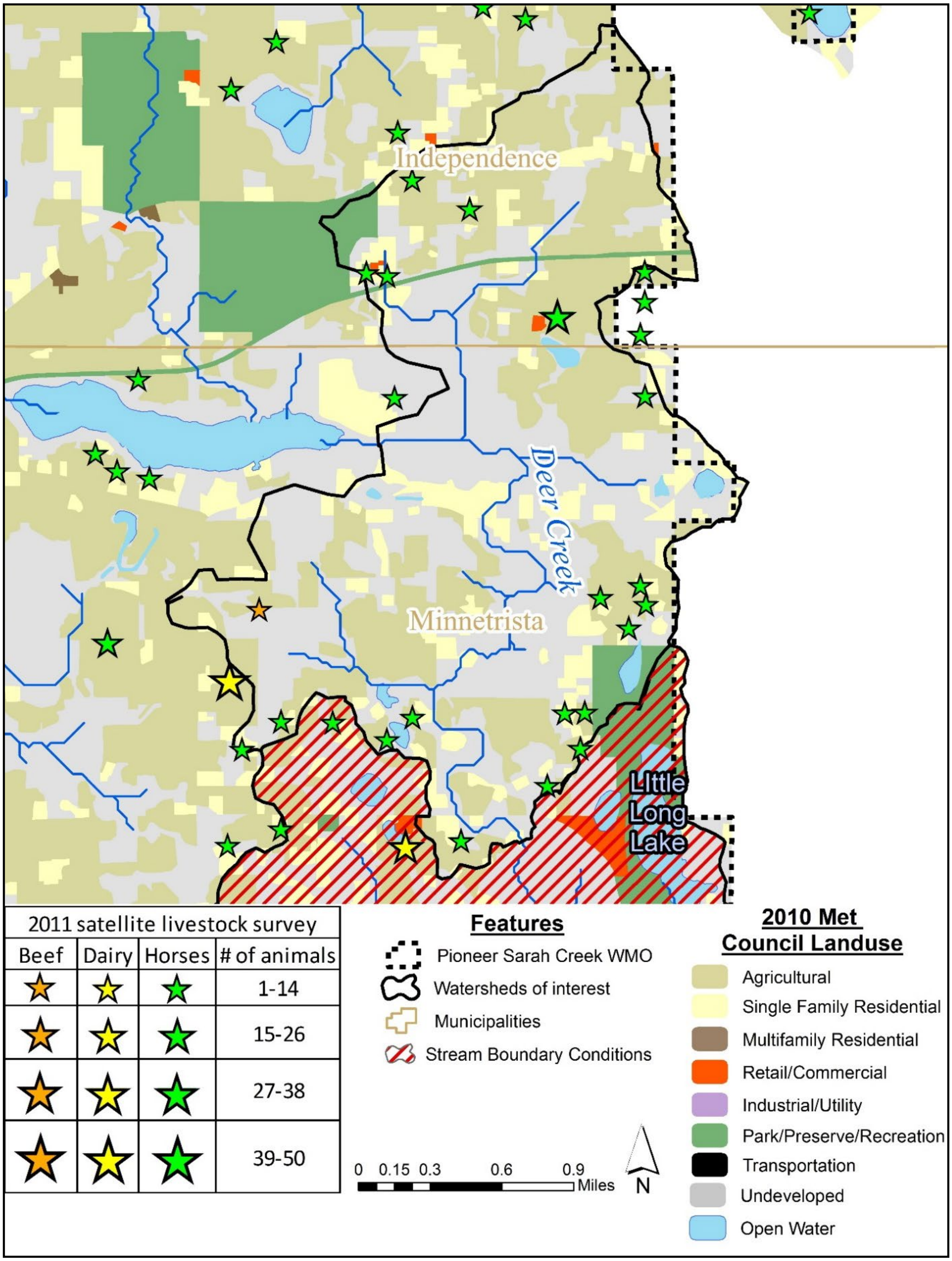


Figure A. 6 - 2011 Satellite imagery livestock inventory Deer Creek (AUID 594)

Appendix B: GWLF-E Model Methods, Inputs and Outputs for Lakes

1. Introduction

This appendix describes the modeling approach using the GWLF-E Watershed model to determine the flow and TP concentration inputs for the lake BATHTUB model. Covered in the section is an overview of the GWLF-E model, inputs for/outputs from the model, how the model was constructed to reflect conditions in the project area, and the modeling results. This appendix focuses on the watersheds draining to the lakes of interest: Peter Lake, Spurzem Lake, Half Moon Lake, Lake Ardmore, South Whaletail Lake, and North Whaletail Lake.

2. Overview of the Generalized Watershed Loading Functions – E plugin (GWLF-E)

GWLF-E is a Geographical Information System (GIS) based watershed modeling tool used within the BASINS MapWindows 4.0 interface (Evans 2011). The original GWLF-E model, which was DOS based, was developed by Haith and Shoemaker (1987). The GWLF-E plug-in was created to use in the freeware MapWindows and has updated functionality with respect to farm animals, urban hydrology and loading, stream bank erosion and potential effects of BMPs.

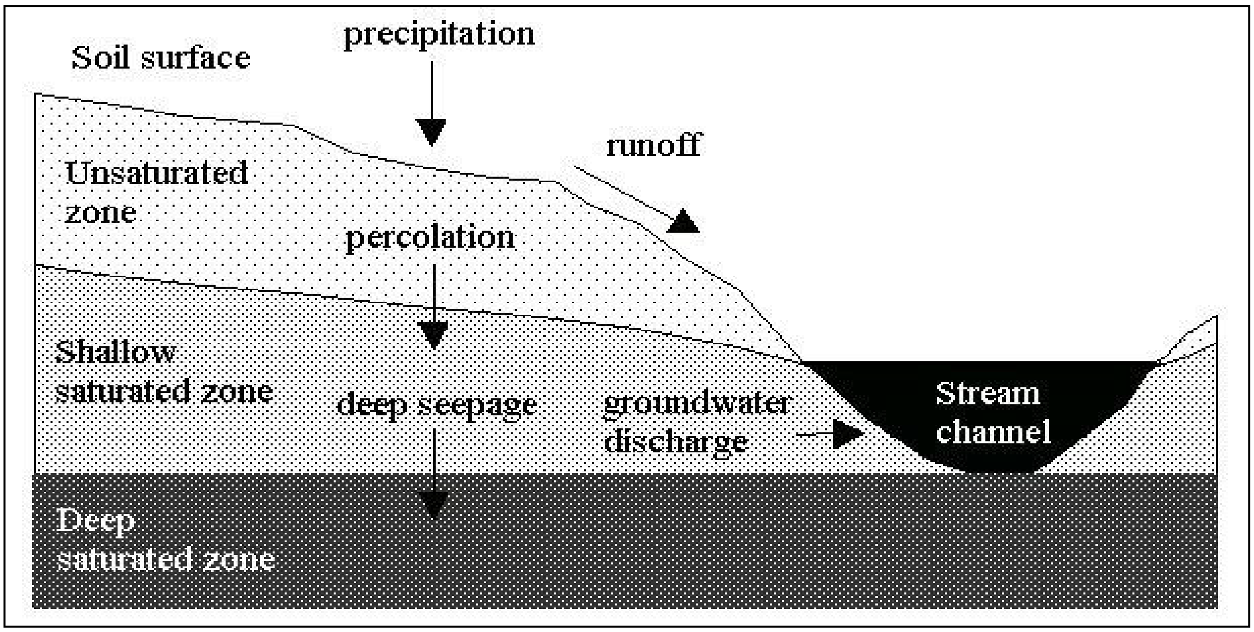
The GWLF-E model is a watershed wide continuous simulation model for runoff, sediment and nutrients (dissolved and total). The water balance and weather operates on a daily time step while the sediment and nutrient loads are based on the daily water balance and accumulated to monthly values. The EPA has identified GWLF-E as a "mid-range" model that is most appropriate for watersheds where nonpoint nutrient sources are of concern and there is insufficient data to support the development of a more detailed model (EPA 1999). GWLF-E was originally developed for use in Pennsylvania (PA) but was adjusted to allow use of data sets from outside of PA.

Since GWLF-E is GIS based, the inputs are automatically created using required GIS layers and various non-spatial model parameters. There are also optional layers and model parameters that have default values if no values are indicated. The required GIS layers include; DEM information, land use, weather, hydrologic basins, streams and soils layers. While the GIS layers provide a spatial network, the model is not spatially distributed and instead aggregates the loads from each source area.

The GWLF-E model is precipitation and temperature driven. Precipitation is distributed between direct runoff and infiltration (Figure B- 1). Runoff is determined from the land use layer using the Soil Conservation Service (SCS) curve number and daily weather inputs. Infiltration is the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration. Water that infiltrates to the un-saturated zone can be lost to evapotranspiration. Evapotranspiration is determined using the daily weather and the land use. There is an option to have a deep saturated infiltration, but it is not recommended by the developers since the estimation of this number is difficult.

In the GWLF-E model, nutrient loads generally expressed on a monthly time-step. Monthly erosion and sediment yields are computed using the Universal Soil Loss Equation (USLE). The nutrient load is calculated using various accepted loading parameters. Urban nutrients are calculated using an exponential accumulation and wash-off function similar to those used in the EPA's Stormwater Management Model (Huber and Dickinson 1988) and the P8 Urban Catchment Model (Walker 1990). The GWLF-E model can attenuate (i.e., reduce) nutrients by means of various in-stream factors such as plant uptake and deposition. The in-stream attenuation loss coefficients are based on the USGS Watershed model SPARROW. The SPARROW model takes travel distance to the outlet into consideration. Subbasins that are further from an outlet have much less effect on nutrient loads at an outlet than the nutrient loading from a sub-basin closer to the outlet due to the longer travel times and natural attenuation processes that can occur in that time. Nutrients can also be reduced by applying a reduction coefficient that represents the attenuating effect of lakes, ponds and wetlands.

Figure B- 1: Routing of water in GWLF-E-E (Evans 2011)



3. Watershed Characteristics

3.1 Watershed Overview

All of the lakes addressed in this project are within the Hennepin County portion of the Pioneer Creek hydrologic watershed, which is part of the South Fork Crow River Watershed (HUC: 07010205). The Pioneer Creek Watershed is 35,305 acres in area, most of which lies in northwestern portion of Hennepin County, with small areas in Wright and Carver counties. The total watershed area for the lakes addressed in this project is just over 5,000 acres. Several tributary streams of significance to this project drain into the Pioneer Creek system, including Spurzem Creek, which discharges to Lake Independence. Pioneer Creek starts at the outlet of Lake Independence.

The GWLF-E model was constructed to address six lakes that have been identified as impaired by nutrients by the MPCA within the Pioneer Creek hydrologic watershed. In this appendix, the lake watersheds will be broken down into two groups, those for the "northern lakes" and those for the "southern lakes". The northern lakes of interest are Peter Lake, Spurzem Lake, Half Moon Lake (all of which are connected by Spurzem Creek) and Lake Ardmore, which is the only northern lake outside the Spurzem Creek drainage. The southern lakes of interest are South Whaletail Lake and North Whaletail Lake, which are the headwaters of Deer Creek. The northern lakes and their watersheds lie within the municipalities of Medina, Independence, Loretto, and Corcoran, while the southern lakes and their watersheds are entirely within Minnetrista.

The location of all six lakes and the communities within which they are located are shown in Figure B- 2, along with the location of the key stations that supplied weather-related input for the GWLF-E model (discussed later in this report). Figure B- 3 shows the delineated watersheds of all six lakes overlain on a 2013 USDA NAIP imagery layer.

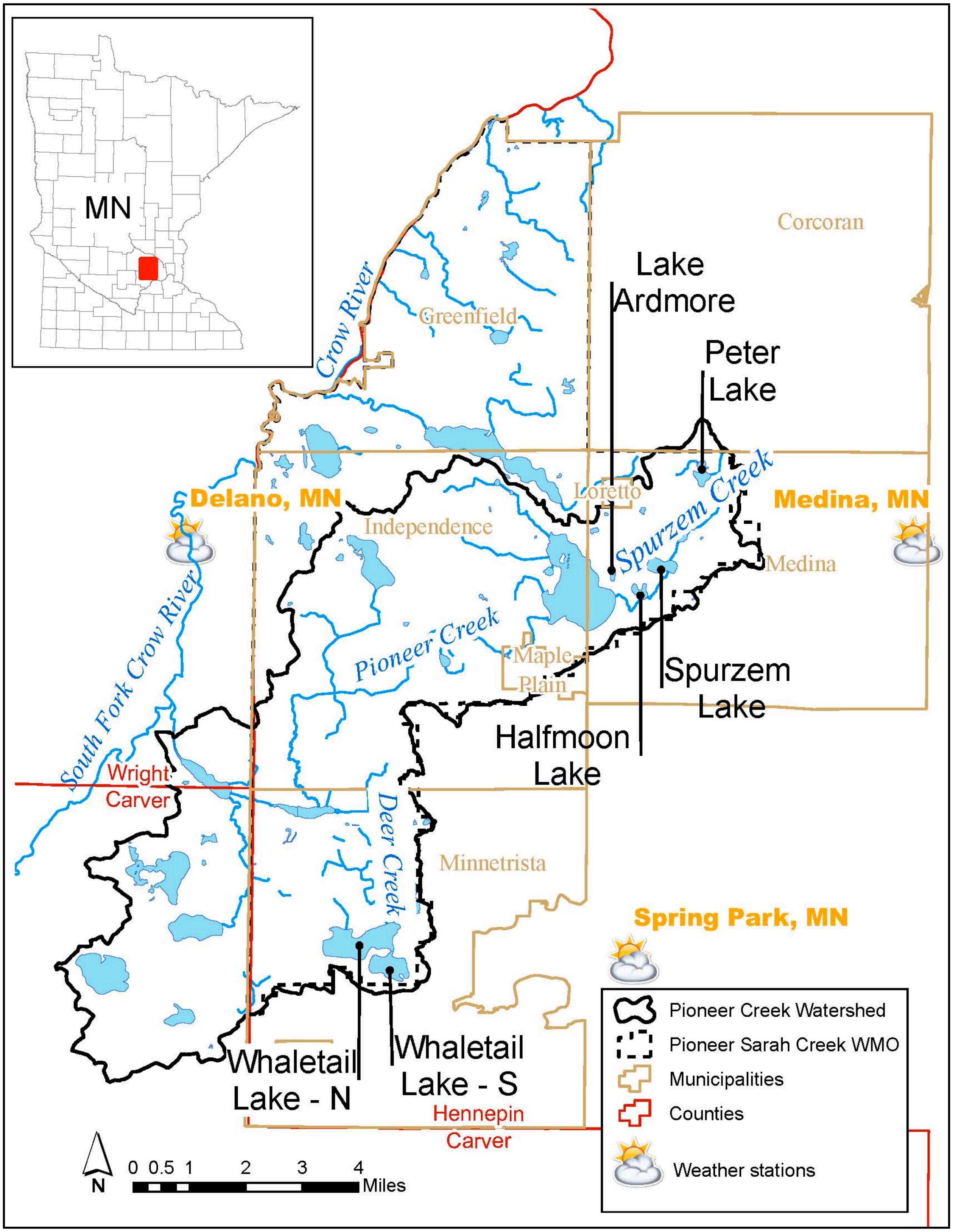
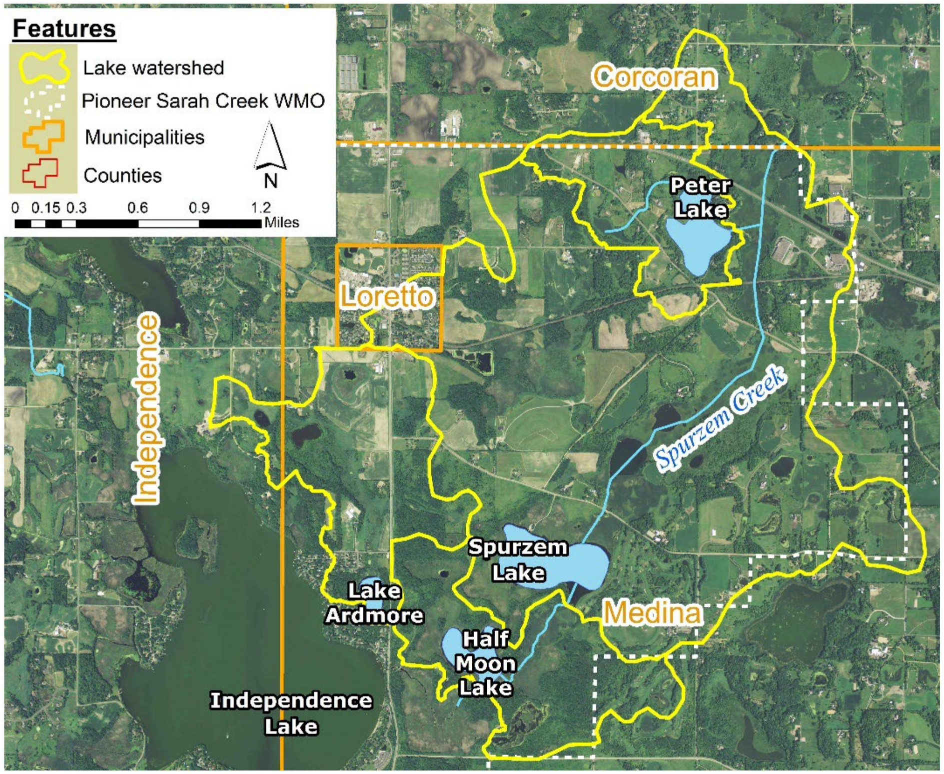
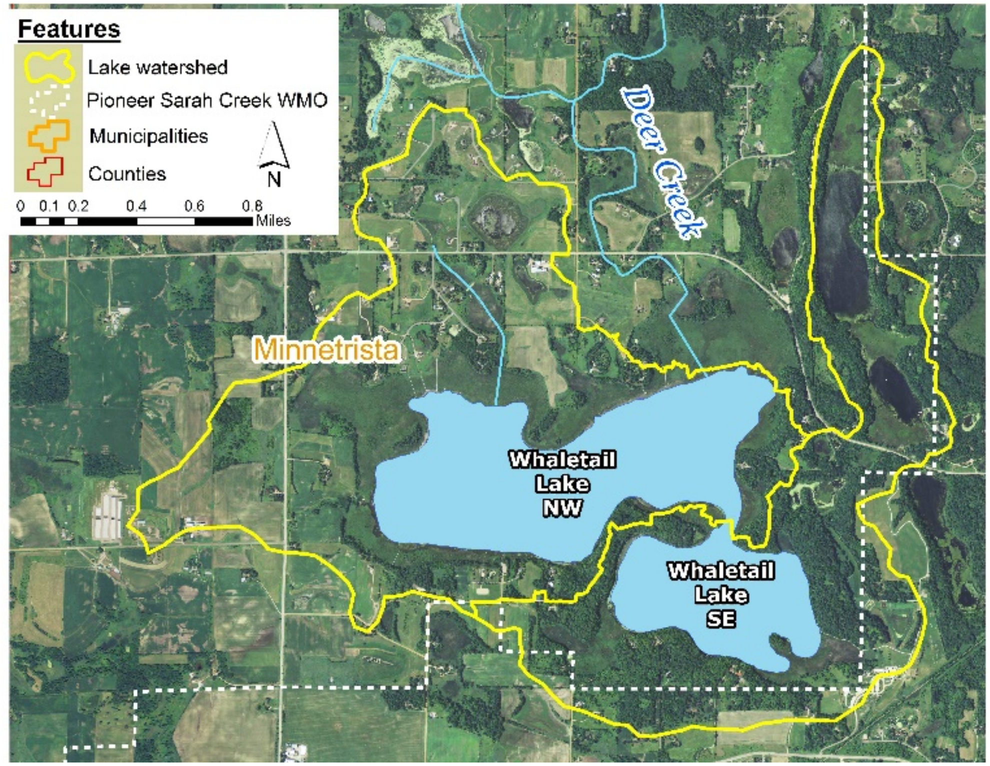


Figure B- 2: Location of Pioneer Creek Watershed lakes of interest, municipal boundaries, and key weather stations.

Figure B- 3: Lake watersheds of interest, with the northern lakes on the left and southern lakes on the right.





3.2 Description of Watersheds by Lake

Peter Lake

The Peter Lake Watershed (Figure B- 4) is considered the headwaters for the northeast portion of the Lake Independence Watershed. The drainage area is approximately 300.7 acres with a watershed to lake area ratio of 5.4 to 1. The primary land use type within the watershed is agricultural with a small portion considered rural residential.

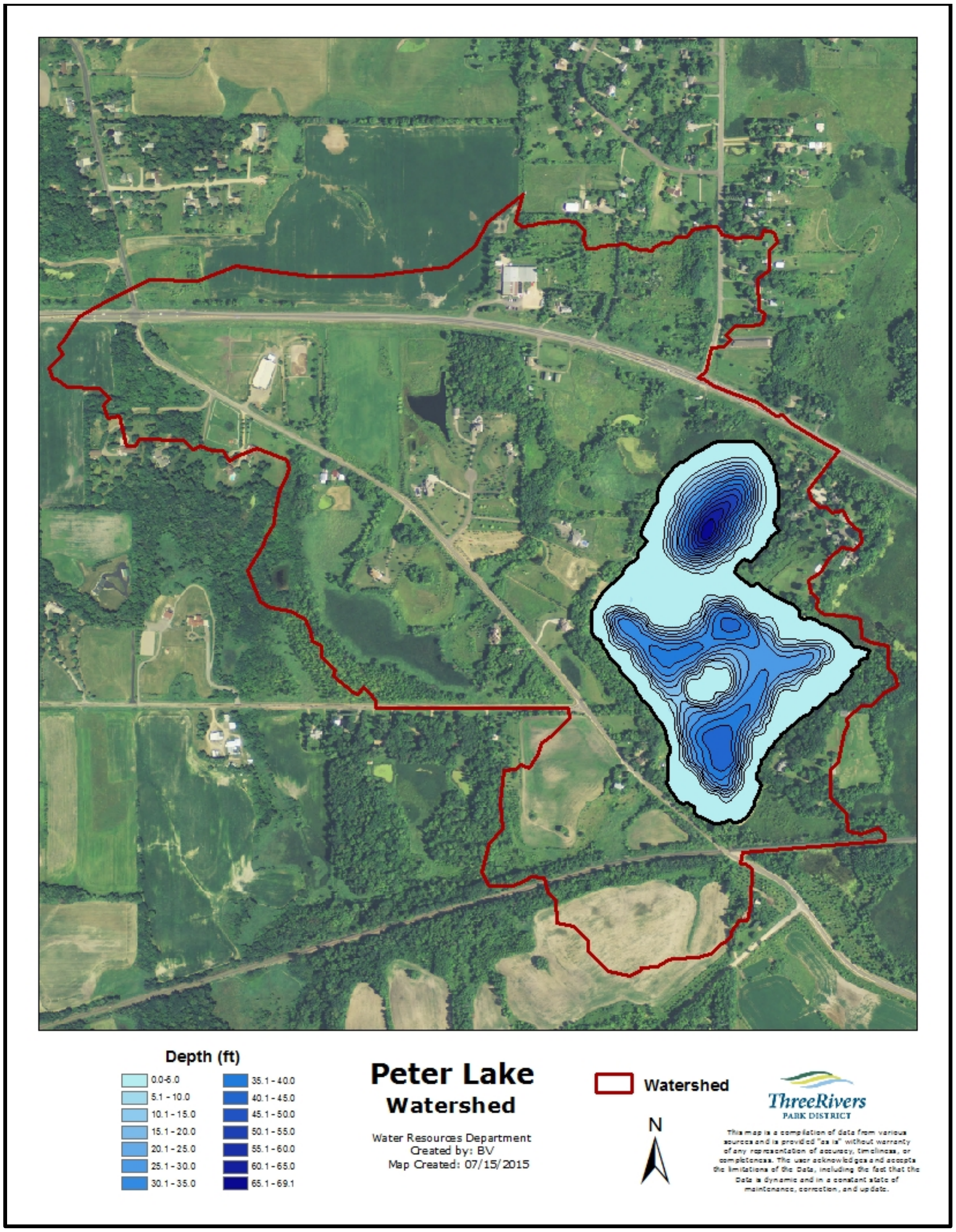


Figure B- 4: Peter Lake Subwatershed boundary for development of the GWLF-E model.

Spurzem Lake

The Spurzem Lake Watershed (Figure B- 5), which includes the Peter Lake Subwatershed, is approximately 2,915 acres with a watershed to lake area ratio of 37 to 1. The large watershed to lake area ratio would suggest that watershed loading to the lake has the potential to significantly influence in-lake water quality. The primary land use type within the Spurzem Lake Watershed is agricultural. A significant portion of the watershed downstream of Peter Lake consists of wetland acreage that ultimately drains to Spurzem Lake.

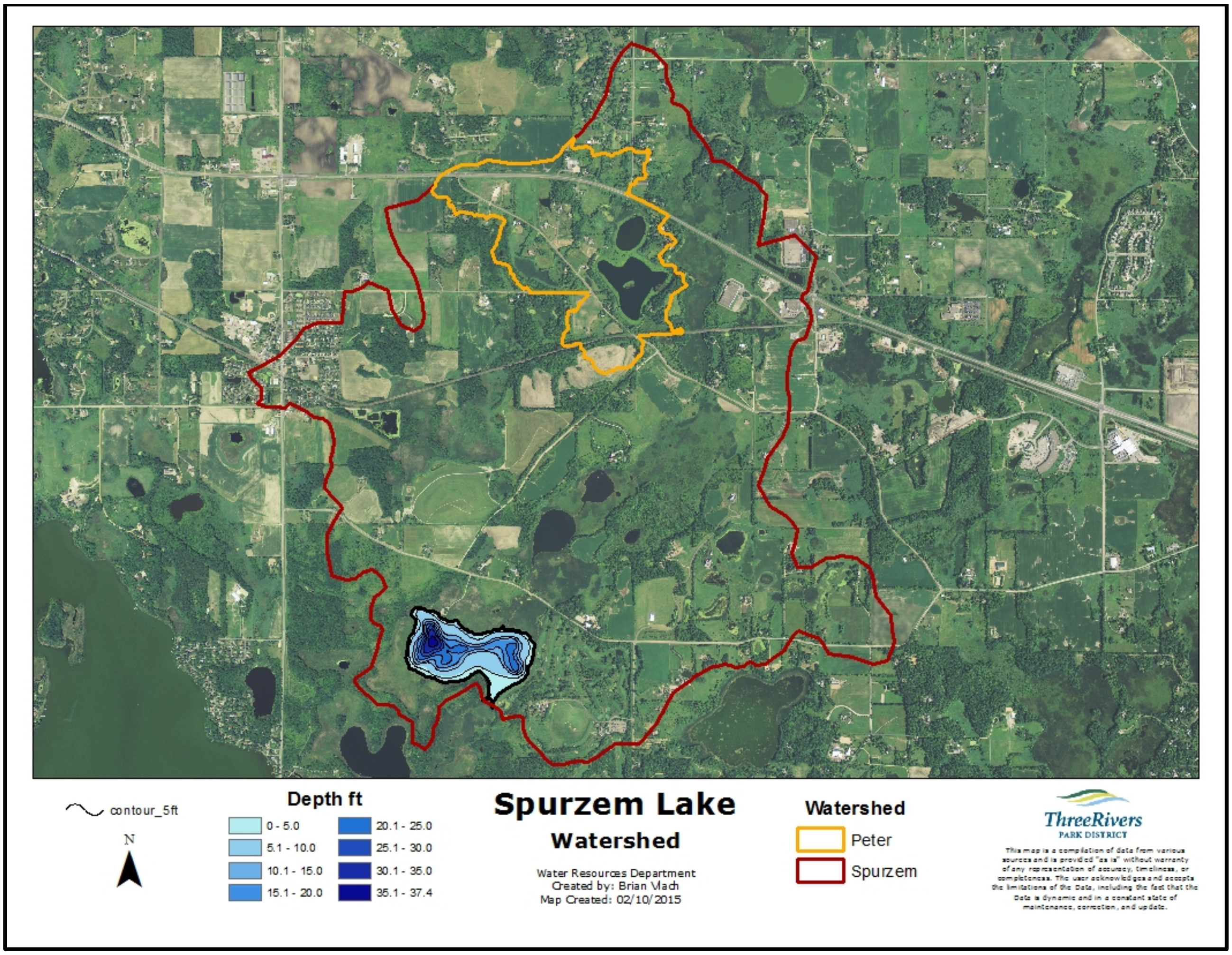


Figure B- 5: Spurzem Lake Subwatershed boundary for development of the GWLF-E model.

Half Moon Lake

The Half Moon Lake Watershed (Figure B- 6) is approximately 3,430 acres with a watershed to lake area ratio of 110 to 1. Similar to Spurzem Lake, the large watershed to lake area ratio would suggest that watershed loading to the lake has the potential to significantly influence in-lake water quality. Spurzem Lake flows to Half Moon Lake through Spurzem Creek, which is channelized through a wetland cattail marsh. Consequently, the water quality of Spurzem Lake and the wetlands between the two lakes also has a potential influence on the in-lake water quality for Half Moon Lake.

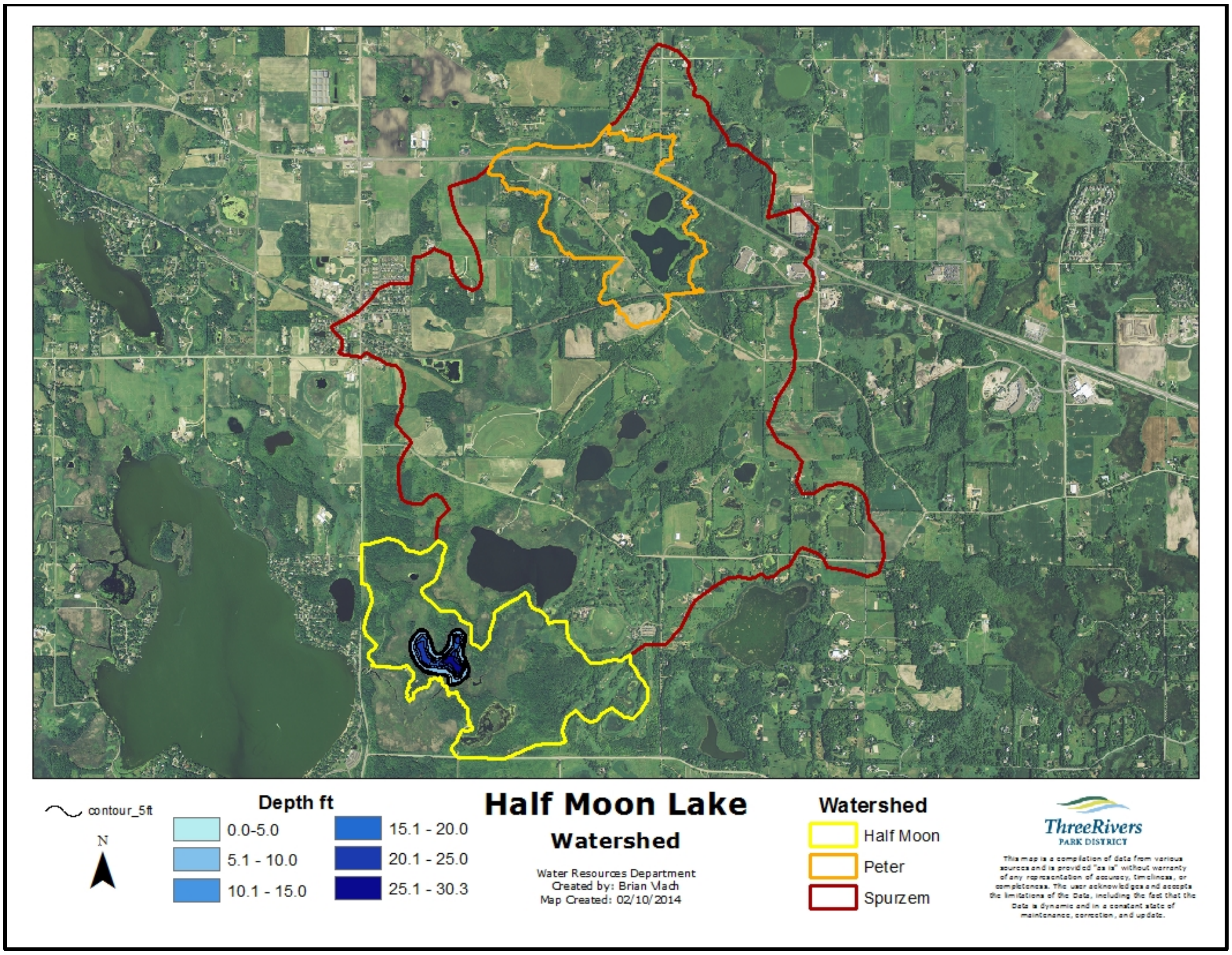


Figure B- 6: Half Moon Lake Subwatershed boundary for development of the GWLF-E model.

Ardmore Lake

The Ardmore Lake Watershed (Figure B- 7) is a relatively small drainage area located east of Lake Independence. The Ardmore Lake Watershed is approximately 507 acres with a watershed to lake area ratio of 38 to 1. The large watershed to lake area ratio would suggest that watershed loading to the lake has the potential to significantly influence in-lake water quality. The primary land use type within the Ardmore Lake Watershed is agricultural. There are a significant number of animal units (AUs) (primarily horses) located immediately upstream of Ardmore Lake.

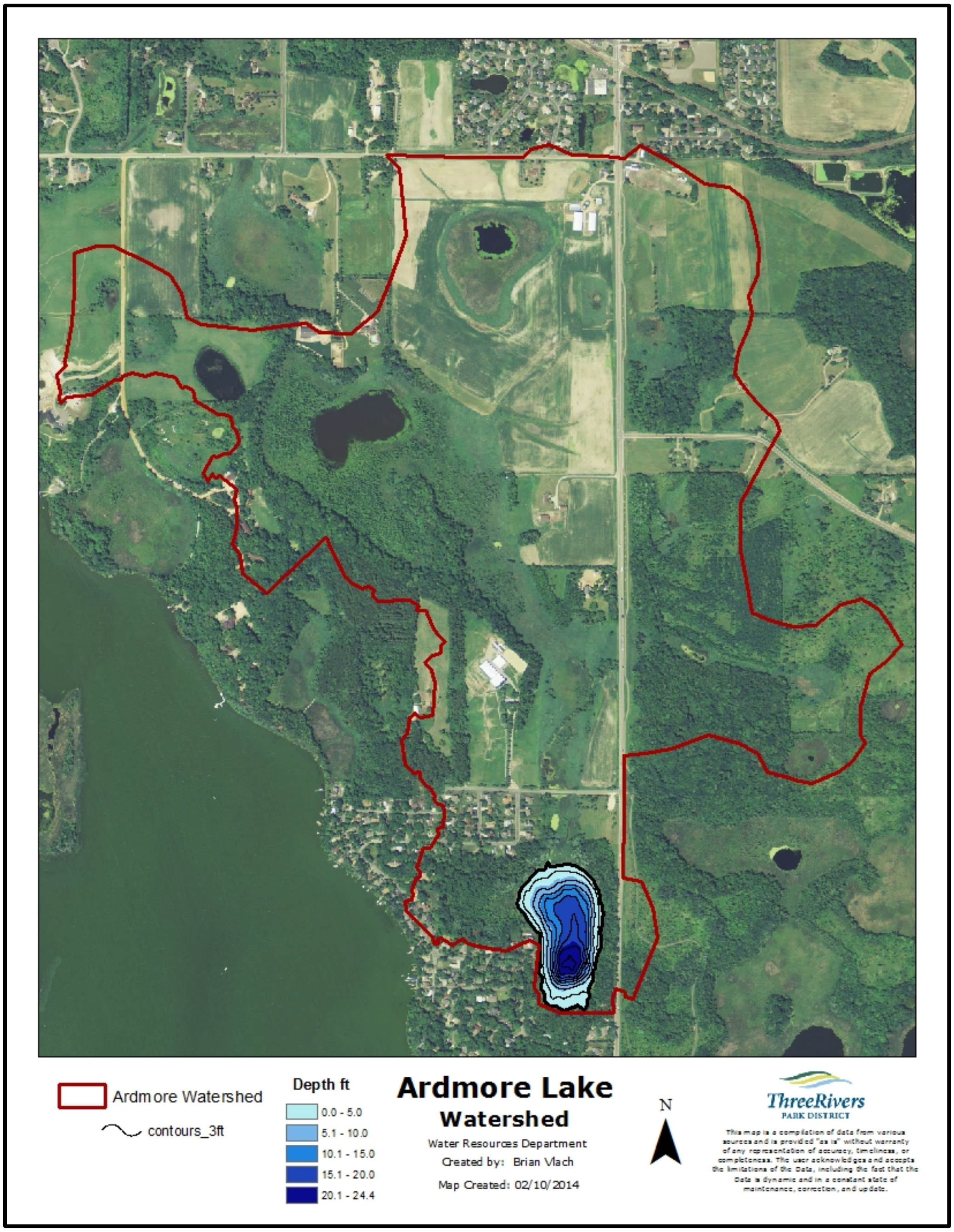


Figure B- 7: Ardmore Lake Subwatershed boundary for development of the GWLF-E model.

South Whaletail Lake

The South Whaletail Subwatershed (Figure B- 8) is approximately 673 acres with a watershed to lake area ratio of 4 to 1. A significant portion of the small subwatershed includes the Little Long Lake drainage area. Little Long Lake has excellent water quality that is currently meeting the MPCA standards. There is also a significant portion of the subwatershed that has parkland (Gale Woods and Kingswood) with forested land use. Consequently, there is not a significant amount of watershed loading to South Whaletail Lake.

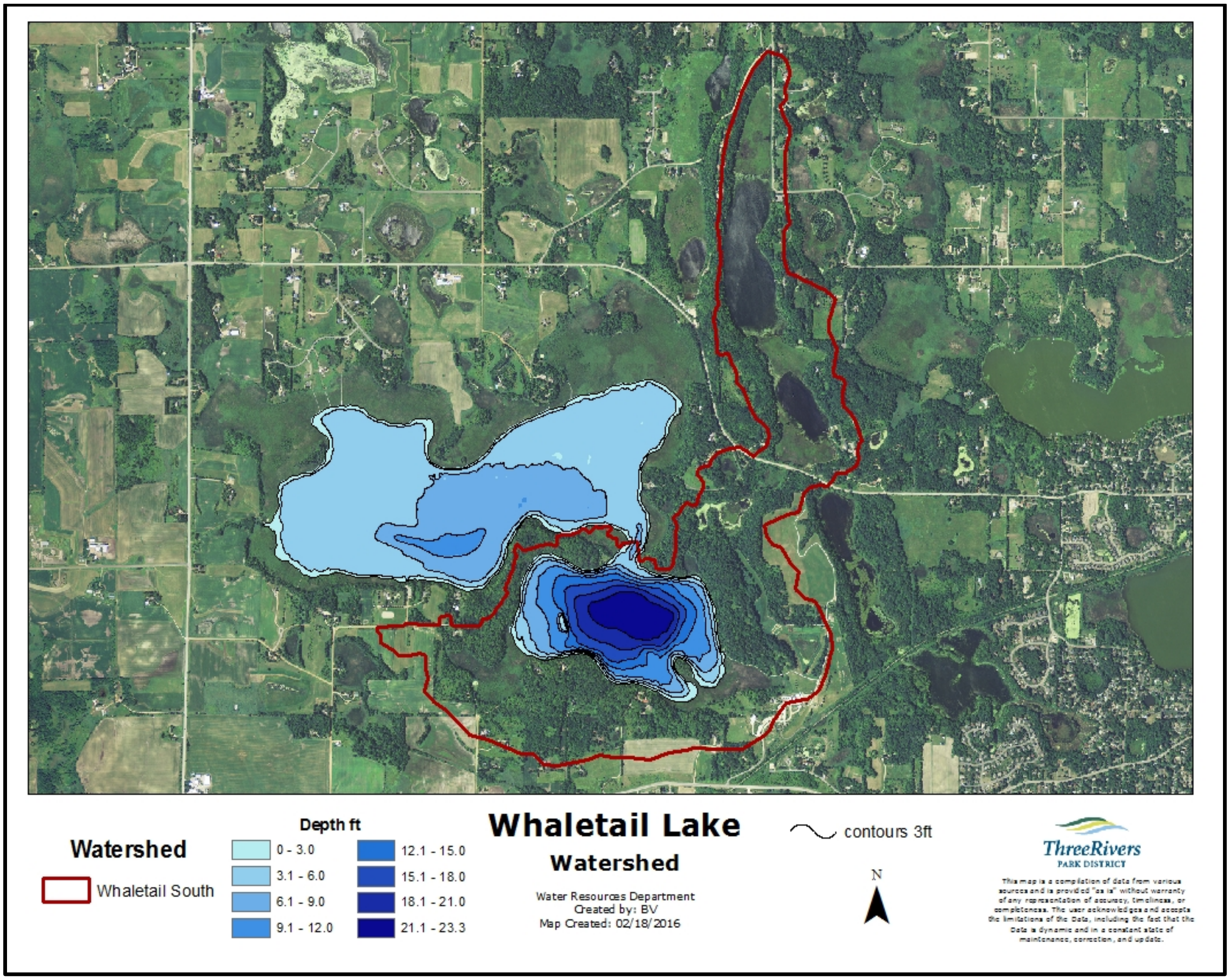


Figure B- 8: South Whaletail Subwatershed boundary for development of the GWLF-E model.

North Whaletail Lake

The North Whaletail Subwatershed (Figure B- 9) is approximately 1,256 acres with a watershed to lake area ratio of 3 to 1. As previously mentioned for Whaletail South, the south subwatershed consists of the Little Long Lake drainage area with parkland/forested land use. However, the portion of the subwatershed that drains directly to the North Whaletail Basin is primarily agricultural land use.

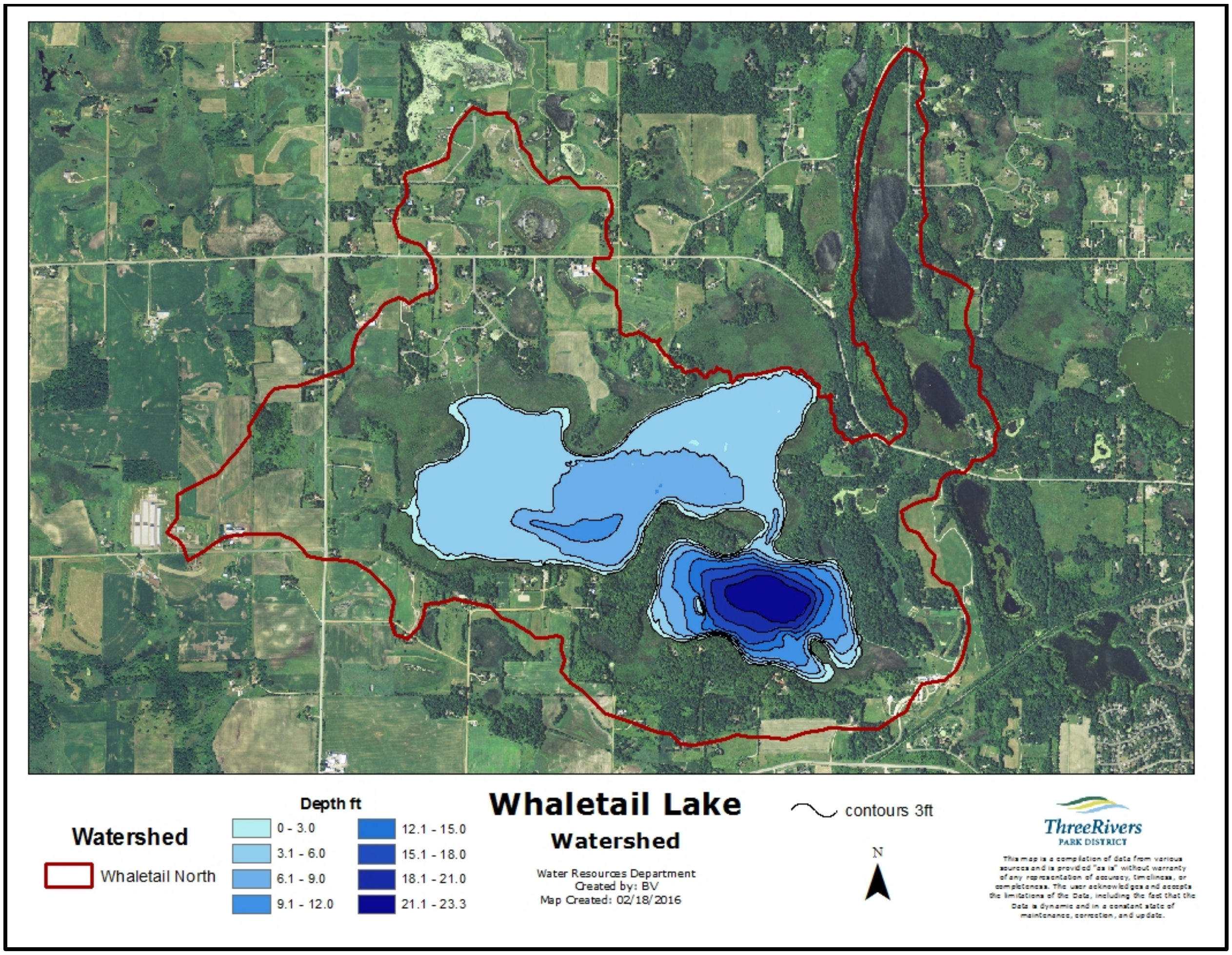


Figure B- 9: North Whaletail Subwatershed boundary for development of the GWLF-E model.

4. Development of GWLF-E model for the impaired lake watersheds

The lake watersheds were broken down into 21 sub-basins for the GWLF-E model (Figure B- 10). The subbasins for each lake were delineated using a 3m LiDAR DEM (Figure B- 3). The northern lakes' watersheds were delineated into 14 sub-basins with an average subbasin size of 716 acres. The watersheds of the southern lakes were delineated into seven sub-basins with an average size of 512 acres.

The GWLF-E model was calibrated and validated using four stream monitoring stations. There were three stream monitoring locations in the northern lakes watersheds along Spurzem Creek/Pioneer Creek, labeled B3, B5 and PS90. In the southern lakes, there was one stream monitoring location along Deer Creek labeled PSD. These monitoring station locations are shown in Figure B- 2.

Since the model is driven by weather inputs, it was important to find relatively close weather stations that had a relatively long, continuous, and reliable data set. Daily precipitation and temperature data were compiled for Delano, Minnesota, Spring Park, Minnesota and Medina, Minnesota (Figure B- 2). All of the data were obtained from the National Oceanic and Atmospheric Administration (NOAA) except for the information for Medina, which was obtained from the Metropolitan Council Environmental Services (MCES). When climate data were missing, either a parallel estimation was made using nearby stations or a climate trend was determined and the missing data were interpolated (Linacre 1992). The average climate is representative of near-normal weather conditions. Average conditions across all three weather stations during the 1990 to 2015 period of record were 30.5 inches of annual precipitation, winter temperature of 31°F, summer temperature of 66°F and an overall average temperature of 45°F. The average conditions during the modeled time period of 2009 through 2015 were similar to the average climate data over 25 years.

To create the inputs for the GWLF-E model, several GIS layers are required. These GIS data requirements are summarized in Table B- 1.

Table B- 1: Summary of GIS layers input to GWLF-E model

Required GIS layer	Obtained from:
Elevation	LiDAR created 5m DEM
Soils	USDA SSURGO
Streams	Created during delineation
Basins	DNR HUC 8
Boundaries	Delineated using 3m DEM
Weather stations	NOAA and Met Council files for Delano, Spring Park and Medina, MN
Land use/cover	2011 National Land Cover Dataset
Optional GIS layer	**Information provided:**
Counties	Cropping management (C) and conservation practice (P)- defaults were used
Animal Density	Created by TRPD by visual inspection of high resolution imagery
Physiographic Provinces	Rainfall erosivity (R) from GWLF-E manual and groundwater recessive values
Point source	Loretto Wastewater Treatment Facility - loading based on 2013/2014 data

The elevation layer was developed using a 5-meter resolution LiDAR DEM. The 3-meter resolution DEM that was used to delineate the subwatersheds was too fine a resolution and therefore generated too large a data set for the model to handle, so a 5-meter resolution DEM was used instead. The soils layer was provided from the SSURGO dataset. The streams layer was developed during sub-basin delineation from satellite imagery. The land cover layer was the 2010 National Land Cover Dataset (NLCD).

The SSURGO data set helped define several of the variables for the GWLF-E model, including the AWC (Available Water Content) and HSG (dominant Hydrologic Soils Group). The AWC controls the moisture content of the unsaturated zone. The recommended depth to assess the AWC is 100 cm of soil. With the recommended 100cm of soil, the minimum AWC for the Pioneer Creek Watershed was 7.37cm while the maximum was 40cm and the average was 19cm. Higher AWC values reflect less permeable soils that tend to be lower in the landscape while lower values represent more upland areas that have better drainage. The HSG tells more about the soil and its draining capabilities. The HSG ranges from A to D, with an A soil representing a sandier soil with better drainage and a D soil, which often has a significant clay component and consequently does not drain well. If a soil had a dual soil group of A/D, B/D or C/D, it was reclassified as a D soil since the first letter in the classification reflects drainage characteristics when the soil is drained by installed infrastructure (drainage tile, etc.) and the second letter when it is not.

USLE Equation: **A = R * K * LS * C * P**

Where:
A = predicted soil loss (tons per acre per year)
R = rainfall and runoff factor (default)
K = soil erodibility factor (SSURGO)
LS = slope factor (length and steepness from DEM)
C = crop and cover management factor (Default)
P = conservation practice factor (Default)

The USLE (see below) is used by GWLF-E to predict soil loss and delivery to receiving waters. The variables accounted for in the USLE include the rainfall and runoff factor (R), soil erodibility factor (K), slope factor (LS), crop and cover management (C), and conservation practice (P). The R variable is a look-up value obtained from the original GWLF-E user's manual (Haith 1992) that is based on geographical location. For the Pioneer Creek Watershed, St. Paul, Minnesota was the closest location listed. The K value is dependent on soil texture, structure and organic matter and was obtained from the SSURGO data set. The K values ranged from 0 to 0.55 with an average value of 0.3. The LS is assessed using the DEM within the GWLF-E program; more of the technical algorithms are described by Moore and Wilson (1992). The C and P values can widely vary. The default C and P values in the GWLF-E documentation are based on mean values for the eastern part of the U.S compiled by Stewart et al (1975). The C value can range from 0-1 with 1 representing bare soil with less cover and 0 representing a very stable plant rooted soil. The default values are 0.002 for wooded areas, 0.03 for pasture and 0.42 for cropped land. The P values are based on slope and represent how a practice will reduce the amount of erosion. A practice that has steep slopes and does not reduce erosion would be a 1 while a more conservation-oriented cropland management practice/lower slope would be lower. There are five default values in GWLF-E that range from 0.52 to 0.74. The K, LS, C and P values are composite values that were assigned to each sub-basin for each of the non-urban land uses.

Table B- 2 shows the land use composition of each of the major subwatersheds represented in this GWLF-E model. The Half Moon Lake Subwatershed includes the subwatersheds of Spurzem Lake and Peter Lake, both of which lie upstream of Half Moon Lake on Spurzem Creek. Similarly, the North Whaletail Lake Subwatershed includes the subwatershed for South Whaletail Lake upstream. The NLCD layer showed that in general, the lake watersheds have few areas supporting conventional urban development and are dominated by pasture/hay, forest and agriculture (Table B- 2). Further, the southern lakes watersheds have a higher percentage of lakes and wetlands compared to the northern lakes watersheds.

Table B- 3 shows that the dominant hydrologic soil groups in each major lake subwatershed are primarily B and D soils with some C soils. HSG A and B soils are generally considered suitable for infiltration BMPs.

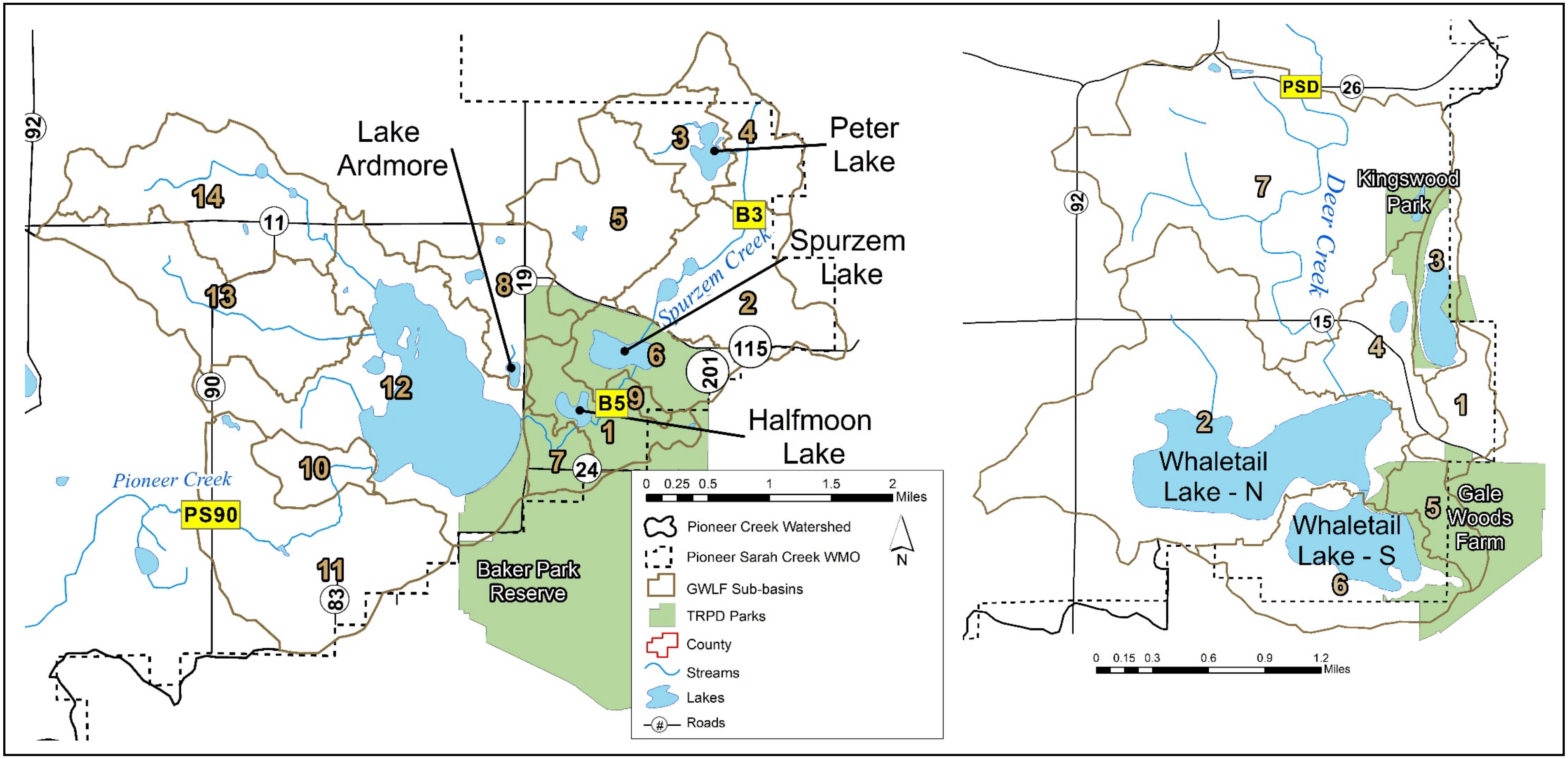


Figure B- 10: GWLF-E numbered sub-basins and stream monitoring sites (B3, B5, PS90 and PSD) for the northern Lakes of Peter Lake, Spurzem Lake, Half Moon Lake and Lake Ardmore and the southern lakes of North Whaletail Lake and South Whaletail Lake

Table B- 2: Acreage and percent of watershed by land use based on 2010 NLCD set for the Lake Ardmore Watershed, the Half Moon Lake Watershed (including Spurzem Lake and Peter Lake Watersheds) and the North Whaletail Lake Watershed (including the South Whaletail Lake Watershed)

Land Use	Half Moon		Ardmore		North Whaletail	
	%	acres	%	acres	%	acres
Pasture/Hay	24%	838	36%	190	24%	499
Forest	21%	741	28%	146	23%	489
Agriculture	16%	571	11%	57	8%	166
Lakes	17%	603	4%	21	28%	591
Rangeland	12%	432	6%	32	5%	96
Wetland	2%	86	8%	39	11%	222
Urban Low Density	4%	133	5%	25	1%	20
Urban Medium Density	1%	44	2%	10	0%	0
Urban High Density	0.4%	12	0%	0	0.1%	2
Total acres		3,462		520		2,085

Table B- 3: Dominant hydrologic soils group (HSG) based on the SSURGO dataset for the Lake Ardmore Watershed, the Half Moon Lake Watershed (including the Spurzem Lake and Peter Lake Watersheds) and the North Whaletail Lake Watershed (including the South Whaletail Lake Watersheds)

Dominant Hydrologic Soils Group	Half Moon	Ardmore	North Whaletail
A	0%	0%	0%
B	36%	54%	26%
C	10%	0%	28%
D	54%	46%	46%

5. Calibration and Validation of GWLF-E model

This section describes the GWLF-E model calibration and validation process with reference to hydrology and TP in the lake watersheds of interest. The hydrology was calibrated first, and then the phosphorus was calibrated. Several statistical metrics were used to assess the degree of agreement between modeled and monitored water and phosphorus loads. Unit phosphorus loads generated by the GWLF-E model for the various land uses in the watershed were also compared with literature values.

5.1 Calibration and Validation Data

There were four calibration/validation stream sites within the lake watersheds, labeled B3, B5, PS90 and PSD (Figure B- 10). Table B- 4 presents a summary of the information for each site, including the period of record for each site, the frequency with which flow data were collected, and whether the site was used primarily for calibration or validation.

Data at site B5 were collected during 2015 to better define watershed inputs that enter the system downstream of Spurzem Lake but above Half Moon Lake. Data collection (including compilation of a continuous flow record) was conducted for the 2015 field season only, a period of near average precipitation conditions. Data collection was also conducted at site B3 to better characterize surface water flows and loads at the upper end of the Spurzem Creek Watershed. The 2015 data at the B3 site was used for model validation, but not as much emphasis was put on data from this site since beaver activity resulted in periodic blockages that affected the stage-discharge relationship in the monitored culvert. Because monitoring site PS90 had a multiple year period of record (April through October for both 2013 and 2014), the GWLF-E model was expanded to include the watershed area at that site, providing another opportunity to calibrate/validate a model that includes the northern lakes watershed against a multi-year monitoring data set. Since the time steps of interest for this exercise were monthly and yearly flow volumes, the routing influence of Lake Independence on those values was minimized. It should be noted that the 2014 monitoring period exhibited higher than normal precipitation, allowing the opportunity to see how well modeled flow volumes matched monitored flow volumes under a higher flow regime. In the “southern lakes” watershed area, monitoring at site PSD was conducted during the field seasons of 2010, 2011, and 2013. As with monitoring site PS90, the GWLF-E model was expanded to the watershed at the PSD monitoring location to calibrate/validate a watershed model that included those of the southern lakes using a multiple year data set. All data were collected by Three Rivers Park District water resources staff, with the data collected at sites PS90 and PSD completed under contract with the Pioneer Sarah Creek Watershed Management Commission.

Table B- 4: Calibration and confirmation stations for the lake watersheds of interest. Streamflow and nutrient data were collected at all sites

Station ID	Description	Period of Record (April-Oct monitoring period)	Frequency	Calibration/ Validation
B3	Spurzem Creek at Hamel Road	2015	Daily	Validation
B5	Spurzem Creek in Baker Golf Course	2015	Daily	Calibration
PS90	Pioneer Creek at Hwy 90	2013, 2014	Daily	Validation
PSD	Deer Creek at Deer Creek Road	2010, 2011, 2013	Daily	Validation

5.2 Model Calibration and Confirmation Approach

The GWLF-E model is a tool that was constructed with the idea of minimal calibration being required. With that in mind, there were two main variables that were adjusted to calibrate the hydrology of the model. The first was the curve number assigned to wetland and lake areas in each sub-basin. It should be noted that lake and wetland areas comprise a large area of many of the subwatersheds modeled. It was important to account for the precipitation falling on these surfaces in order to derive some confidence in the modeling of the monthly flow volumes. The model default curve numbers for wetland/lake areas range from 87 to 90. With the addition of the lake areas, the curve numbers were increased to the range of 98-100. A summary of the original wetland acreage, adjusted wetland acreage and curve numbers for each sub-basin can be found in Appendix B-2.

The second variable that was adjusted to help calibrate the GWLF-E model hydrology was the groundwater recessive coefficient. The groundwater recessive coefficient relates how "flashy" a stream can be (i.e., how responsive to precipitation event). It also influences flow volumes by establishing how much of the precipitation goes into the soil profile and is subject to loss by plant uptake and evapotranspiration. The values can range from 0 to 1 with lower values representing less flashy events and higher values representing more flashy events. The default in GWLF-E is 0.06 while the typical values are between 0.01 and 0.2. In the northern lakes, a steady value of 0.01 was used for all the sub-basins since the watersheds are not as flashy due to the abundance of large wetland complexes dominated by emergent like cattails. In the southern lakes, the headwaters of the system have higher values of 0.1 since the small watersheds deliver the precipitation more quickly to the lakes and streams. Further downstream, at the North Whaletail Lake sub-basin, the water begins to move slower and so the groundwater recessive coefficient was reduced to 0.07. The settings for each subbasin can be found in Appendix B-2.

To calibrate the phosphorus levels, the percent drainage to lakes, wetlands and ponds was adjusted. This setting reduces the nutrient and sediment loads by accounting for the attenuating effects of lakes, ponds and wetlands. The values can range from 0% to 100% and represent the proportion of the landscape that is drained to lakes, wetlands and ponds which can attenuate downstream nutrient transport. In the northern lakes, the drainage was set to 0% for all of the subbasins. Even though there are many wetlands in the system, monitoring data analysis suggested that the wetlands were having little to no effect in reducing nutrient concentrations, possibly due to historical high loads of nutrients from large watersheds that over-whelmed the assimilative capacities of the wetlands. In the southern lakes, the headwaters of the system were assigned a value of 100%, since the small watersheds and high-quality water bodies up stream that drain to those wetlands suggest that a high assimilative capacity for the wetlands remains intact. Further downstream, in the North Whaletail Lake subbasin, the lake is shallow and many of the particles are re-suspended due to wind action and so the attenuation effect of the lake is less and the value was dropped to 30%. The settings for each subbasin can be found in Appendix B-2.

Once the hydrologic calibration of flows was completed, the nutrients were assessed. To determine the measured load of nutrients, the nutrient data and flow data collected during the monitoring period was analyzed using FLUX. FLUX is a model created by the Army Corps of Engineers that predicts the flow-weighted load of nutrients. These values were compared to the modeled data and assessed using statistical measures (Table B- 8). The selected nutrient parameter was adjusted within an acceptable range and the model was run with the new adjustments to see how much the loading changed. The updated results of the model were reviewed to determine whether the changes had improved the model fit. The process continued until a good agreement was achieved for both flow and phosphorus. Although the GWLF-E watershed model runs covered the time period 2006 through 2015, only the model output from 2009 through 2015 was used to support the lake modeling, since this is the period for which in-lake data were available to support the BATHTUB calibration/verification.

Statistical Metrics

The calibration of the GWLF-E model was assessed statistically. The streamflow was presented as daily and monthly time-series plots. Three statistical metrics were used to assess the modeled streamflow performance compared to measured data: the coefficient of determination (r^2), Nash-Sutcliffe model of Efficiency coefficient (NSE) and the percent bias (PBIAS). The nutrient loads were assessed as the PBIAS between measured and modeled data on a yearly basis.

The statistical metrics used to assess the GWLF-E modeled flow versus the measured flow are listed and summarized in Table B- 5. The r^2 assessed the goodness of fit by comparing the "explained" variation to the total variation. The r^2 can range from 0 to 1 with a value of 0 indicating the model explains none of the variability and a value of 1 indicating the model explains all of the variability. The NSE compares the observed data versus the simulated data and how closely that relationship resembled a 1:1 relationship. The values for NSE range from negative infinity to 1 with a value of 1 being a perfect fit, a value of 0 indicating the model predicts only as well as using the mean observed data and a value less than 0 indicating the mean observed data would be a better predictor than the model (Moriasi et al. 2007). The PBIAS measures the average tendency of the simulated values to be larger or smaller than the observed values. The optimal PBIAS value is 0 with lower values indicating an unbiased model simulation. Positive PBIAS numbers indicate the model has an underestimation bias while negative values indicate the model has an overestimation bias (Gupta et al. 1999).

Table B- 5: Summary of statistical metrics used to compare modeled versus measured data from the GWLF-E model

Metric	Description	What is measured	Value range	Formula**
r^2	Coefficient of determination	Goodness of fit	0 to 1	$r^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2} \sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}} \right)^2$
NSE	Nash-Sutcliffe efficiency coefficient	Fit observed to simulated on 1:1 line	-∞ to 1	$NSE = 1 - \left(\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \right)$
PBIAS	Percent Bias	Tendency of simulated to be larger or smaller than observed	Optimal value = 0	$PBIAS = \left[\frac{\sum_{i=1}^{n}(S_i - O_i) * (100)}{\sum_{i=1}^{n} O_i} \right]$

** O = Observed, S = simulated

Model Performance Targets

For each statistical metric used, there were different performance targets as summarized in Table B- 6. These performance targets adhere to generally accepted hydrology recommendations (Moriasi 2007; Legates and McCabe 1999; and Ramanarayanan et al. 1997). The performance targets apply to the monthly mean values and, when enough data were available, to the yearly mean values. The daily flows were not assessed statistically since the GWLF-E model is not capable of routing runoff effectively and therefore typically delivers the calculated runoff to the receiving waters much faster than occurs in reality, creating very "flashy" events. The main concern was whether the total flow was reasonable on a monthly, monitoring season, and annual basis. It should be noted that the BATHTUB model uses annual hydrologic inputs.

Table B- 6: Summary of hydrologic statistical performance targets for monthly and annual comparisons

Rating	Hydrologic Statistical metric		
	r^2	NSE	PBIAS
Very Good	>0.70 to 1.0	>0.65 to 1.0	< ± 15%
Satisfactory	0.50 to 0.70	0.40 to 0.65	±15% to ±25%
Unsatisfactory	<0.50	<0.40	> ±25%

5.3 Calibration and Validation Results

Hydrology

There were limited stream data collected in the Pioneer Creek Watershed. Site B5 was the calibration site, with B3 and PS90 providing validation information for the northern lakes. In the southern lakes, PSD was the closest stream validation site to the outlet of North Whaletail Lake.

The model performance was evaluated by comparisons of observed versus simulated streamflow. In Figure B- 11 to Figure B- 18, the monthly flow totals are shown on a 1:1 plot and on a monthly time-series plot during the monitoring period. In Appendix B-3, there are daily time series plots for flow at each of the monitoring locations. The monitoring periods flow data were very complete and the only site missing flow data was PSD for 14 days in 2011. The missing dates were left out of the analysis.

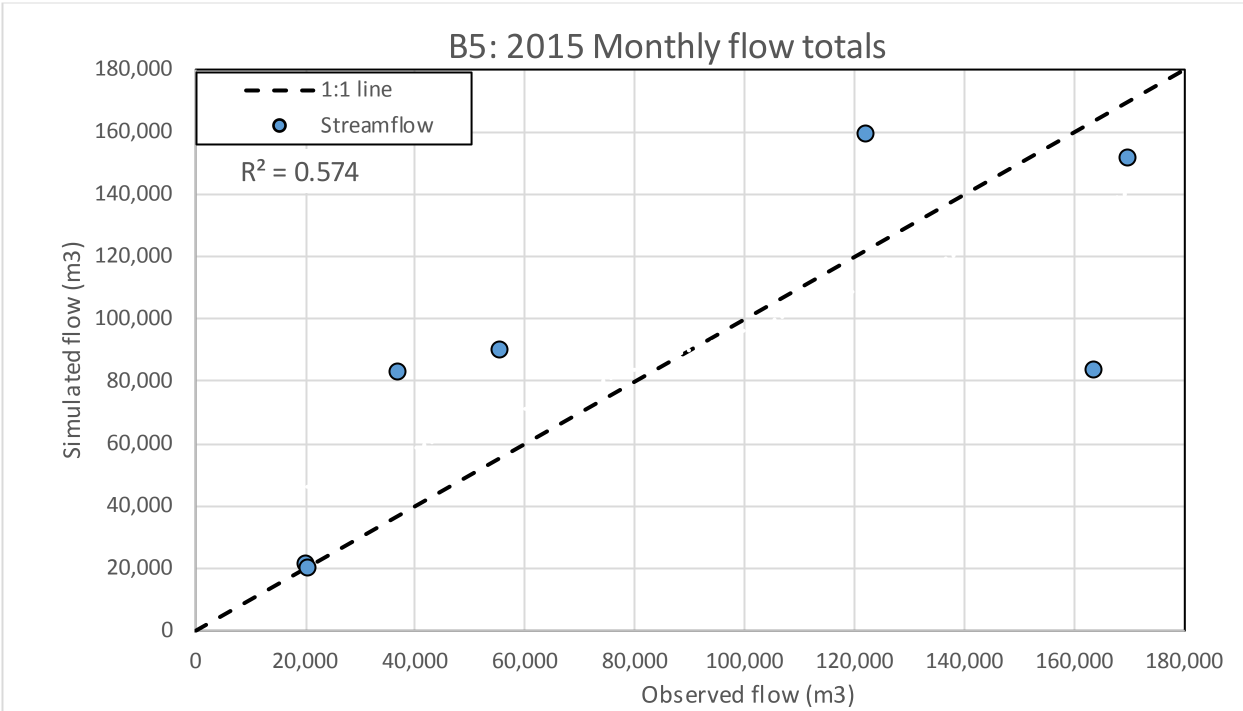


Figure B- 11: Monthly flow volumes for the calibration site B5 from April to October in 2015 on a 1:1 plot

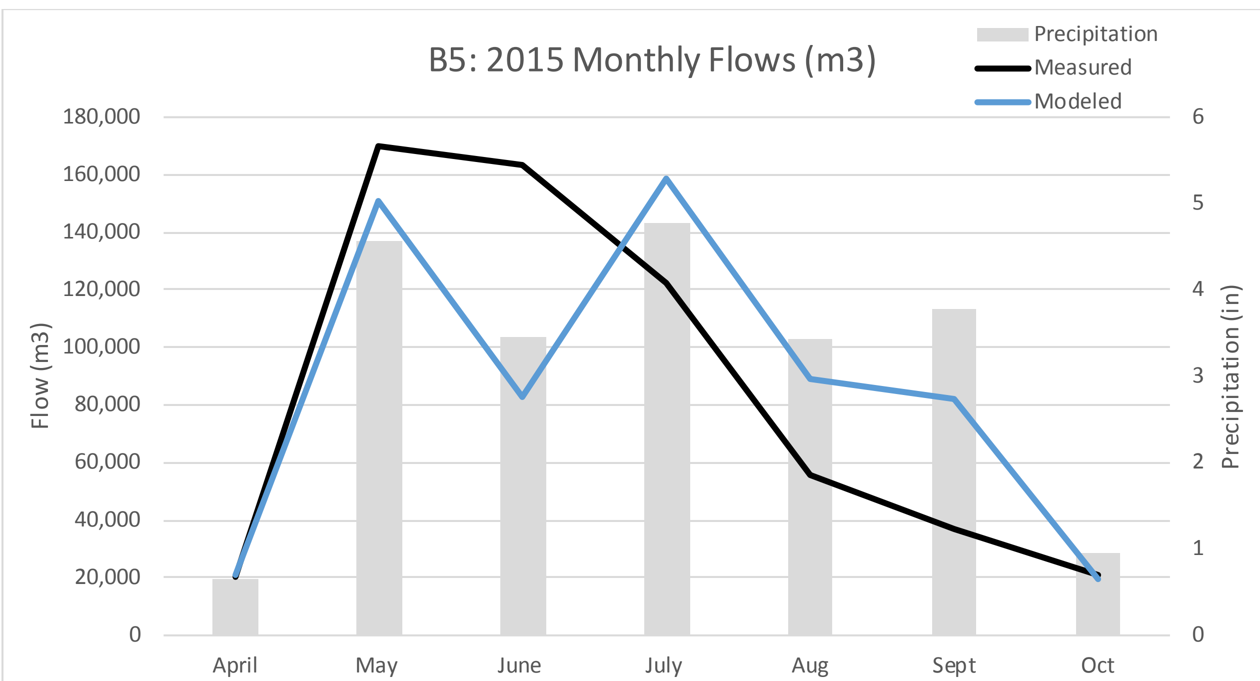


Figure B- 12: Observed and modeled monthly cumulative flow volumes by month for B5 with monthly cumulative precipitation

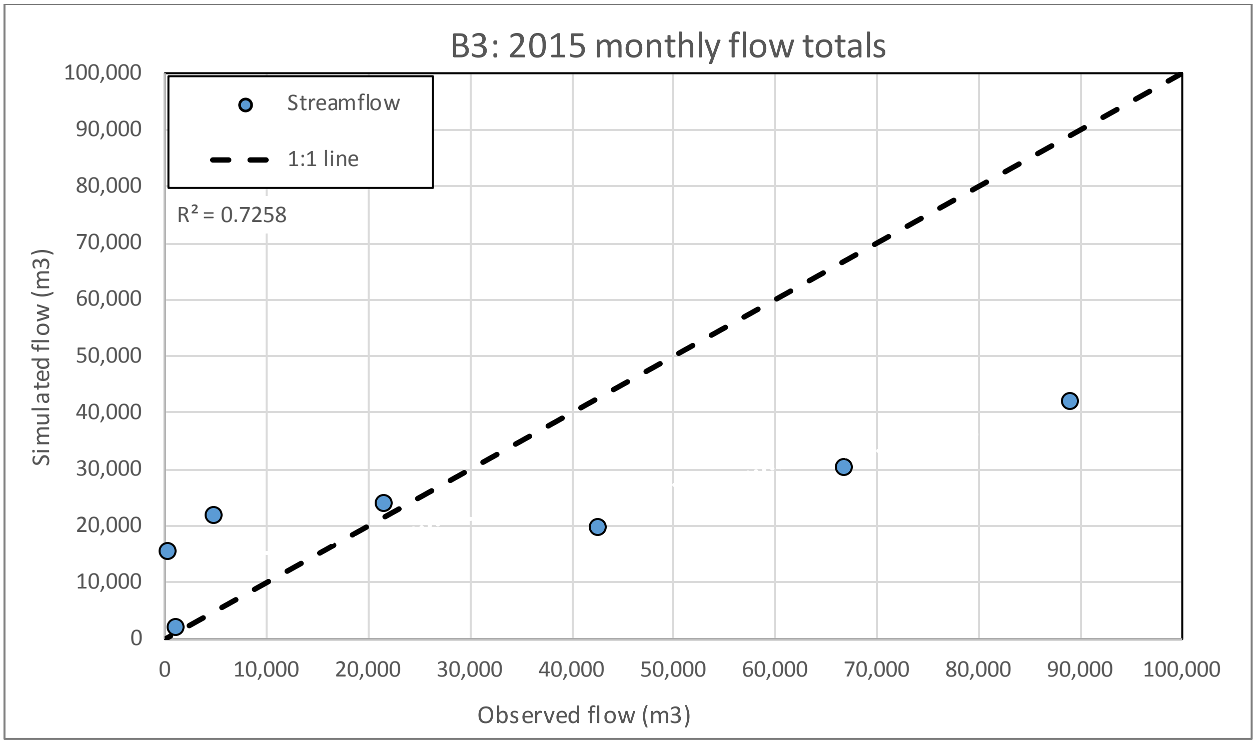


Figure B- 13: Monthly flow volumes for confirmation site B3 from April to October in 2015 on a 1:1 plot

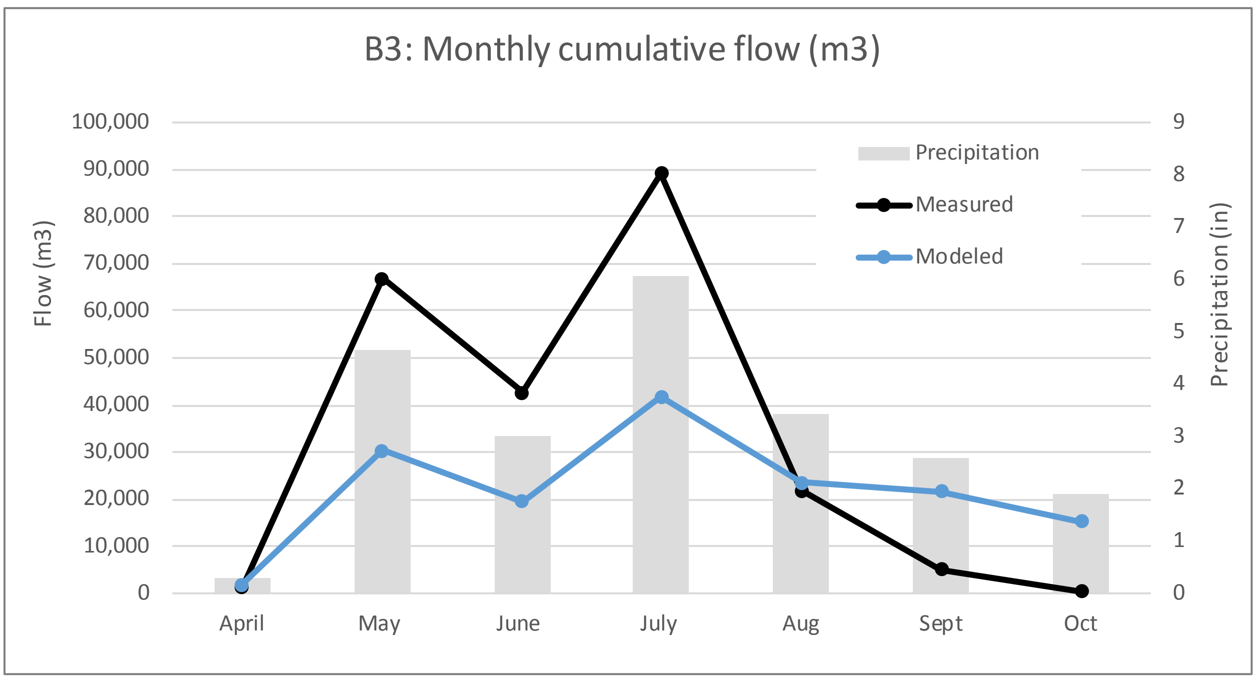


Figure B- 14: Observed and modeled monthly cumulative flow volumes by month for B3 with monthly cumulative precipitation

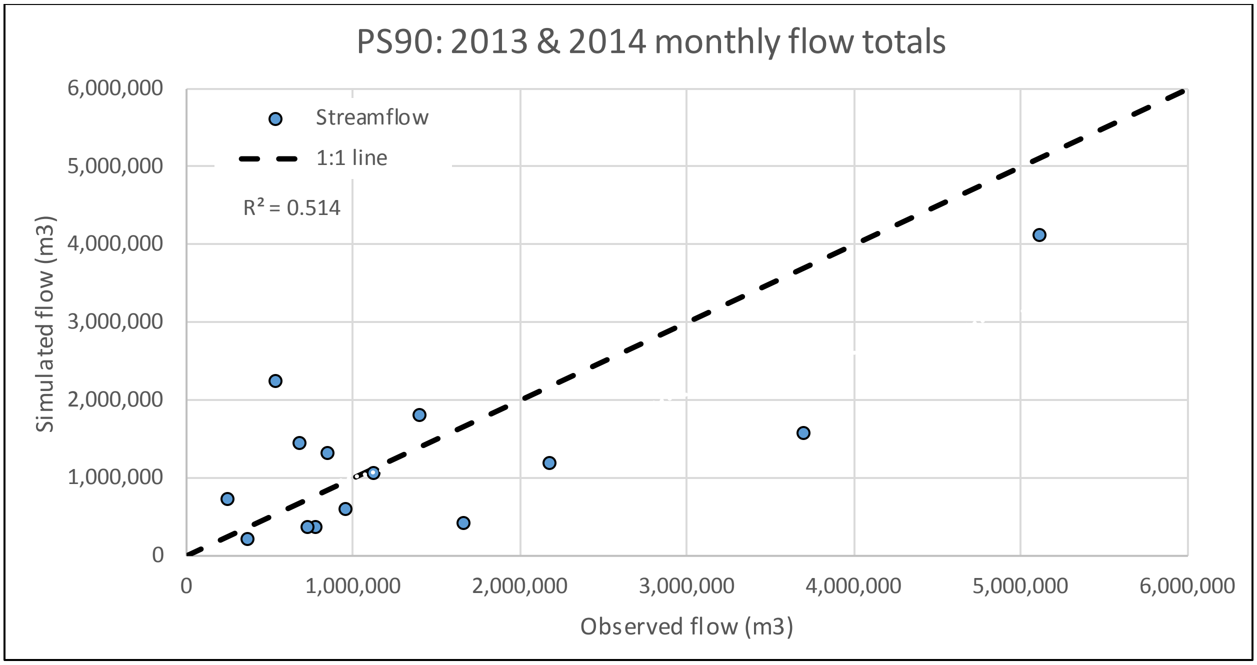


Figure B- 15: Monthly flow volumes for the confirmation site PS90 from April to October in 2013 and 2014 on a 1:1 plot

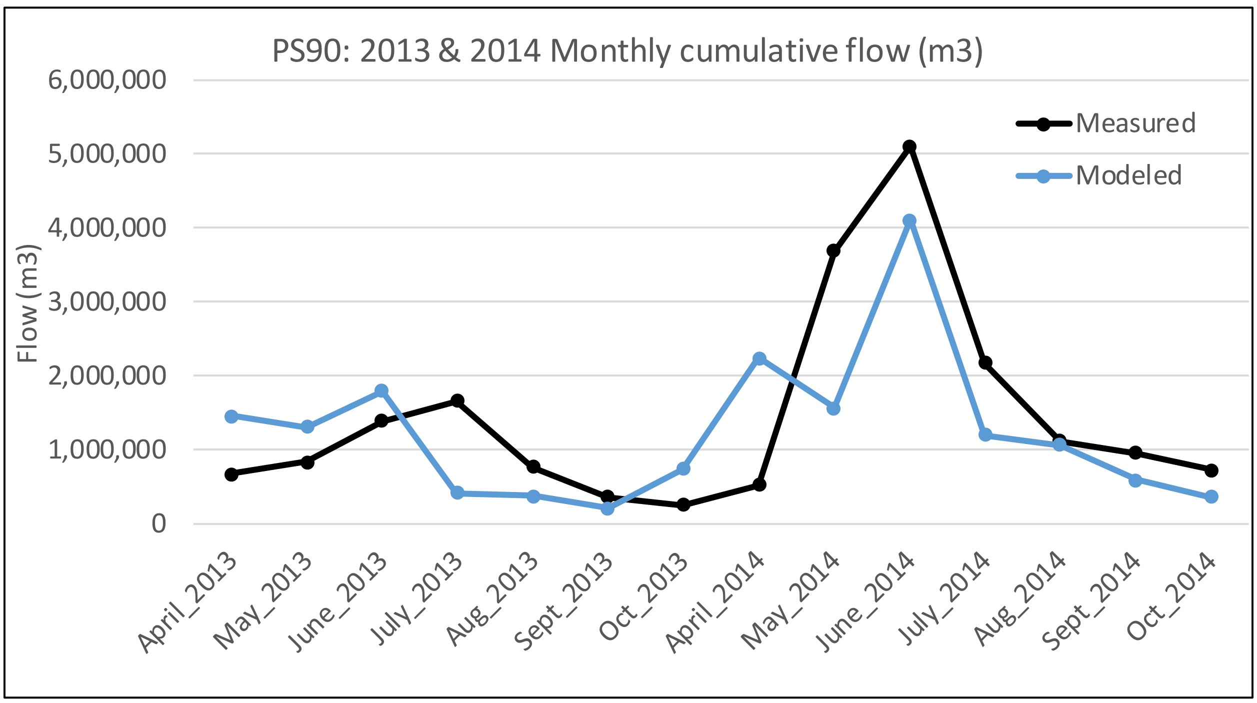


Figure B- 16: Observed and modeled monthly cumulative flow volumes for PS90

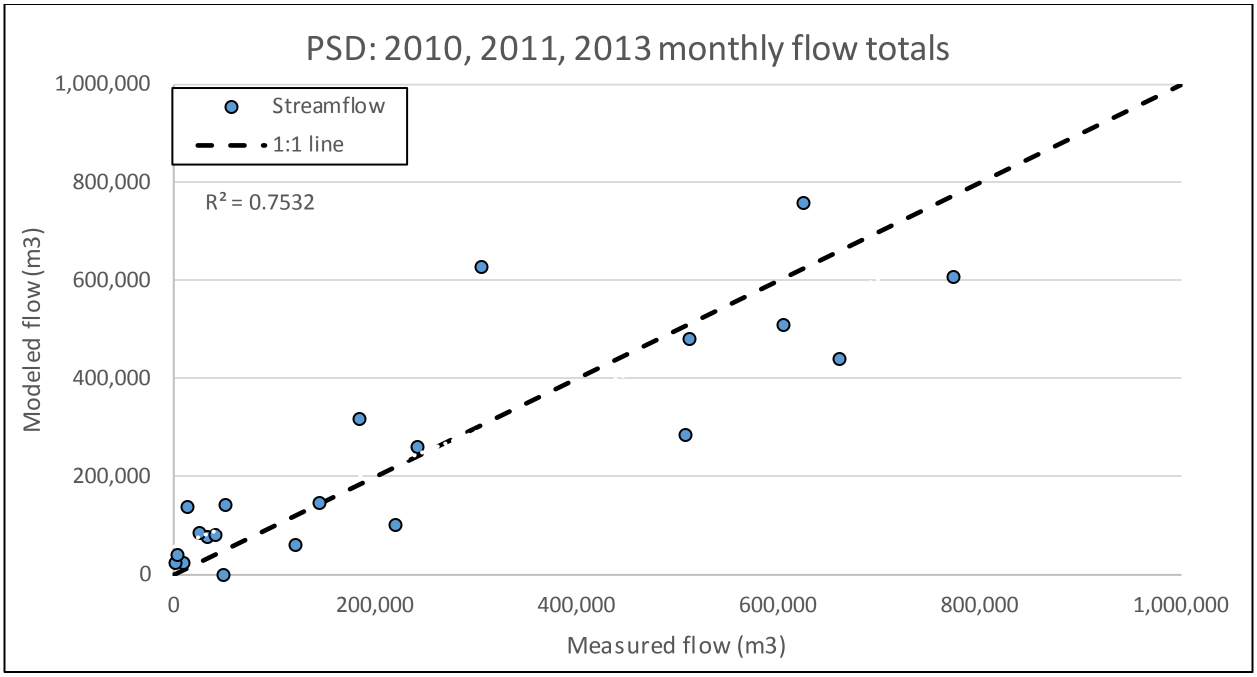


Figure B- 17: Monthly flow volumes for the confirmation site PSD from April to October in 2010, 2011 and 2013 on a 1:1 plot

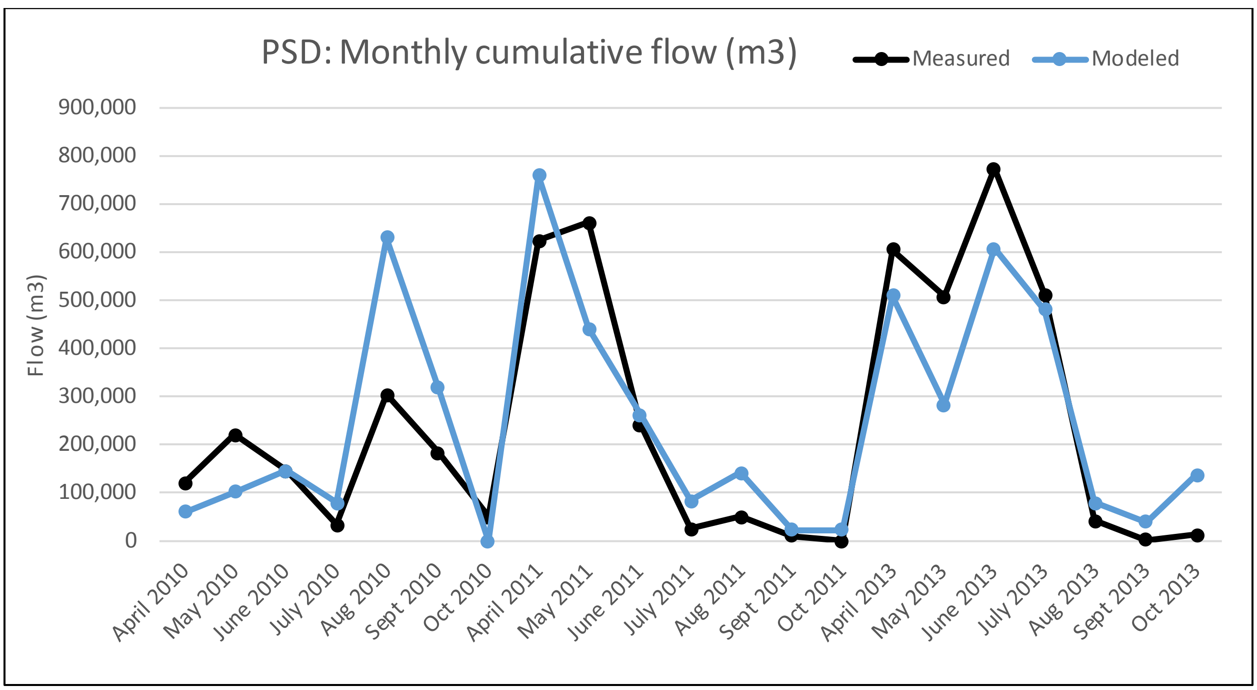


Figure B- 18: Observed and modeled monthly cumulative flow volumes for PSD

The statistical model results for the hydrology calibration and validation sites are shown in Table B- 7. Overall, the calibration of streamflow was "very good" to "satisfactory". Monthly statistical metrics were performed at all locations. With only one year of data, sites B3 and B5 were not assessed on a yearly basis. Site PS90, had two years of data and site PSD had three years of data and were assessed on a yearly basis. A brief summary of the model performance is below:

- While the r^2 and NSE at the calibration site (B5) were in the "satisfactory" range, the PBIAS was within the "very good" range with a difference of 3% between the measured and modeled volume of water. The model is very responsive to the amount of precipitation as seen in Figure B- 12 making the r^2 and NSE lower. There were no precipitation gauges within the B5 watershed, and so discrepancies in precipitation amounts could have made the r^2 and NSE lower.
- B3 has a "very good" r^2, but the NSE and PBIAS were "unsatisfactory" and it is believed that the primary reason for this is the influence from beaver activity. The altered flow conditions in the culvert would have caused the data logger to falsely read flow – so the measured flow would be higher than the actual flow and modeled estimates as well. This is confirmed with the high positive PBIAS, which indicates that the measured data overestimates the modeled estimates.
- PS90 was added as another validation site for the northern lakes since B3 had the beaver influence. Since PS90 is downstream of Lake Independence and has flow coming from the west side of Lake Independence (Figure B- 10), there is almost four times as much flow at PS90 as for the northern lakes. With the routing influence of the upstream large body of water – Lake Independence – the measured flow is more smoothed out than the modeled data, giving lower statistical metrics. The annual NSE increased substantially.
- PSD had the most data points since there were three years of data. The model did a fairly good job representing this site as shown by the high statistical metrics for both monthly and annual time steps. As shown in Appendix B-2, the settings for the southern lakes were different from the northern lakes. When the same calibration values for the northern lakes were input for the southern lakes, the model results compared to the measured results were "unsatisfactory". The makeup of the southern lake watershed is a little different, since there are larger waterbodies and more wetlands in the system as well as a lower watershed to lake area ratio. Therefore, the watershed required higher groundwater recessive coefficients and a higher percent of area drained to lakes, wetlands and ponds.

Table B- 7: Summary of metric results for the monitoring sites

Time Interval	Metric	Calibration	Validation		
		B5	B3	PS90	PSD
Monthly	Coeff. Of Determination (r^2)	0.57	0.73	0.51	0.75
	Nash-Sutcliffe Efficiency (NSE)	0.57	0.37	0.49	0.75
	Percent Bias (PBIAS)	-2.7	32	13.7	1.52
Annual	Coeff. Of Determination (r^2)	--	--	1.0	0.99
	Nash-Sutcliffe Efficiency (NSE)	--	--	0.71	0.81
	Percent Bias (PBIAS)	--	--	-13.7	1.55

Along with statistical metrics, the hydrology was compared to literature review values in two ways. The first was to look at the water balance and the other was to assess the runoff coefficients for the watersheds. In Minnesota watersheds, it has been found that about 76% of the precipitation is lost to evapotranspiration (Baker et al 1979). The average annual precipitation for the PSC Watershed from

2009 through 2015 was 30 inches. The water balance of precipitation for the northern lakes was 73% evapotranspiration, 25% runoff and 3% groundwater. In the southern lakes, the water balance of the precipitation was: 75% evapotranspiration, 24% runoff and 2% groundwater. The second assessment were the runoff coefficients which compares the modeled flow to the precipitation for the area (watershed area*average precipitation). In Minnesota watersheds near the Pioneer Creek Watershed, it has been found that the runoff coefficients range from 0.21 to 0.25 (Vandergrift 2010; Maple Grove 2016; Baker et al. 1979). For the northern lakes, the runoff coefficients ranged between 0.20 and 0.25 depending on the watershed. For the southern lakes, the runoff coefficients ranged between 0.29 and 0.39. The higher values for the southern lakes were due to the large lakes areas in small watersheds creating more direct runoff into the streams and lakes.

In summary, the hydrology calibration and validation sites in the Pioneer Creek Watershed resulted in achieving a large majority of the model performance targets and are within literature review value ranges. The model was able to simulate watershed hydrology and streamflow with a reasonable level of accuracy. The model, therefore, provides a suitable foundation for the simulation of landscape-driven hydrologic inputs. The final hydrology model calibration parameters are provided in Appendix B-1 and Appendix B-2

Total Phosphorus

The TP routines in GWLF-E include dissolved and solid-phase phosphorus in streamflow. The dissolved phosphorus sources are from point sources, groundwater and rural runoff. The solid phase nutrients are from point sources, soil erosion and rural and urban runoff (Evans 2011). To determine the dissolved P load, the model uses the runoff volumes for each land type and multiplies it by the dissolved P concentration for that land type. The dissolved P concentration is based on a relationship developed by Vadas et al. (2005) between land type soil test P concentrations and dissolved P in surface runoff. The solid phase P is estimated by looking at the phosphorus concentration of eroded sediment that is transported to nearby waterways. For the urban routines, the nutrients are built up and then wash off with precipitation events. The GWLF-E model accumulates nutrients on a monthly basis. More about these routines can be found in the GWLF-E manual (Evans 2011) and the original GWLF manual (Haith 1992).

To assess the modeled phosphorus, the simulated P load was compared to the observed P load and the unit area loadings (UALs) were compared to literature reviewed UALs. The measured phosphorus loads were estimated at the monitoring locations using the FLUX model. FLUX estimates the flow weighted phosphorus load using measured streamflow and concentration data. The FLUX TP load was compared to the GWLF-E modeled load during the monitoring period and assessed using the PBIAS. For the UAL analysis, the pounds of phosphorus per acre (based on land use) were compared to commonly accepted literature value UALs.

The PBIAS for the phosphorus loads are shown in Table B- 8. Overall, the flow weighted phosphorus loads compared to the modeled phosphorus loads resulted in a “very good” PBIAS statistical metric. A brief summary of the phosphorus loads is provided below:

- The calibration site of B5 had a “very good” PBIAS metric

- Site B3 was influenced by a beaver, so the measured flows were much higher than the modeled flows. This lead to the TP load being much higher and a very "unsatisfactory" PBIAS metric. Since the beaver influence would have increased flow, the model may be a better representation of the TP load at this site than the measured values
- Site PSD had three years of data and had a "very good" PBIAS metric

Table B- 8: Summary of modeled and measured flow along with FLUX flow weighted TP load versus GWLF-E modeled TP load

Method	Variable	Calibration	Validation		
		B5	B3*	PS90**	PSD***
FLUX	Measured flow (m^3)	589,531	227,174	20,273,550	5,131,994
	Flow weighted TP load (kg)	146	58		986
GWLF-E	Modeled flow (m^3)	605,237	153,810	17,489,137	5,211,452
	Modeled TP load (kg)	143.2	32		1064
	PBIAS - Yearly TP load	-2%	-45%		8%

*With the modeled flow being about half as much, the TP load is also much lower (beaver influenced site)
**This site is after Lake Independence, and quite a ways from the lakes of interest, so a TP analysis was not completed
***This data is over 3 years

The phosphorus load was assessed as modeled UALs versus commonly accepted UALs from a literature review (Reckhow 1980) as shown in Table B- 9. The UALs produced by the model were all within or just below the ranges that the literature review provided. A brief review of the UALs is provided below:

- The literature review of agricultural TP UALs found that the range is very wide depending on manure spreading practices. The lake watersheds of interest all had lower TP UALs than the literature median value. The main difference between the Pioneer Creek Watersheds with higher TP UALs compared to watersheds with lower TP UALs was the number of animals in the watersheds. As can be seen in Figure B- 19, the Lake Ardmore Watershed has a higher concentration of livestock than the other watersheds and it is reflected in the higher agricultural UAL for the Lake Ardmore Watershed.
- It should be noted that in the southern lake watersheds, subbasin five has a higher concentration of animals in it. These animals are primarily at the Gale Woods Farm that is operated by the Three Rivers Park District and steps have been taken to reduce the animals' impact in the watershed (i.e., preservation of un-grazed buffers, rotational grazing, exclusion fencing, etc.)
- The literature UALs for urban land uses are generally higher than what the GWLF-E model predicted for the lake watersheds of interest. The lake watersheds of interest have relatively little areas of urban land use (Table B- 2) and the urban areas are lower density, so the loading is lower than the literature review values.
- The forested UALs and pasture UALs for the lake watersheds of interest are both at the lower end of the literature UALs for those land uses

- The overall loading ranged between 0.25 to 0.42 lbs/acre/year (Table B- 9). These loading rates are comparable to nearby watersheds of Bassett Creek with a median of 0.33 lbs/acre/year (MCES 2010), the Crow River with a median of 0.25 (MC 2014) and the Elm Creek Watershed, which reported 0.42 lbs/acre/year (Elm Creek Watershed Management Commission 2015).

Table B- 9: Summary of TP unit area loadings (lbs/acre/year) for a literature review (Reckhow, 1980) compared to the lake watersheds of interest (averaged over 2006-2015). The watersheds are listed as Half Moon Lake (which includes Spurzem and Peter Lakes), Lake Ardmore, and North Whaletail (which includes South Whaletail)

	TP (lbs/acre/year)			
Land Use Type	Literature Range: Median (min - max)	Half Moon Lake Watershed	Lake Ardmore Watershed	North Whaletail Watershed
Agriculture	2.00 (0.23 - 16.6)	1.30	1.46	0.95
Urban	0.98 (0.17 - 5.56)	0.19	0.14	0.18
Forest	0.18 (0.01 - 0.74)	0.01	0.01	0.01
Pasture	0.72 (0.12 - 4.37)	0.19	0.19	0.14
Overall		0.36	0.42	0.25

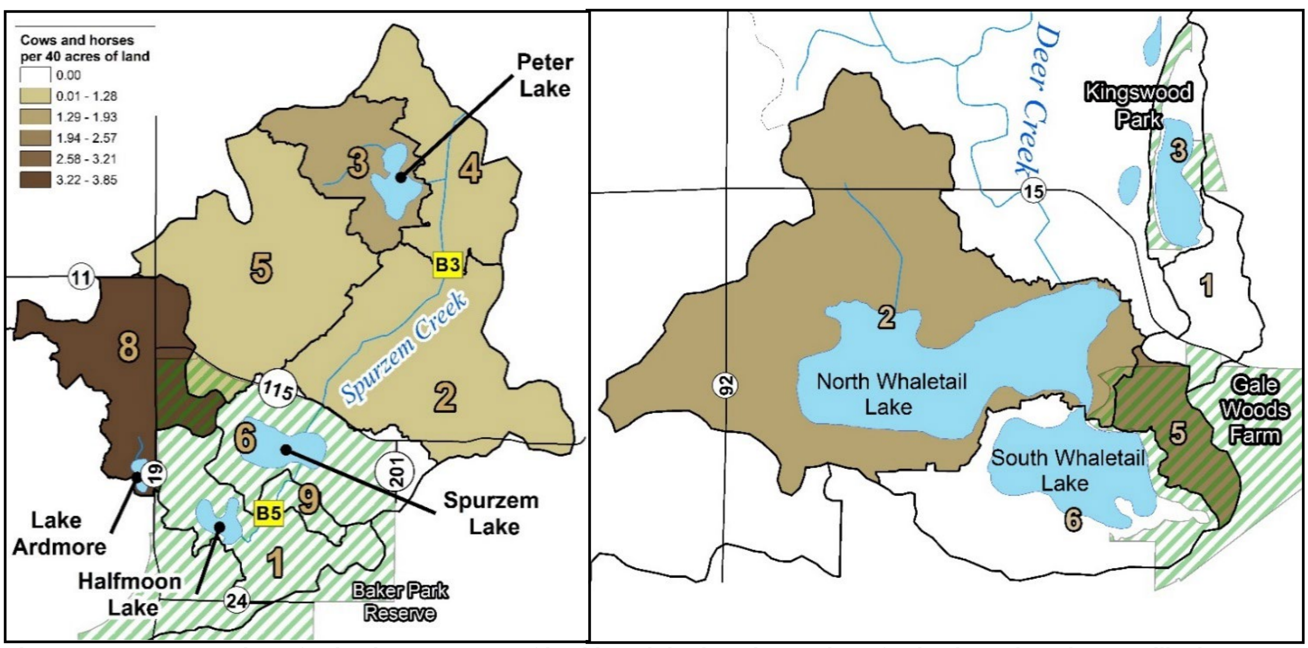


Figure B- 19: Concentration of animals per 40 acres of land by sub-basins. The number of animals are based on satellite imagery surveys conducted by TRPD. The northern lakes are on the left and the southern lakes are on the right

Once the TP was calibrated, the TP loading was assessed across the watershed, on a monthly basis and on a yearly basis. Overall, the GWLF-E model predicted that cropland contributed the largest percentage of TP loading to the watersheds of interest, with hay/pasture land being the second largest contributor (Figure B- 20). Looking at the monthly loading average over 2006 through 2015, the most loading occurred during June and May while January and February had the least amount of loading (Figure B-21). In Figure B- 22, the loading to the different lakes by year (2009 through 2015) is shown with yearly precipitation totals. Since this is cumulative, Peter Lake has one-eighth the loading that Spurzem and

Half Moon Lakes have. In the North Whaletail Watershed, South Whaletail has one-sixth the loading that North Whaletail, has, so most of the loading occurs in the watershed that directly discharges to North Whaletail. Figure B- 23 shows the TP loading by subbasin in lbs/acre to the lakes of interest as well as the stream monitoring sites since the TP loading was calibrated to the stream monitoring sites. The sub-basins that are more natural and have parks in them have less loading, while sub-basins with more animals and agriculture have higher loading.

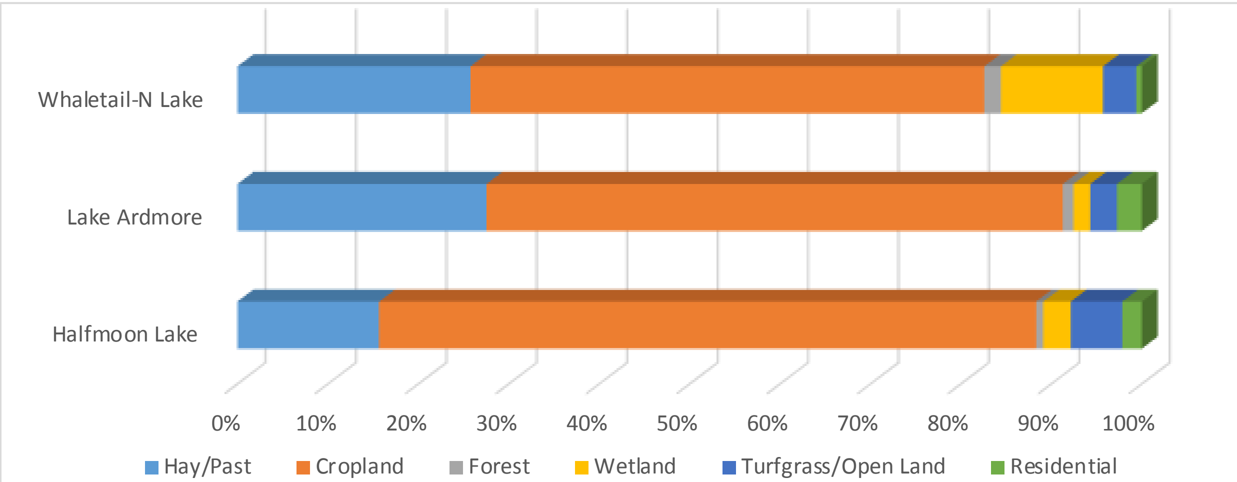


Figure B- 20: Percentage of TP load attributed to different land uses for the Half Moon Lake Watershed (including Spurzem and Peter Lake Watersheds), Lake Ardmore Watershed and North Whaletail Watershed (including South Whaletail Lake Watershed)

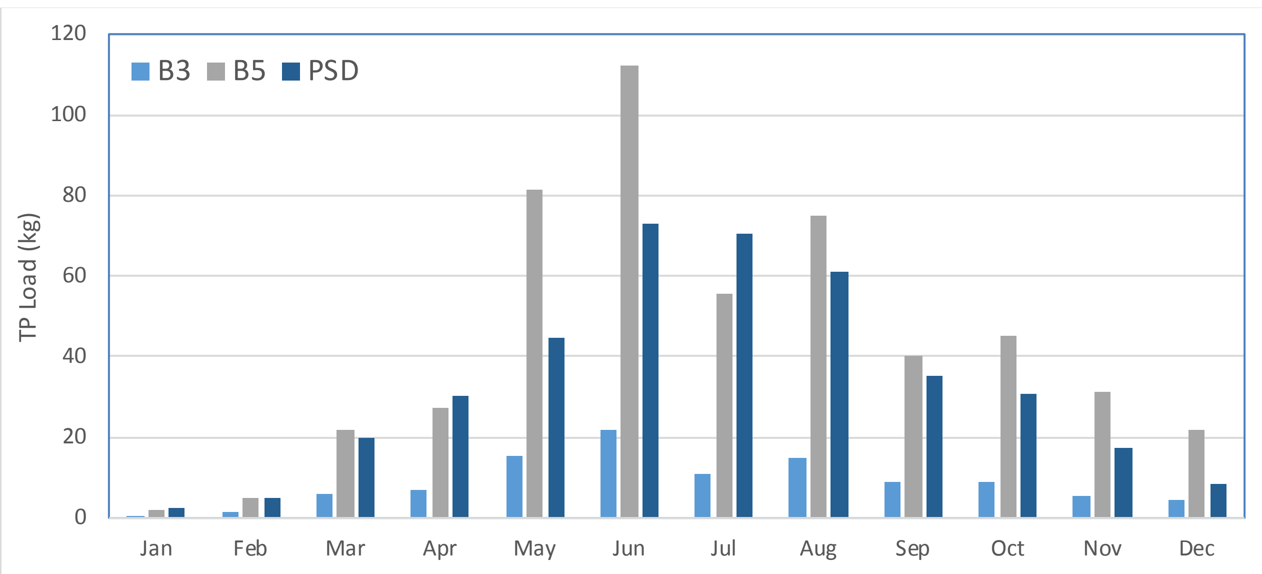


Figure B- 21: Average TP loading (kg) from 2006-2015 for the stream monitoring sites by month

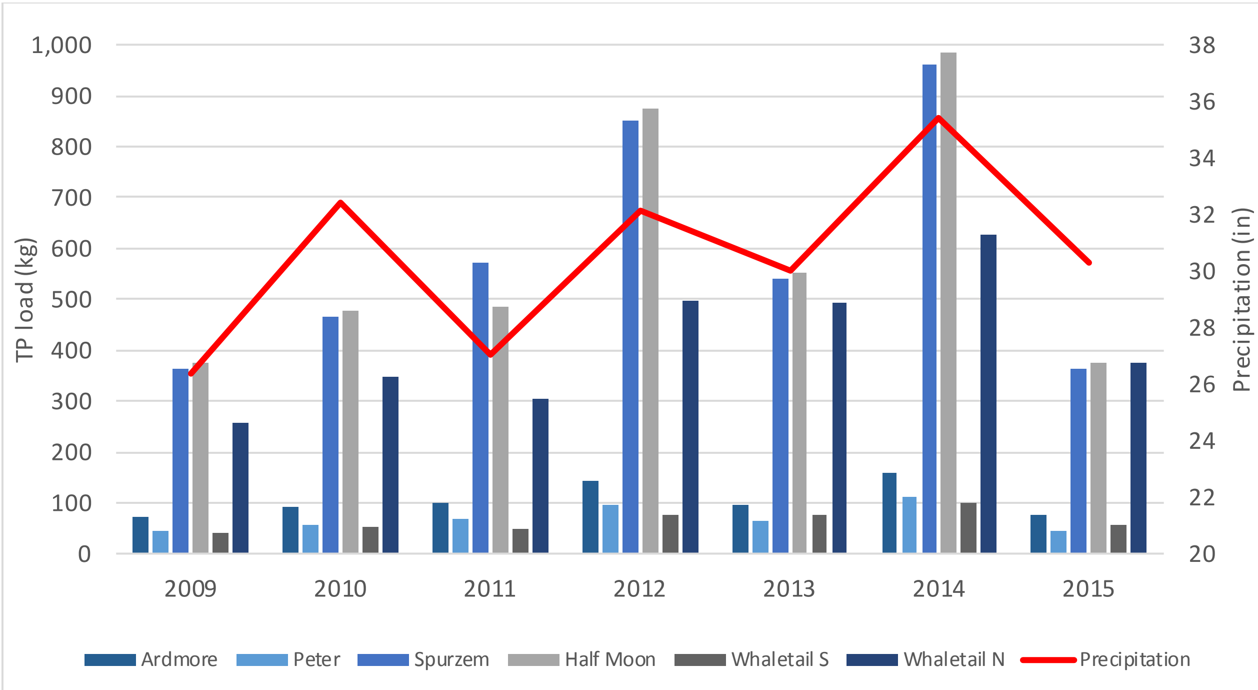


Figure B- 22: Yearly cumulative TP loading for lake watersheds of interest. Plotted with annual precipitation

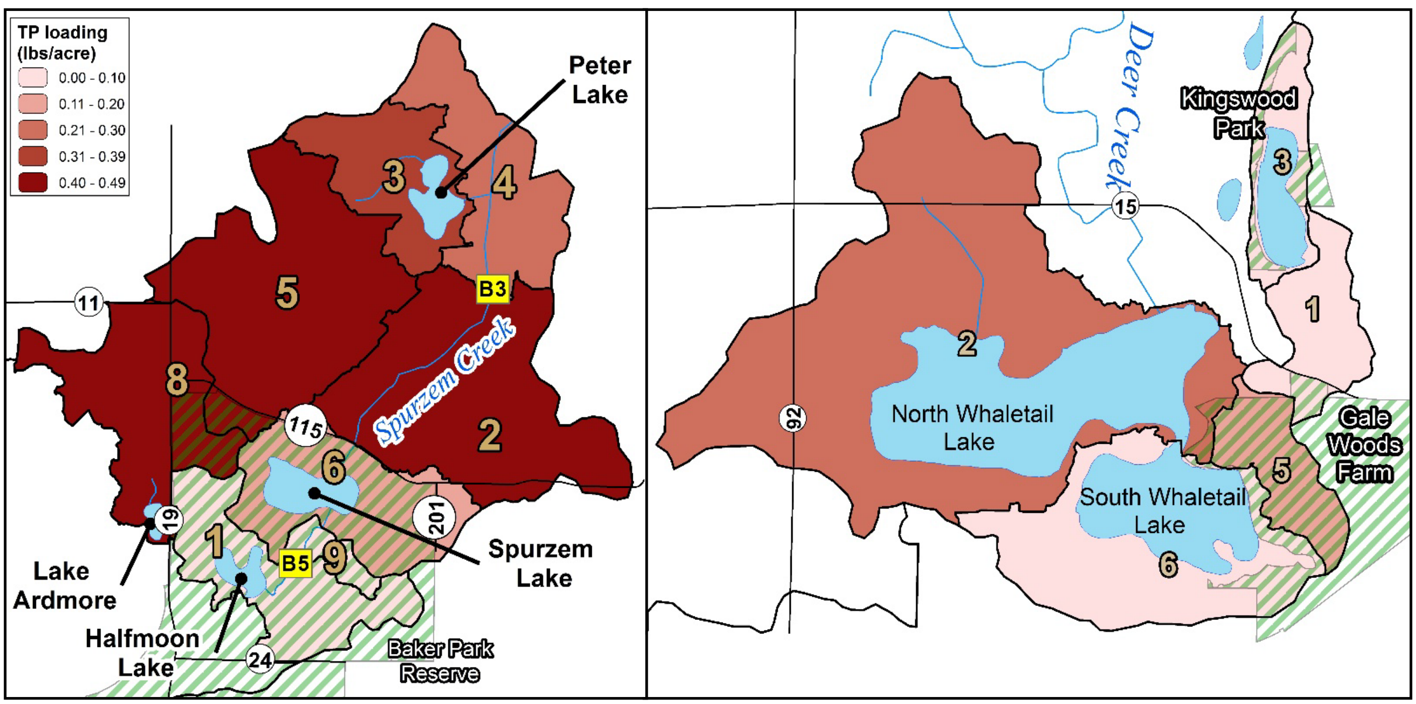


Figure B- 23: Average TP loading (lbs/acre/year) during 2006-2015 by sub-basin for the northern and southern lakes of interest

6. Inputs to BATHTUB

Once the GWLF-E model was calibrated for hydrology and TP, the stream flow and TP concentrations were used in the BATHTUB model. The specifics of the configuration and results of the BATHTUB model are in Appendix C. In Table B- 10 and Table B- 11 the output from the GWLF-E model for 2009 to 2015 are listed. The flow and concentrations were averaged and those averages were used as input to the BATHTUB model to calculate the TP load.

Table B- 10: Summary of northern lakes BATHTUB inputs. Values highlighted in blue were input to the BATHTUB model

Year	Peter		Spurzem		Half Moon		Ardmore		
	Flow (hm3)	Concentration (µg/L)	Flow (hm3)	Concentration (µg/L)	Flow (hm3)	Concentration (µg/L)	Flow (hm3)	Concentration (µg/L)	Precipitation (in)
2009	0.15	289	1.28	284	1.68	224	0.17	413	26
2010	0.17	327	1.48	313	1.94	246	0.19	479	32
2011	0.38	178	2.69	213	3.17	153	0.45	223	27
2012	0.30	329	2.51	340	3.07	285	0.37	384	32
2013	0.25	255	1.91	282	2.38	232	0.27	363	30
2014	0.56	198	4.18	230	4.89	201	0.72	221	35
2015	0.13	337	1.10	331	1.52	246	0.15	499	30
Average	0.28	273	2.16	285	2.66	227	0.33	369	31

Table B- 11: Summary of southern lakes BATHTUB inputs. Values highlighted in blue were input to the BATHTUB model

Year	Whaletail S		Whaletail N		Watershed wide
	Flow (hm3)	Concentration (µg/L)	Flow (hm3)	Concentration (µg/L)	Precipitation (in)
2009	0.75	25	1.61	73	26
2010	0.84	29	1.82	87	29
2011	0.90	25	2.01	69	23
2012	0.97	35	2.32	98	31
2013	1.03	33	2.44	92	31
2014	1.43	31	3.34	85	34
2015	0.93	28	1.99	85	33
Average	0.98	30	2.22	84	29

7. Summary

This appendix summarized the development and calibration of the GWLF-E model for the nutrient impaired lakes in the Pioneer Creek Watershed. There were six lakes of interest including: Peter Lake, Spurzem Lake, Half Moon Lake, Lake Ardmore, South Whaletail Lake and North Whaletail Lake. The watershed model was calibrated for flow and TP. There were several stream sites used to calibrate/

validate the GWLF-E Watershed model. Along with the stream sites to compare the modeled data to the simulated data, there were also literature reviewed values to which model outputs were compared.

Overall, the simulated water flow and TP were in good agreement with the measured flow and TP loads, based on generally accepted statistical metrics. Attributes such as land use, climate, hydrologic and physiographic variables were taken into consideration. The model was able to reproduce temporal (monthly, yearly) variation in streamflow and UALs of nutrients from the landscape. Thus, the performance of the model provides confidence that the model can be used to inform landscape loadings to the lake model (BATHTUB).

The GWLF-E model provides some insight as to where in the watersheds higher landscape loads of TP appear to be coming from. Model simulations suggest that cropland areas are a significant contributor to the TP loads in the Pioneer Creek Watershed. The TP loading from the different lake watersheds ranged from 0.25 to 0.42 pounds per acre depending on land use.

The limitations of this model are noted as follows. This is a “mid-range” model that does not account for all the processes that occur in a watershed. While this is true, the model has been tested in many different scenarios and has provided reasonable results. The model is a lump sum model, so it accumulates the nutrients on a monthly basis versus a daily basis. For the flow, when precipitation goes in, it all goes into the model at one time versus spread out over the entire day making the model more ”flashy” than conditions may actually be.

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Appendix B-1
General Model Calibration Parameters

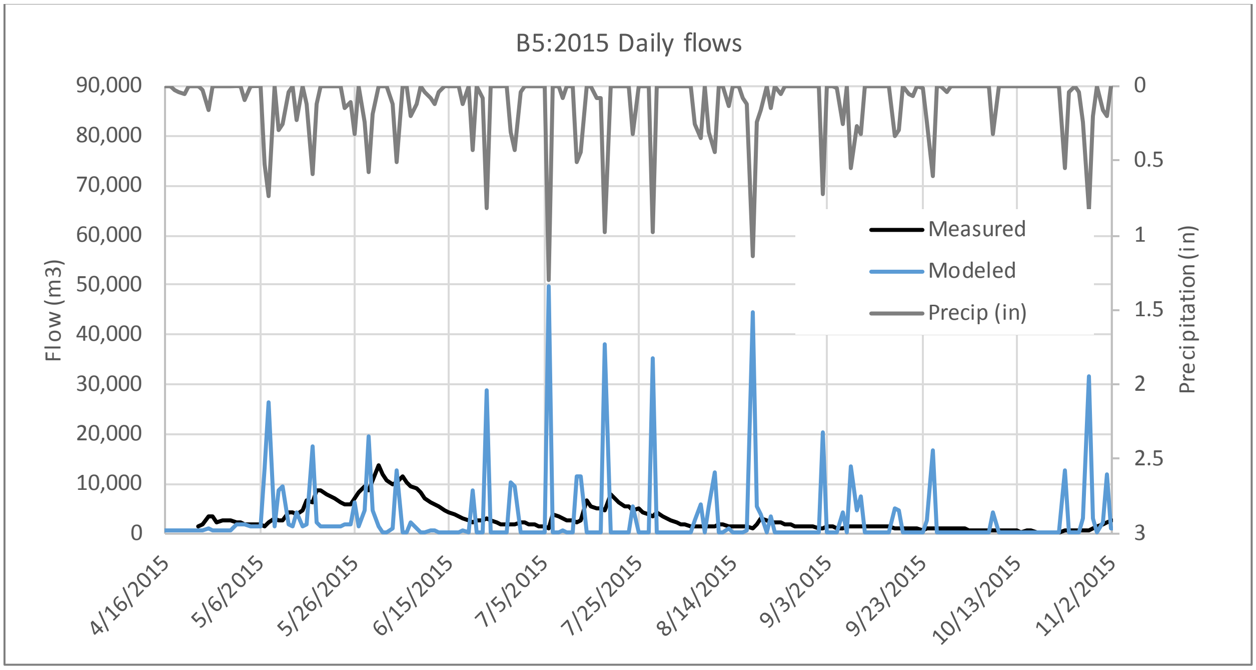
Tab	Parameter	Description	Default value	Assigned value
Transport	Percent impervious	Percent of urban areas that does not allow infiltration	range of values	used defaults
	Curve number (CN)	Combines HSG and land use to estimate CN for each source area	range of values	used defaults
	CN for wetlands	Used as a calibration adjustment	87-90	98-100
	Area of wetlands	Lake areas are not included in GWLF-E - to account for those areas, the hectares of lake were added to the hectares of wetland	from land use layer	from land use layer
	K	Area weighted soil erodibility from SSURGO dataset	range of values	used defaults
	LS	Length and slope as derived from 5m DEM	range of values	used defaults
	C	Cropping management	Row Crop: 0.42 Hay/pasture: 0.03 Woodlands: 0.002	Row Crop: 0.42 Hay/pasture: 0.03 Woodlands: 0.002
	P	Erosion control practice	P1 (1.1-2% slope): 0.52 P2 (2.1-7%): 0.45 P3 (7.1-12%): 0.52 P4 (12.1-18%): 0.66 P5 (>18%): 0.74	P1 (1.1-2% slope): 0.52 P2 (2.1-7%): 0.45 P3 (7.1-12%): 0.52 P4 (12.1-18%): 0.66 P5 (>18%): 0.74
	Ket	Average monthly evapotranspiration rates that are based on the land use and are a function of daylight hours and climate data	range of values	used defaults
	Adjust % ET	A way to increase or decrease evapotranspiration on a monthly basis	1	1
	Day hours	Number of daylight hours based on latitude	range of values	used defaults
	Grow Season	Growing season of vegetation	0	May to September/Oct
	Eros Coef	Erosivity coefficient - function of rainfall intensity in an area. Assigned values are for St Paul MN in the GWLF-E manual	Cool: 0.18 Warm: 0.28	Cool: 0.10 Warm: 0.26
	Stream Extract	Water withdrawals from surface water	0	0
	Ground Extract	Water withdrawals from ground water	0	0

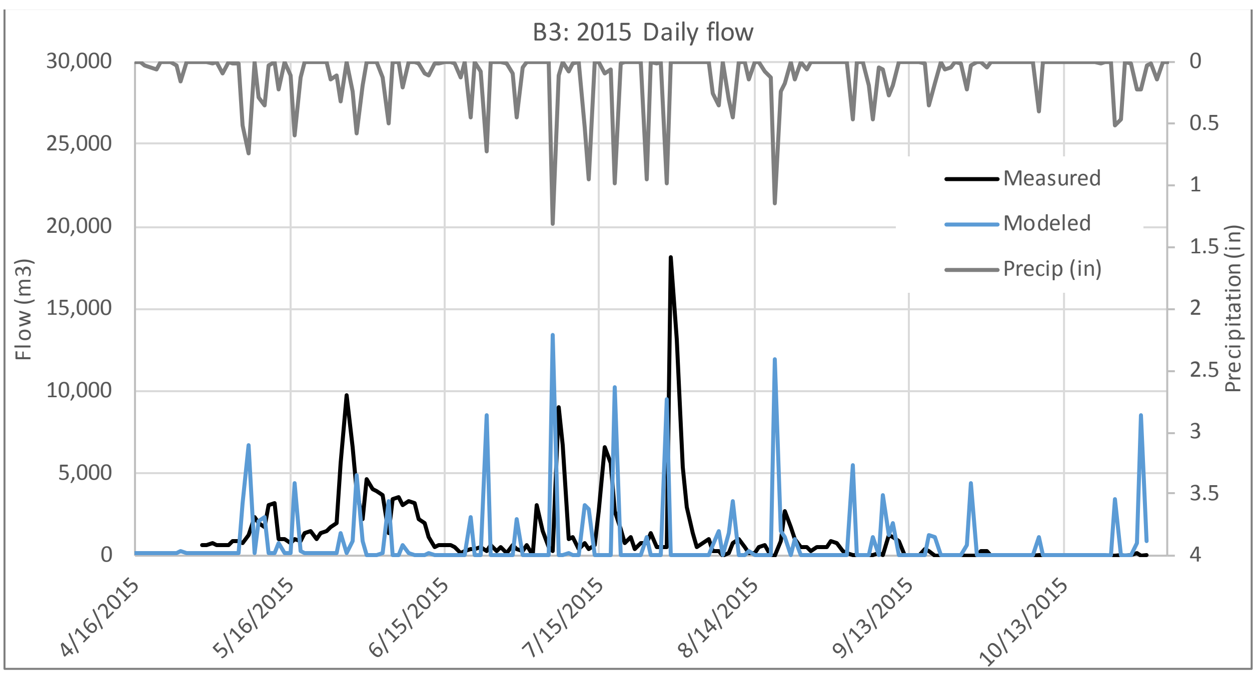
Tab	Parameter	Description	Default value	Assigned value
Transport cont.	Sediment A Factor	The eroded sediment that deposits before entering nearby water bodies - based on watershed size	range of values	used defaults
	Sed A adjustment	To increase/decrease sediment being deposited before reaching water bodies	1	1
	Avail Water Cap (AWC) (cm)	Area weighted AWC from SSURGO dataset for 100 cm of soil	10 cm	Ranged from 13-25 cm – based on watershed
	GW Recess Coeff	Determines how "flashy" a stream is; lower values for less flashy	0.06	based on watershed
	GW Seepage Coeff	Accounts for water table fluctuation from year to year	0	0
	% Tile Drained (Ag)	Percent of agricultural land that is assumed to be tiled	0	0
Nutrient	Dissolved runoff coeff	Various nutrient concentrations in runoff, groundwater and soil	range of values	used defaults
	Point source loads	Loretto Wastewater Treatment Plant	0	May : kg P: 8.21, MGD: 0.31 Nov: kg P: 2.96, MGD: 0.23
	Urban buildup	Uses exponential buildup and washoff coefficients for urban areas	range of values	used defaults
Animal	Number of animal by type	Visual assessment of high resolution satellite imagery	0	range of values
	Land applied, loss/uptake rates	Nutrients from animals and how they are distributed - default loss and uptake rates based on literature reviews	range of values	used defaults
Delivery	Attenuation	In-stream attenuation as a function of travel time	range of values	used defaults
	Loss Rate (%/day)	Loss rates used in attenuation algorithms	N: 0.287 P: 0.226 TSS: 0.0	N: 0.287 P: 0.226 TSS: 0.0
	Stream flow Volume	Adjustment factor of stream flow	1	1
	Retention	The amount nutrients will be decreased by if a percent drainage is indicated. Default retention values are based on literature reviews.	Total N: 0.12 Total P: 0.29 Total Sed: 0.84	Total N: 0.12 Total P: 0.29 Total Sed: 0.84
	Percent Drainage	Percent drainage to lakes or wetlands - reduces nutrients by means of settling out; used in calibration	0	range of values

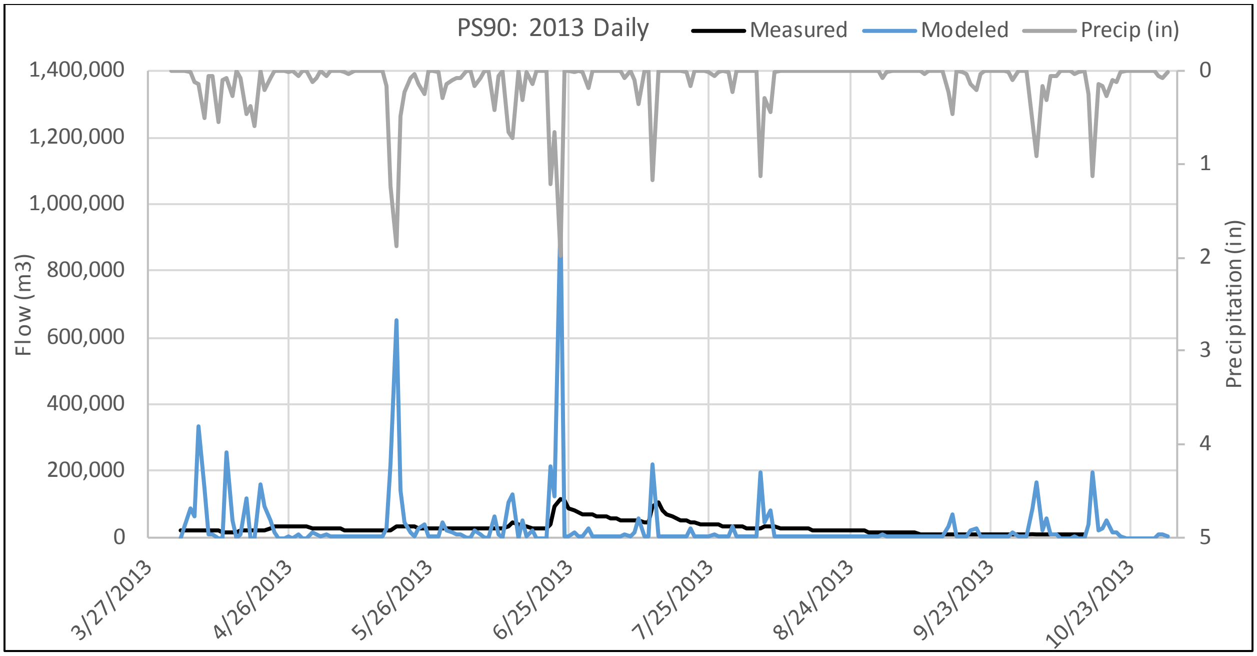
Appendix B-2
GWLF-E Configuration by Subbasin

	Sub-basin	General description of watershed	Sub-basin area (ha)	Cumulative area (ha)	Water area (ha)	Original Wetland (ha)	GWLF-E Wetland (ha)	Wetland Curve number	% drainage to lakes/wetlands	GW Recess Coeff
Northern lakes	1	Half Moon	163	1,401	27	19	46	100	0	0.01
	2	Thomas/Winterhalter	354	1,021	14	56	70	98	0	0.01
	3	Peter	144	144	21	3	24	98	0	0.01
	4	B3	177	321	0	39	39	98	0	0.01
	5	WWTP	346	346	1	32	33	98	0	0.01
	6	Spurzem	191	1,212	33	27	60	98	0	0.01
	7	Hwy 19	77	1,478	0	25	25	100	0	0.01
	8	Ardmore	211	211	9	16	25	98	0	0.01
	9	B5	26	1,238	3	4	7	100	0	0.01
	10	After Independence	103	3,501	4	19	23	99	0	0.01
	11	PS90	555	4,055	4	102	106	100	0	0.01
	12	Independence	820	3,397	342	69	411	99	0	0.01
	13	Northwest	443	443	15	41	56	100	0	0.01
	14	Southwest	446	446	11	26	37	100	0	0.01
Southern Lakes	1	After Little Long	55	109	7	6	13	100	1	0.1
	2	Whaletail N	508	844	154	66	220	98	0.3	0.07
	3	Little Long	54	54	19	4	23	100	1	0.1
	4	After Whaletail N	100	944	7	27	34	98	0.3	0.07
	5	Before Whaletail S	48	156	0	2	2	100	1	0.1
	6	Whaletail S	179	336	59	12	71	100	1	0.1
	7	PSD	506	1,450	32	33	65	98	0.3	0.07

Appendix B-3
Additional Calibration Figures







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Modeled
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1,000,000
800,000
600,000
400,000
200,000
0
Flow (m3)
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1
2
3
4
5
Precipitation (in)
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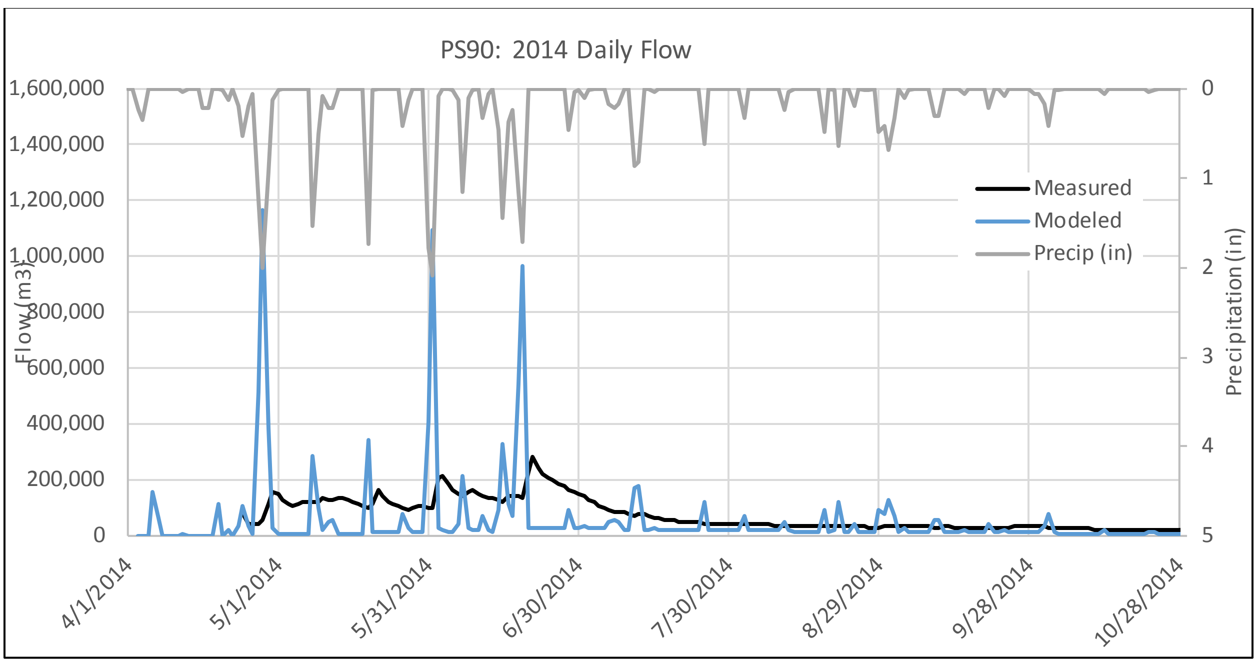
10/23/2013



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Modeled
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Flow (m3)
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2
3
4
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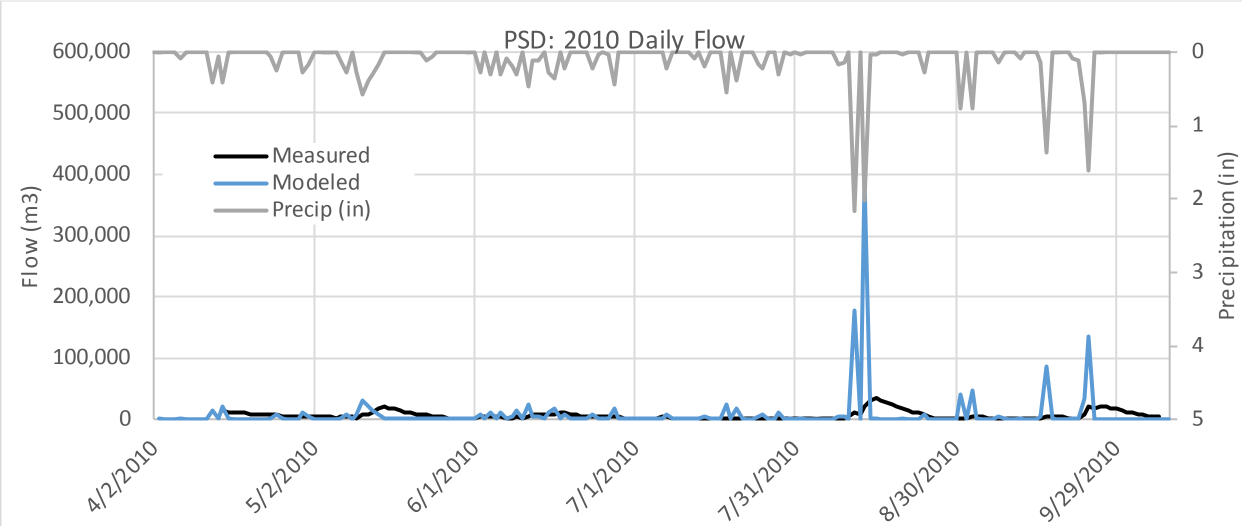
9/28/2014
10/28/2014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Flow (m3)
Precipitation (in)
Measured
Modeled
Precip (in)
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300,000
200,000
100,000
0
0
1
2
3
4
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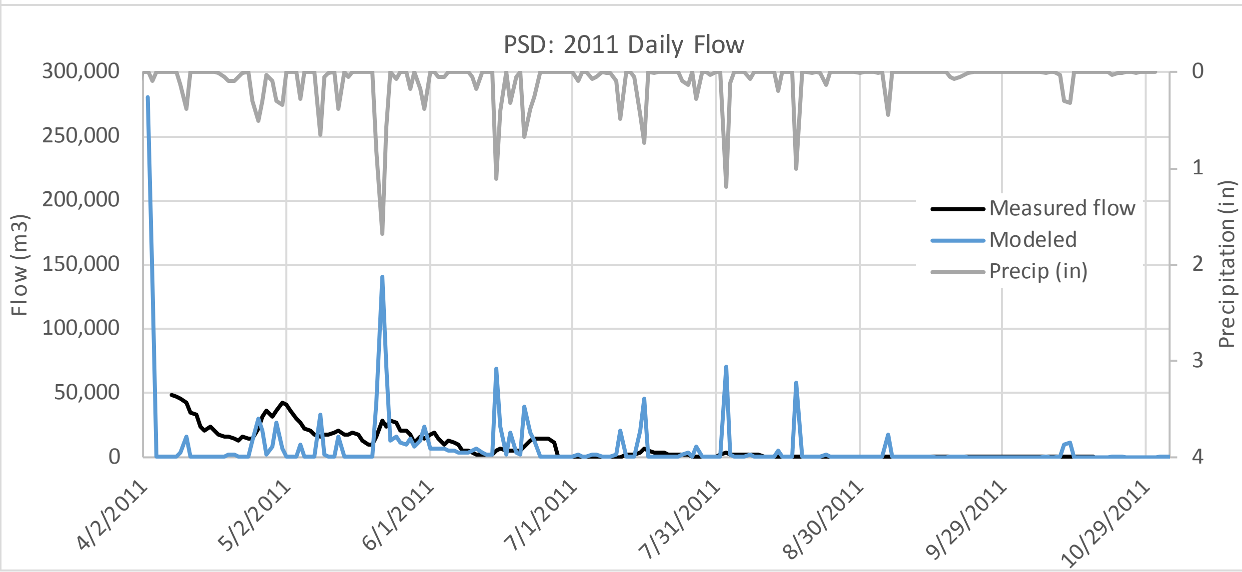
4/2/2010
5/2/2010
6/1/2010
7/1/2010
7/31/2010
8/30/2010
9/29/2010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Flow (m3)
Precipitation (in)
Measured flow
Modeled
Precip (in)
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200,000
150,000
100,000
50,000
0
0
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2
3
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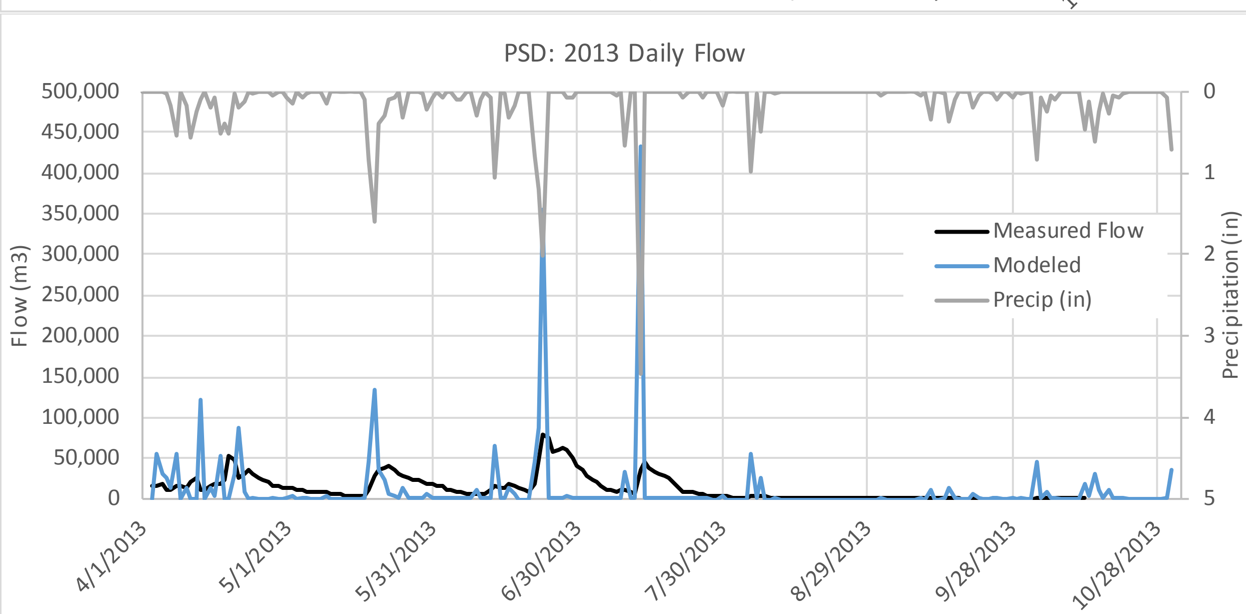
10/29/2011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Measured Flow
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5/1/2013
5/31/2013
6/30/2013
7/30/2013
8/29/2013
9/28/2013
10/28/2013

Appendix C: BATHTUB Model Methods, Inputs, and Outputs for Lakes

1.0 Introduction

This section describes the modeling approach and information used to develop TMDLs for lakes within the Pioneer and Sarah Creek Watershed. The BATHTUB model was the lake response model used for all five lakes. The supporting appendix sections present the following detailed information for each lake:

C1 Lake Bathymetry and BATHTUB Model Lake Morphometry Inputs

C2 BATHTUB Model Tributary Loading Inputs

C3 BATHTUB Model Internal and Atmospheric Loading Inputs

C4 BATHTUB Model Nutrient Mass Balance

C5 BATHTUB Model Calibration

C6 BATHTUB Model Load Response Curves

C7 BATHTUB Model Inputs and Outputs

The BATHTUB model Version 6.20 developed by William Walker, Jr., Ph. D. for the Environmental Laboratory of the U.S. Army Corp of Engineers Waterways Experimental Station (1985 and 1996) was used for all in-lake response model simulations. The model estimates in-lake water quality conditions based on the lake's morphological characteristics as well as the lake's water and nutrient-mass balance. The general modeling approach is outlined below and described in more detail in the following sections.

- Characterize the morphology of each lake as inputs into the BATHTUB model.
- Estimate each lake's nutrient sources as BATHTUB model inputs:
  - Watershed loading
  - Internal loading
  - Atmospheric loading
- Calibrate the BATHTUB model to observed water quality conditions.
- Perform in-lake response model simulations to determine the loading capacity necessary to meet the MPCA water quality standards.

The years used for developing the BATHTUB model were based on conditions from 2009 through 2015. The average local precipitation for 2009 through 2015 (Table C-1) was similar to the long-term average of approximately 28 inches per year. This time period seemed to be representative of the variation in annual precipitation conditions for the area.

Table C-1: The annual precipitation for the modeling time period.

Year	Precipitation	
	cm	in
2009	65.1	25.6
2010	74.0	29.1
2011	57.3	22.6
2012	77.8	30.1
2013	79.0	31.1
2014	85.4	33.6
2015	83.5	32.9
Average	74.6	29.3

2.0 BATHTUB Model Lake Morphometry and Water Quality Inputs

Each impaired lake was modeled as one segment or basin within the BATHTUB model. The morphological input parameters included the lake surface area, mean depth, mixed layer depth, length, and mean hypolimnetic depth. The mean hypolimnetic depth corresponds to late spring or early summer after the onset of stratification. The BATHTUB model morphological characteristics are based on bathymetry measurements collected during aquatic vegetation surveys (Appendix D). Bathymetric maps were developed in ArcMap using Kriging analysis. The morphological characteristics for each lake were then derived from spatial analysis of the bathymetric data (Appendix C1).

The observed in-lake water quality conditions are also input into the BATHTUB model. The available data collected from 2009 through 2015 was used to describe the in-lake water quality conditions. Monitoring data were collected by Three Rivers Park District and /or the Metropolitan Council's Citizens Assisted Monitoring Program. The in-lake water quality conditions were expressed in the model as an average of the annual growing season average calculated for each lake. The years used to calculate the in-lake water quality conditions are represented in Table C-2. The BATHTUB model is ultimately calibrated to the observed in-lake water quality conditions, which is further described in Section 6.0 of Appendix C.

Table C-2: Water quality data used to calculate the average in-lake conditions for the BATHTUB model.

Lakes	Water Quality Data						
	2009	2010	2011	2012	2013	2014	2015
Peter							
Spurzem							
Half Moon							
Ardmore							
Whaletail South							
Whaletail North							

3.0 Watershed Loading

Watershed loads for each lake were estimated using the Generalized Watershed Loading Functions – E plugin (GWLF-E) model (see Appendix B). The GWLF-E model was calibrated to watershed monitoring data. The details for the development and calibration of the GWLF-E model were further described in Appendix B of the report. The calibrated GWLF-E model was run for each year from 2009 through 2015, and the average tributary loads from these simulations, expressed as runoff flow volume and TP concentrations (Appendix C2), were used as inputs to the BATHTUB models.

4.0 Internal Loading

There were two primary sources of internal loading that were considered for each impaired lake within the Pioneer and Sarah Creek TMDL: sediment release and senescence of CLPW. Independent estimates of these internal loadings were aggregated and compared to the internal loading estimates used as part of the phosphorus calibration in the BATHTUB model (see section 6.0, BATHTUB Model Calibration, for more details). The process of independently estimating the internal load for each source is described below.

Sediment Release of phosphorus

The phosphorus release from sediments was considered a primary source of internal loading for the impaired lakes within the TMDL. Sediment release of phosphorus primarily occurs during the summer after the onset of lake stratification, and can occur in areas of the lake that have aerobic and anaerobic conditions. The area of the lake that has anaerobic conditions generally yield higher sediment phosphorus release rates, but the sediment phosphorus release from areas of the lake with aerobic conditions can also contribute significantly to internal load. Wind mixing and changes in stratification can transport these nutrients to the surface.

Rates of phosphorus sediment release were estimated from laboratory incubation experiments with in-lake sediment cores. Three Rivers Park District collected sediment cores at the deepest location from each of the six impaired lakes. Sediment cores were collected from one location for three of the lakes (Half Moon, Ardmore, and Whaletail South) and from two locations for the remaining three lakes (Peter, Spurzem, and Whaletail North). Sediment release rates for aerobic and anaerobic conditions (Table C-3) were measured by William James from the University of Wisconsin-Stout in Menomonie, Wisconsin (James 2014, James 2015, and James 2016). To estimate internal loading, the respective 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/year. This estimate represents the internal load for anaerobic and aerobic areas of each lake during the time period of stratification.

Table C-3: Phosphorus release rates from sediment cores under anaerobic and aerobic conditions.

Lake	Portion of Lake	Phosphorus Release Rates (mg/m²-day)	
		Anaerobic	Aerobic
Peter	North	5.26	1.44
	South	6.37	1.25
Spurzem	West	19.1	4.22
	East	6	1.37
Half Moon	Main	9.5	5.68
Ardmore	Main	21.3	4.37
Whaletail South	Main	5	1
Whaletail North	West	0.29	0.37
	East	0.23	0.03

The temperature and dissolve oxygen profiles collected bi-weekly during routine water quality monitoring from 2009 through 2015 were used to determine the depth and time period of stratification. The anaerobic depth was defined as having a DO concentration of less than 2 mg/L. The anaerobic depth varied from lake to lake, but was consistent for each lake from 2009 through 2015. Those areas of the lake that were shallower than the anaerobic depth were considered having aerobic conditions. The surface areas for anaerobic and aerobic conditions were derived from geo-spatial analysis of lake bathymetric data. The anoxic interval was based on the annual changes in lake stratification for each lake. In cases where data sufficed to identify variations in annual stratification, the annual time period of anoxia was used to establish the minimum and maximum range for estimates of internal loading (Table C-4). The approach used for estimating internal load in the TMDL was similar to the Nürnberg's method for anoxic internal load (Nürnberg 2003, 2005, and 2009).

Table C-4: The minimum and maximum number of anoxic days for each lake based on bi-weekly temperature and dissolve oxygen profiles collected from 2009 through 2015.

Lake	Anoxia Time Internal			
	Minimum		Maximum	
	Year	Days	Year	Days
Peter	2013	168	2015	168
Spurzem	2009	128	2012	161
Half Moon	2011	130	2012	181
Ardmore	2013	156	2015	189
Whaletail South	2011	112	2010	179
Whaletail North	2009	89	2012	148

Senescence of curly-leaf pondweed

CLPW is a significant factor inhibiting recreational use as well as potentially degrading lake water quality. CLPW is an exotic species that competes with other native plant species because of its unique life cycle. The plant germinates from turions (seed structures) in early fall when most native plants have died back, and it 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. CLPW senescence provides an internal nutrient source for several impaired lakes of the Pioneer and Sarah Creek Watershed. 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 clarity earlier in the season.

To estimate the amount of internal loading from CLPW senescence, Three Rivers Park District performed phosphorus analysis on CLPW biomass samples collected from a 1-m^2 quadrant survey that was performed on a lake (Medicine Lake) with nuisance growth conditions (Vlach and Barten 2004). The CLPW laboratory analysis provided an estimate of dry weight biomass and TP concentration for high and low density conditions. This estimate was converted to the average pounds of phosphorus/acre (Table C-5).

Table C-5: Total Phosphorus Loading estimates from curly-leaf pondweed (Vlach and Barten 2004).

Curly-Leaf Pondweed Density Category	Biomass		TP Areal Density
	Areal Density (g dry weight/m^2)	TP Concentration (mg/g dry weight)	(lbs/acre)
Low Density	38.6	4.91	1.65
High Density	83.4	4.8	3.19

The acreage of CLPW for each lake was based on aquatic vegetation point intercept survey data (Appendix D). Those areas that had a rake density of one or two were considered having a low density of CLPW, and those areas with a rake density of 3 to 5 were considered having a high density of CLPW. Polygons were constructed for those areas with low and high CLPW rake densities. It was assumed that those areas with low density of CLPW would represent minimal internal load, and those areas with high density of CLPW would represent maximum internal load. The total estimated internal load attributed to CLPW was determined by multiplying the acreage for low and high density with the respective unit area load (lb/acre).

4.1 Description of Internal Load Estimation Approach by Lake

4.1.1 Peter Lake Internal Load

The estimated internal loading for Peter Lake from sediment P release is 294 lb/yr (Table C-6). This estimate is based on the average of the lake's North and South sediment core results since the core-to-core variation was small (Table C-3). Temperature and dissolve oxygen profiles were monitored in Peter Lake for only two years (2013 and 2015), and the anoxic time period was the same for both years (Table C-4). Consequently, internal loading was estimated without a minimum–maximum range. CLPW was found only in low abundance in Peter Lake (Appendix D) and was not considered a significant contributor to the total internal load. The internal load needed to calibrate Peter Lake's BATHTUB model (292 lb/yr; see Appendix C3) was very similar to the independent internal load estimate described in this section.

Table C-6: Peter Lake estimated annual internal load from phosphorus sediment release rates.

Conditions	Internal Load (lbs/yr)
Anaerobic	235.8
Aerobic	58.4
Total	294.2

4.1.2 Spurzem Lake Internal Load

The estimated internal load attributed to sediment P release ranged from a minimum of 717 pounds to a maximum of 901 pounds (Table C-7). The annual variation in anoxia from 2009 through 2015 was used to establish the minimum and maximum range. The minimum number of days with anoxia occurred in 2009 (128 days; see Table C-4), and the maximum number of days with anoxia occurred in 2012 (161 days; see Table C-4). The phosphorus sediment release rates were significantly different between the west and east basins of Spurzem Lake (Table C-3). Consequently, the P sediment release internal load for Spurzem Lake was calculated separately for the west and east basins, and the sum of the internal load for the two basins represented the total P release internal load for the lake (Table C-7).

Table C-7: Spurzem Lake minimum and maximum internal load estimate from sediment phosphorus release.

	Minimum Estimate of Internal Load			Maximum Estimate of Internal Load		
	Internal Load (lbs)		Total Load	Internal Load (lbs)		Total Load
Conditions	West	East	(lbs/yr)	West	East	(lbs/yr)
Anaerobic	489.4	78.8	568.2	615.5	99.1	714.6
Aerobic	115.2	33.1	148.3	144.9	41.7	186.6
Total	604.6	111.9	716.5	760.4	140.8	901.2

Aquatic vegetation surveys indicated that CLPW senescence has the potential to be a significant influence on internal load for Spurzem Lake (Appendix D). Aquatic vegetation surveys were conducted from 2009 through 2015. The amount of CLPW acreage varied for each year and was taken into consideration when estimating the internal load due to senescence. The internal load attributed to CLPW senescence ranged from 28.8 to 94.5 pounds of phosphorus per year (Table C-8).

Table C-8: Spurzem Lake annual internal load estimate attributed to curly-leaf pondweed senescence.

Spurzem Lake Curly-Leaf Pondweed Phosphorus Loading							
	CLP Area by Density (acres)		Areal Rate (lbs/acre)		CLP Load (lbs/yr)		Total Load
Year	Low	High	Low	High	Low	High	(lbs/yr)
2009	17.44	0.00	1.65	3.19	28.78	0.00	28.78
2013	27.72	15.27	1.65	3.19	45.74	48.71	94.45
2014	15.14	13.14	1.65	3.19	24.98	41.92	66.90
2015	15.39	15.12	1.65	3.19	25.39	48.23	73.63
Average	18.92	10.88	1.65	3.19	31.22	34.72	65.94

The total internal phosphorus load from sediment release and CLPW was estimated to range between 745.3 and 995.6 pounds per year. The internal load that was required to calibrate to the in-lake TP concentration for the BATHTUB model was approximately 809.1 pounds (Appendix C3). This internal load estimate was within the range of the independent estimate of internal load from sediment release and CLPW senescence.

4.1.3 Half Moon Lake Internal Load

The phosphorus sediment release rates from cores collected from Half Moon Lake were 9.5 mg/m^2-day for anaerobic conditions, and phosphorus sediment release rates were 5.7 mg/m^2-day for aerobic conditions (Table C-3). The annual variation in anoxia from 2009 through 2015 was used to establish the minimum and maximum range. The minimum number of days with anoxia occurred in 2011 (130 days;

see Table C-4), and the maximum number of days with anoxia occurred in 2012 (181 days; see Table C-4). The estimated internal load attributed to sediment P release ranged from a minimum of 311 pounds to a maximum of 433 pounds (Table C-9).

Table C-9: Half Moon Lake minimum and maximum internal load estimate from sediment phosphorus release.

Conditions	Internal Load Estimate (lbs/yr)	
	Minimum	Maximum
Anaerobic	263.1	366.3
Aerobic	47.7	66.4
Total	310.8	432.7

Aquatic vegetation surveys (2009, 2013, 2014, and 2015) indicated that CLPW was consistently present in Half Moon Lake (Appendix D). The amount of CLPW acreage varied for each year and was taken into consideration when estimating the internal load due to senescence. The internal load attributed to CLPW senescence ranged from 3.9 to 22.4 pounds of phosphorus per year (Table C-10).

Table C-10: Half Moon Lake annual internal load estimate attributed to curly-leaf pondweed senescence.

Half Moon Lake Curly-Leaf Pondweed Phosphorus Loading							
Year	CLP Area by Density (acres)		Areal Rate (lbs/acre)		CLP Load (lbs/yr)		Total Load (lbs/yr)
	Low	High	Low	High	Low	High	
2009	2.35	0.00	1.65	3.19	3.88	0.00	3.88
2013	5.27	0.00	1.65	3.19	8.70	0.00	8.70
2014	2.06	1.87	1.65	3.19	3.40	5.97	9.36
2015	1.39	6.30	1.65	3.19	2.29	20.10	22.39
Average	2.77	2.04	1.65	3.19	4.57	6.52	11.08

The total internal phosphorus load from sediment release and CLPW was estimated to range from 314.6 and 455.0 pounds per year. The internal load that was required to calibrate the Half Moon Lake BATHTUB model was approximately 373.7 pounds (Appendix C3). This internal load estimate was within the range of the independent estimates of internal load from sediment release and CLPW senescence.

4.1.4 Ardmore Lake Internal Loading

Ardmore Lake had the highest phosphorus sediment release rates for anaerobic conditions (21.3 mg/m^2-day) in comparison to all of the other impaired lakes for the TMDL. The aerobic phosphorus sediment release rates (4.37 mg/m^2-day) were also considered significant contribution to the internal load. The minimum and maximum range for estimating internal loading was based on the anoxic period from 2013 through 2015. The minimum number of days with anoxia occurred in 2013 (156 days; see Table C-4), and the maximum number of days with anoxia occurred in 2015 (189 days; see Table C-4). The estimated internal load attributed to sediment release ranged from a minimum of 259 pounds to a maximum of 314 pounds of phosphorus (Table C-11). Based on aquatic vegetation surveys, CLPW was not found in Ardmore Lake and was not considered a significant component to the total internal load (Appendix D). The internal load required to calibrate to the Ardmore Lake BATHTUB model was 265 pounds (Appendix C3), which was within the range of the independent estimate of internal loading (Table C-11).

Table C-11: Ardmore Lake minimum and maximum internal load estimate from sediment phosphorus release.

Conditions	Internal Load Estimate (lbs/yr)	
	Minimum	Maximum
Anaerobic	222.3	269.3
Aerobic	36.7	44.5
Total	259.0	313.8

4.1.5 South Whaletail Lake Internal Loading

The south portion of Whaletail Lake had low phosphorus sediment release rates for anaerobic (5.0 mg/m^2-day) and aerobic (1.0 mg/m^2-day) conditions (Table C-3). The minimum and maximum range for estimating internal loading was based on the anoxic period from 2009 through 2015. The minimum number of days with anoxia occurred in 2011 (112; see Table C-4), and the maximum number of days with anoxia occurred in 2010 (179 days; see Table C-4). The estimated internal load attributed to sediment release ranged from a minimum of 412 pounds to a maximum of 658 pounds of phosphorus (Table C-12). An aquatic vegetation survey indicated that there was no CLPW observed in South Whaletail Lake in 2013 and was not considered part of the total internal load (Appendix D). The internal load required to calibrate to the South Whaletail Lake BATHTUB model was 423.5 pounds (Appendix C3). This estimate was within the range for the independent estimate of internal loading (Table C-12).

Table C-12: South Whaletail Lake minimum and maximum internal load estimate from sediment phosphorus release.

Conditions	Internal Load (lbs/yr)	
	Minimum	Maximum
Anaerobic	319.7	510.9
Aerobic	92.1	147.1
Total	411.8	658.0

4.1.6 North Whaletail Lake Internal Loading

The phosphorus release rates for North Whaletail Lake were the lowest for anaerobic (0.26 mg/m2-day) and aerobic (0.20 mg/m2-day) conditions in comparison to all of the impaired lakes in the TMDL (Table C-3). The estimated internal load was based on an average of the lake's west and east sediment core results since core-to-core variation was small. There was considerable annual variation in the anoxic period from 2009 through 2015 to establish a minimum and maximum range for estimates of internal loading (Table C-4). The estimated internal load attributed to sediment release ranged from a minimum of 63 pounds to a maximum of 104 pounds of phosphorus (Table C-13).

Table C-13: North Whaletail Lake minimum and maximum internal load estimate from sediment phosphorus release.

Conditions	Internal Load (lbs/yr)	
	Minimum	Maximum
Anaerobic	17.5	29.1
Aerobic	45.3	75.3
Total	62.8	104.4

An aquatic vegetation survey performed in 2013 suggested that CLPW senescence has the potential to be a significant influence on internal load for North Whaletail Lake (Appendix D). The amount of CLPW acreage was taken into consideration when estimating the internal load due to senescence. The internal load attributed to CLPW senescence was 214 pounds of phosphorus per year (Table C-14).

Table C-14: North Whaletail Lake annual internal load estimate attributed to curly-leaf pondweed senescence.

Whaletail North Curly-Leaf Pondweed Loading							
	CLP Area by Density (acres)		Areal Rate (lbs/acre)		CLP Load (lbs/yr)		Total Load
Year	Low	High	Low	High	Low	High	(lbs/yr)
2013	74.05	28.62	1.65	3.19	122.18	91.30	213.48

The total internal phosphorus load from sediment release and CLPW was estimated to range from 276 and 317 pounds per year. The internal load required to calibrate the North Whaletail BATHTUB model was 291 pounds (Appendix C3), which was within the range of the independent estimate of internal load.

5.0 Atmospheric Loading

The atmospheric depositional loading was estimated within the BATHTUB model. The default BATHTUB value for atmospheric deposition was 0.27 lbs/acre-year (30 mg/m^2-yr). The BATHTUB default value was similar to other atmospheric TP loading rates reported in a technical memorandum to the MPCA (2007). The total surface area of the lake is multiplied by the atmospheric depositional load to determine the load delivered to the lake. The atmospheric depositional loading was included in the overall lake nutrient balance and is identified in the BATHTUB model as precipitation loading. The atmospheric loading was documented in the Appendix C3.

6.0 BATHTUB Model Calibration

The BATHTUB model is calibrated to the observed in-lake water quality conditions. BATHTUB is an empirical model that estimates lake and reservoir eutrophication using several different algorithms. The algorithms selected for the different in-lake parameters were based on the model that predicted nearest to the observed in-lake conditions. Although the algorithms used for estimating in-lake water quality conditions varied for each lake, the calibration approach and methodology was consistent among all of the lakes. All of the BATHTUB model simulations were performed for years that were representative of average annual precipitation conditions. The predicted and observed in-lake water quality conditions were documented within the Appendix C5.

The BATHTUB model was initially calibrated to the in-lake TP concentration. There are essentially eight different TP algorithms available for selection within the model. The algorithm selected was based on the model that provided the best estimate of in-lake TP concentration that was similar to observed conditions. All of the models calculate in-lake phosphorus concentration based on the lake morphological characteristics and the different sources of phosphorus loading (watershed, internal, and atmospheric). An average rate of internal loading is implicit for each model since each algorithm is based on empirical data from lakes that have natural internal loading. However, the impaired lakes within the Pioneer and Sarah Creek Watershed have excessive nutrients with rates of internal loading that are higher than the implicit background levels. Consequently, an additional internal loading component was necessary to calibrate to the in-lake phosphorus concentration. The internal loading rate was adjusted (in the segment portion of the BATHTUB model) to the observed in-lake TP concentration. The additional internal load required to calibrate to the in-lake phosphorus concentration was compared to the manual estimated internal load from sediment release and CLPW senescence. The internal load required to calibrate the BATHTUB model for each lake seemed reasonable when comparing to the manual estimates of internal load (Appendix C3). The estimated internal load to calibrate the BATHTUB model was used in the overall lake nutrient balance (Appendix C4).

The BATHTUB model was calibrated to Chl-*a* and secchi depth transparency after the overall nutrient balance was established through the calibration process of TP (Appendix C4). The Chl-*a* and secchi depth transparency are considered water clarity response variables that are influenced by the overall phosphorus balance in each lake. The procedure for calibration of the water clarity response variables simply provided a more robust model that simulated the existing impaired water quality conditions. The response variables were not used to simulate the water clarity changes in response to achieving the assimilative phosphorus capacity of each lake to meet the MPCA standards. There are six different Chl-*a* algorithms available for selection within the model, and there are four different secchi depth transparency algorithms available for selection within the model. The BATHTUB model was initially calibrated to Chl-*a* because of the influence it has on water clarity. The Chl-*a* and secchi depth algorithms were selected based on the model that predicted nearest to the observed in-lake condition (Appendix C5). The Chl-*a* and secchi depth model coefficients were adjusted incrementally to further calibrate to the observed in-lake water quality conditions.

7.0 Loading Capacity Determination

The BATHTUB model load-response function was used to evaluate the in-lake water quality response to varying phosphorus loads from the watershed. The load-response analysis was conducted to determine the watershed load reductions necessary to meet the in-lake MPCA standard. The impaired lakes within the Pioneer and Sarah Creek Watershed are located within the NCHF Ecoregion. The MPCA water quality standard for the eco-region is dependent upon whether the lake is classified as a shallow or deep lake. The load-response function was performed on each lake to meet the in-lake TP standard (Appendix C6). It was assumed that the water clarity response variable (Chl-*a* and secchi depth transparency) standards would be achieved if the in-lake TP standard was met. The load-response function incrementally adjusts the inflow phosphorus concentrations for all of the tributaries and estimates the change in the in-lake water quality conditions.

The impaired lakes within the Pioneer and Sarah Creek Watershed are extremely eutrophic due to the past excessive amounts of nutrient loading. The internal load seems to have a significant influence on water quality conditions and has accounted for a significant portion of the nutrient balance for all of the impaired lakes (Appendix C4). The majority of the load response simulations indicated that the long-term in-lake phosphorus standard was not attainable with the internal loading components in the model. The long-term in-lake water quality standards most likely would be attainable if the excess internal loading were controlled or managed. It was assumed that the internal loading would have to be controlled in order for the lakes to meet water quality standards. To determine the loading capacity necessary to achieve the long-term water quality standards, the additional internal load used for calibration of the BATHTUB model was subsequently removed from the model for majority of the lakes.

There was only one lake (South Whaletail Lake) that was able to achieve the phosphorus standard while performing the load response function with internal loading remaining in the model. This particular lake was currently close to already meeting the phosphorus standard.

The loading capacity is defined as the maximum load that a specific lake can receive and still meet water quality standards. The BATHTUB model provides a load response curve that reflected the relationship between watershed loading and in-lake water quality. The model does not take into account the atmospheric load and any additional internal load remaining in the model (i.e. South Whaletail Lake) at the time the load response curve was developed. Consequently, the atmospheric load and any internal load that remained in the model were added to the watershed load to determine the total loading capacity for each lake. The load response simulations to determine individual lake loading capacity was further identified within the Appendix C6. The total loading capacity for each lake was then used for the development of the TMDL equation.

8.0 Literature Cited

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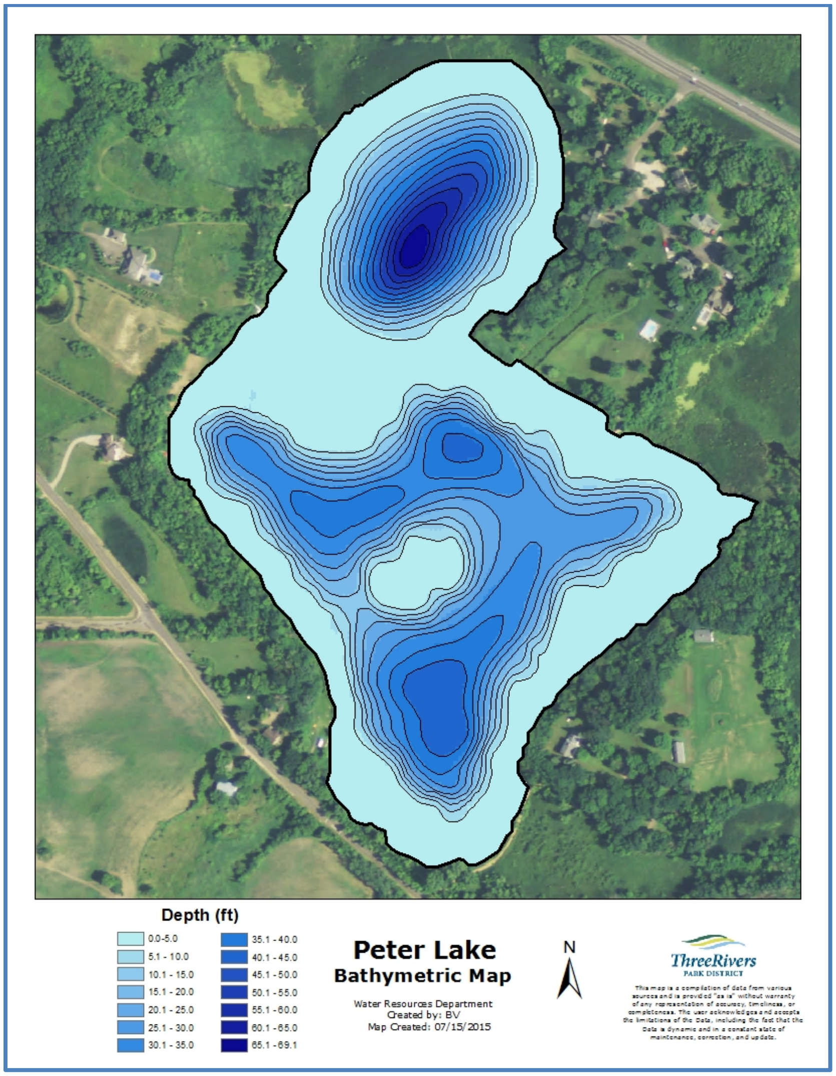
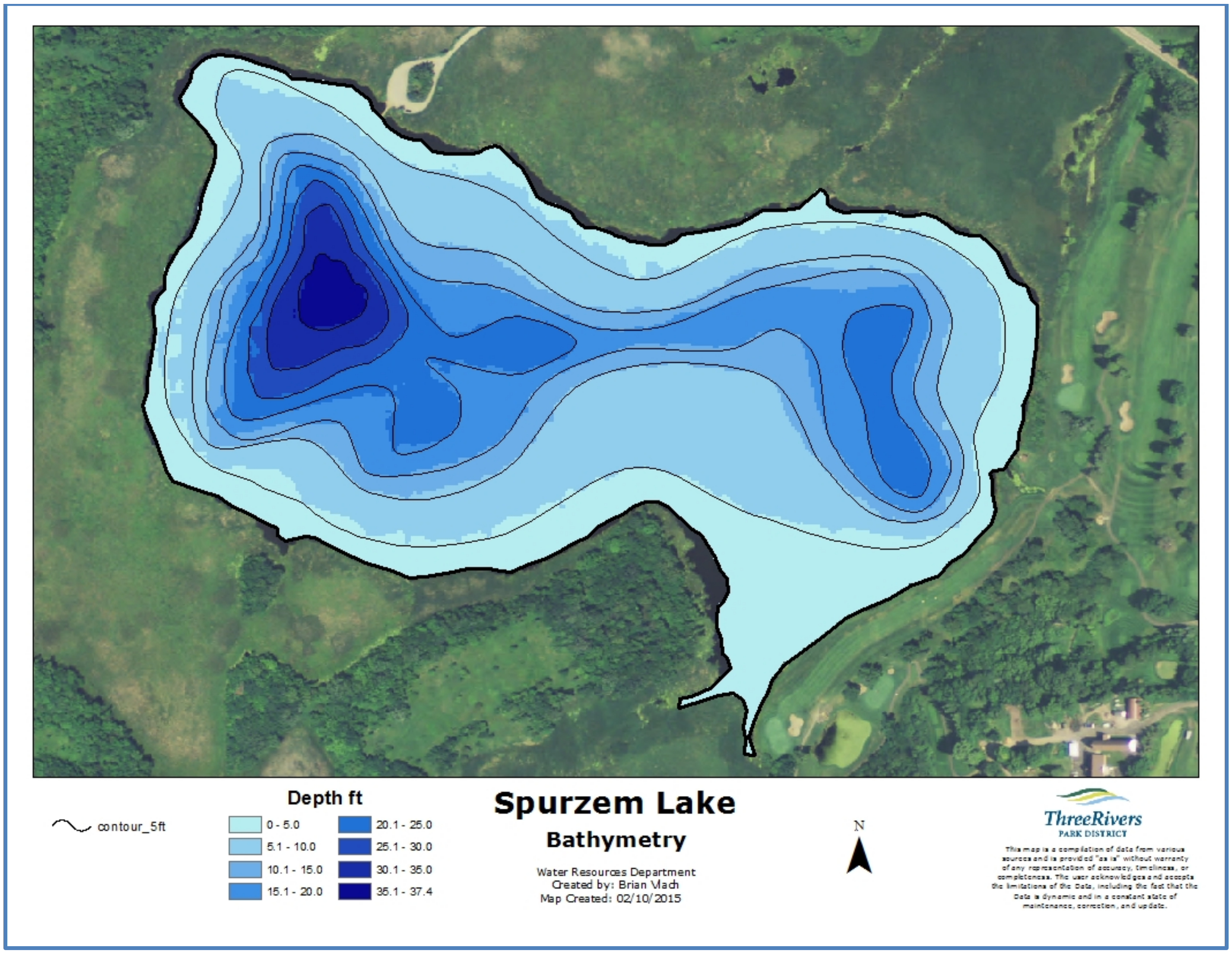
Appendix C1
Lake Bathymetry and BATHTUB Model Morphometry Inputs

Peter Lake



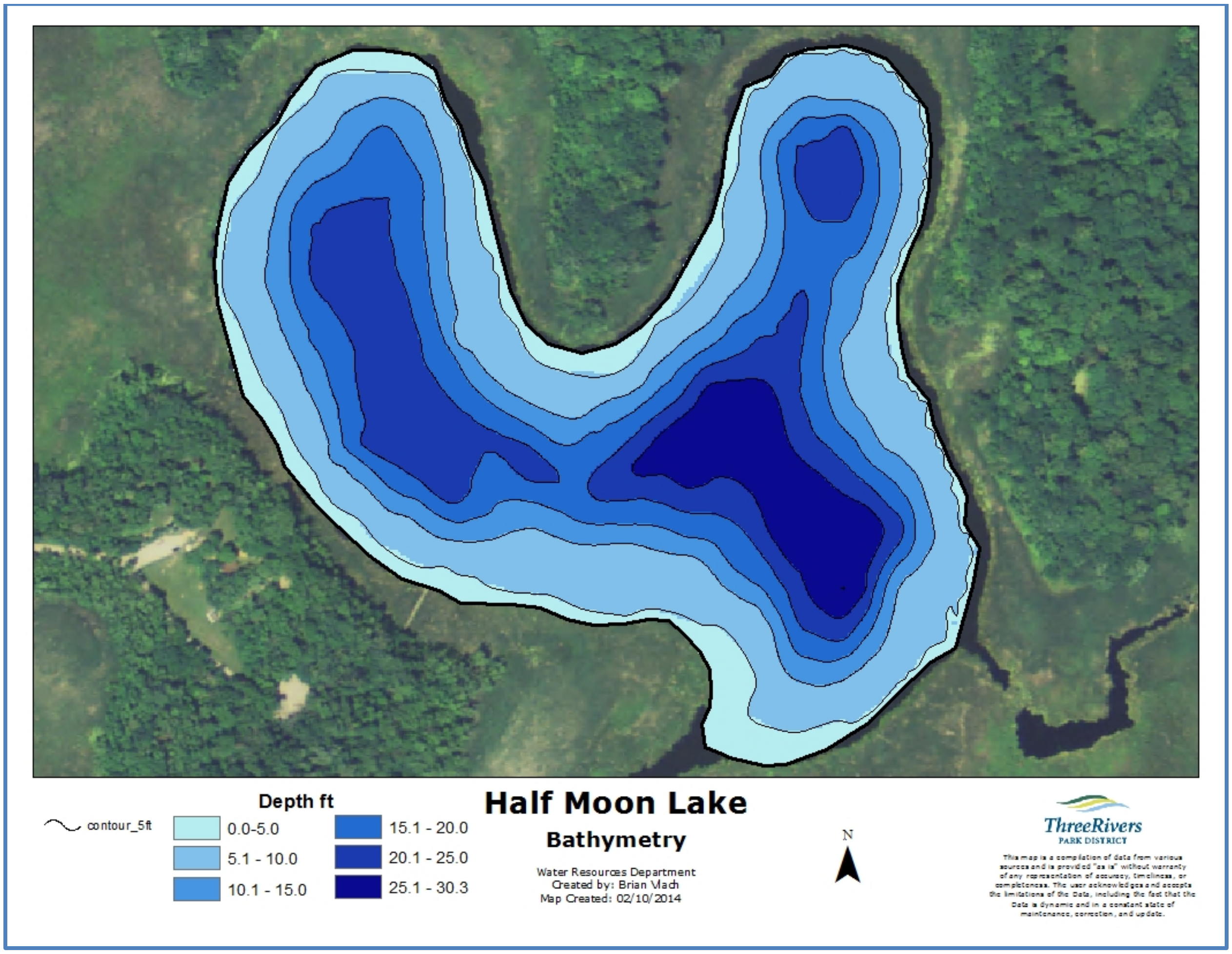
Peter Lake	
DNR ID	27-0147-00
Lake Area	0.23 km^2 (55.8 Acres)
% Littoral (≤ 15 ft in depth)	58%
Mean Depth	4.59 m
Maximum Depth	21.1 m
Mixed Layer Depth	4.3 m
Length	0.79 km
Classification	Deep Lake

Spurzem Lake



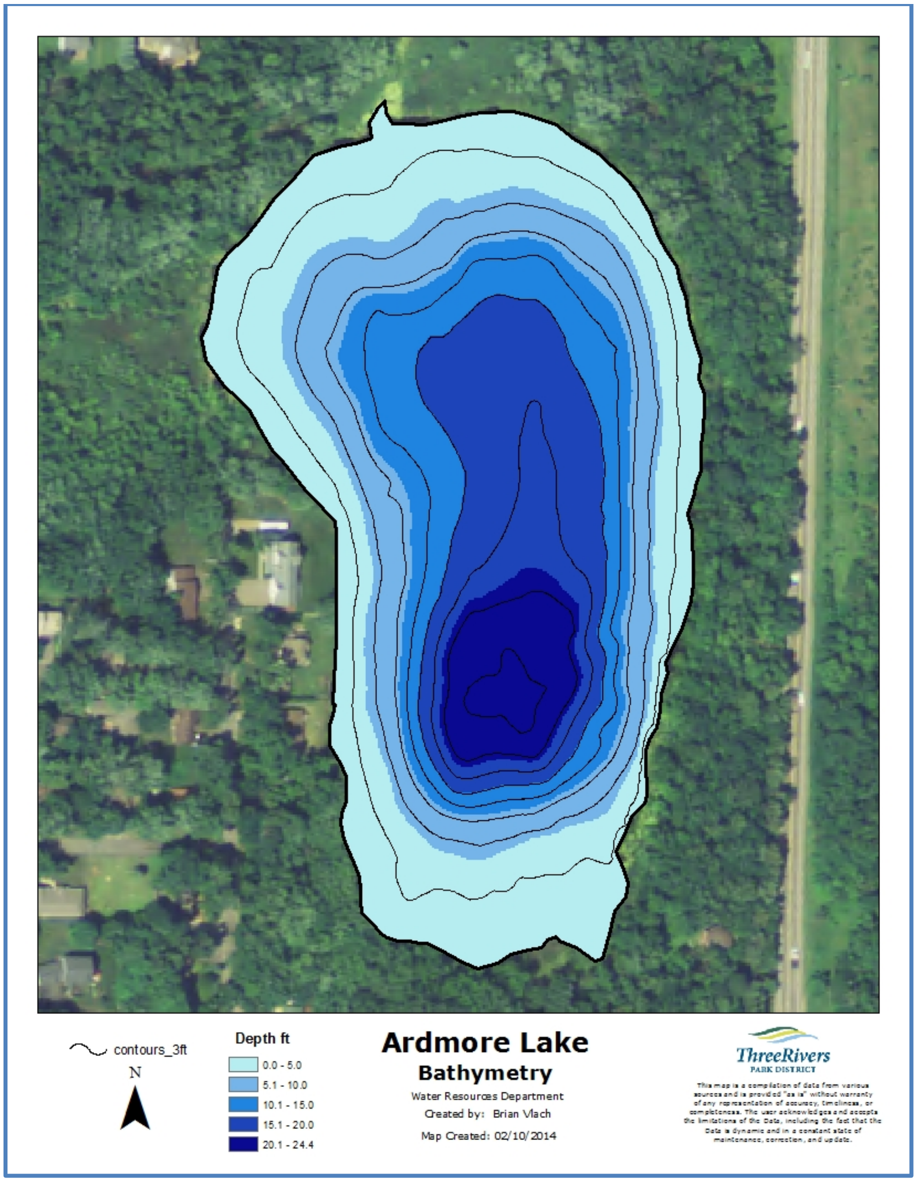
Spurzem Lake	
DNR ID	27-0149-00
Lake Area	0.32 km^2 (78.6 Acres)
% Littoral (≤ 15 ft in depth)	70%
Mean Depth	3.38 m
Maximum Depth	11.4 m
Mixed Layer Depth	2.71 m
Length	0.86 km
Classification	Deep

Half Moon Lake



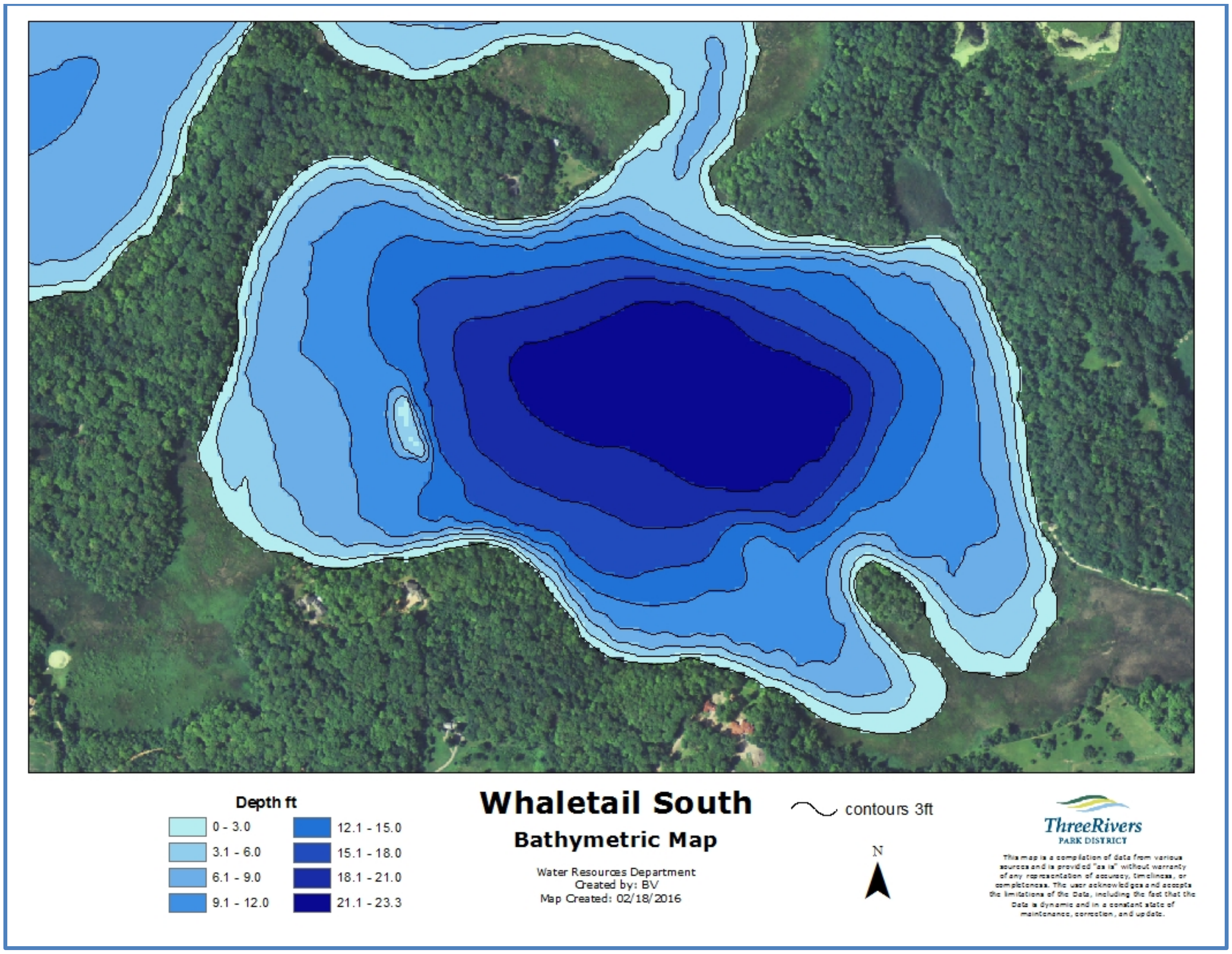
Half Moon	
DNR ID	27-0152-00
Lake Area	0.13 km^2 (31.1 Acres)
% Littoral (≤ 15 ft in depth)	59%
Mean Depth	4.08 m
Maximum Depth	9.24 m
Mixed Layer Depth	2.65 m
Length	0.53 m
Classification	Deep Lake

Ardmore Lake



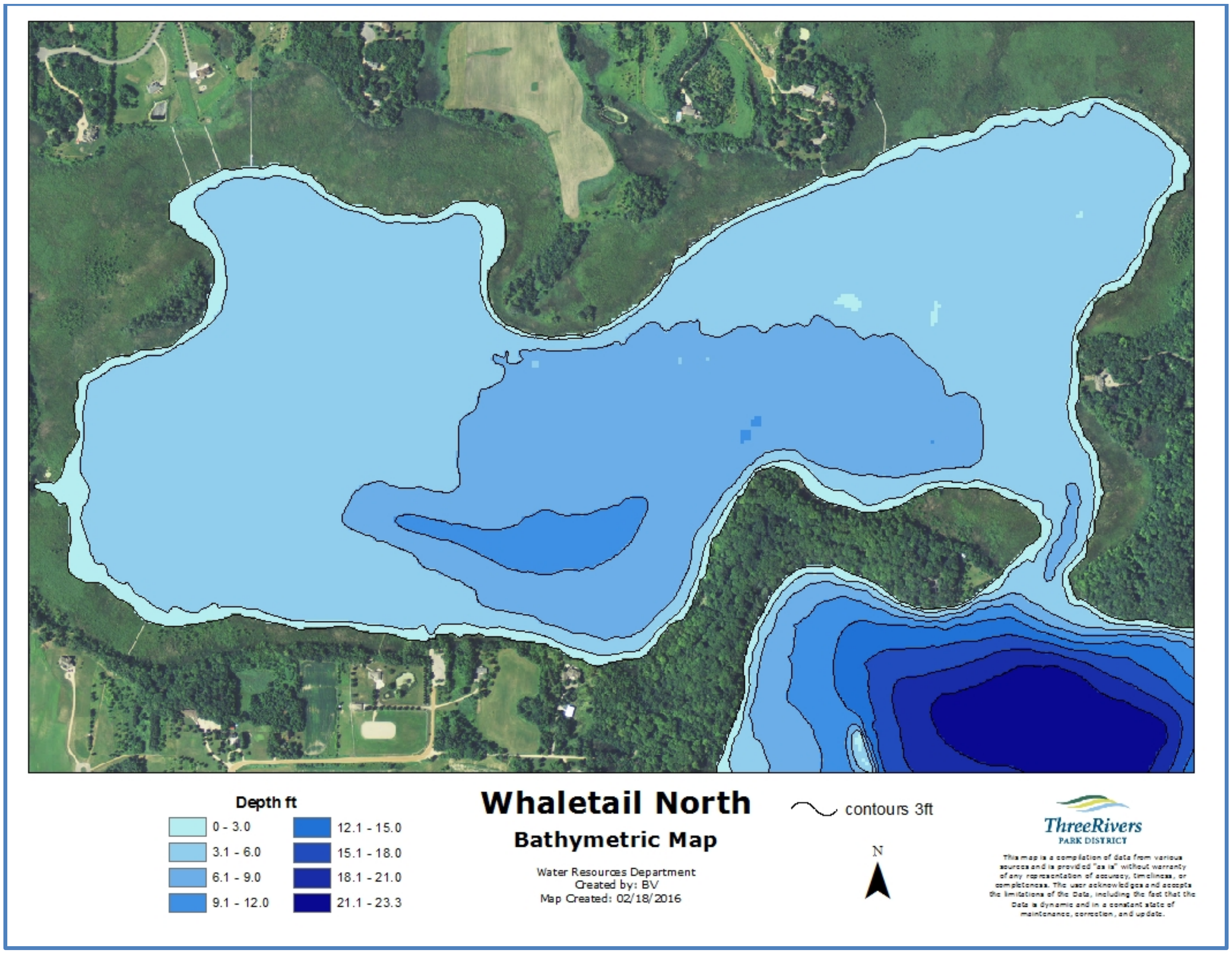
Ardmore	
DNR ID	27-0153-00
Lake Area	0.055 km^2 (13.5 Acres)
% Littoral (≤ 15 ft in depth)	75%
Mean Depth	2.87 m
Maximum Depth	7.44 m
Mixed Layer Depth	2.38 m
Length	0.36 m
Classification	Deep Lake

Whaletail South Lake



Whaletail South	
DNR ID	27-0184-02
Lake Area	0.63 km^2 (156.1 Acres)
% Littoral (≤ 15 ft in depth)	66%
Mean Depth	3.7 m
Maximum Depth	7.10 m
Mixed Layer Depth	3.6 m
Length	1.1 km
Classification	Deep Lake

Whaletail North Lake



Whaletail North	
DNR ID	27-0184-01
Lake Area	1.5 km^2 (369.9 Acres)
% Littoral (≤ 15 ft in depth)	100%
Mean Depth	1.57 m
Maximum Depth	3.14 m
Mixed Layer Depth	1.5 m
Length	1.07 km
Classification	Shallow Lake
Condition / State	Algal/Turbid Dominated

Appendix C2
BATHTUB Model Tributary Loading Inputs

Peter Lake Bathtub Model Tributary Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Peter Lake Watershed	1.21	0.275	273.4

Spurzem Lake Bathtub Model Tributary Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Spurzem Direct Watershed	10.66	1.886	320.2
Upstream Lake (Peter)	1.44	0.278	43.8

Half Moon Lake Bathtub Model Tributary Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Half Moon Direct Watershed	1.5	0.496	511.7
Upstream Lake (Spurzem)	12.42	2.168	161.3

Ardmore Lake Bathtub Model Tributary Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Ardmore Direct Watershed	2.09	0.331	368.7

Whaletail South Lake Bathtub Model Tributary Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Whaletail South Direct Watershed	2.71	0.977	29.5

Whaletail North Lake Bathtub Model Tributary Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Whaletail North Direct Watershed	3.72	1.234	111.4
Upstream Lake (Whaletail South)	3.34	0.984	49.9

Appendix C3
Phosphorus Internal and Atmospheric Loading for BATHTUB Models

The annual internal load input into the BATHTUB model compared to the manual estimated minimum and maximum range of internal load from sediment release and curly-leaf pondweed senescence.

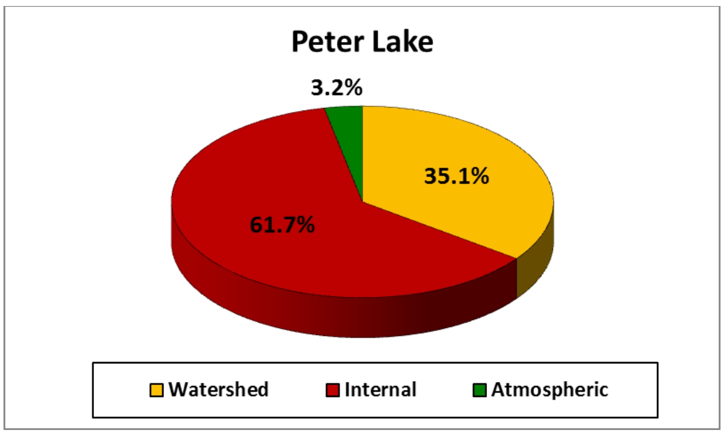
Lake	Phosphorus Internal Load (lbs/year)				Phosphorus Internal Load (kg/year)			
	Estimated			Bathtub	Estimated			Bathtub
	Minimum	Maximum	Average	Model	Minimum	Maximum	Average	Model
Peter Lake			294.2	291.7			133.4	132.3
Spurzem Lake	745.3	995.6	888.8	809.1	338.1	451.6	403.2	367
Half Moon Lake	314.6	455	381.6	373.7	142.7	206.4	173.1	169.5
Ardmore Lake	259	313.8	282.2	265	117.5	142.3	128.0	120.2
Whaletail South	411.7	658.1	573.5	423.5	186.7	298.5	260.1	192.1
Whaletail North	275.8	317.4	298.4	291	125.1	144.0	135.4	132

The annual atmospheric load input into the BATHTUB model.

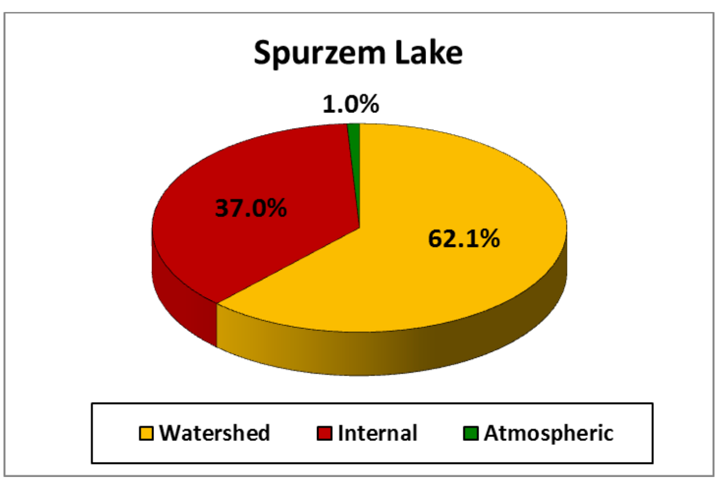
Lake	Atmospheric Load	
	lbs/year	kg/year
Peter Lake	15.2	6.9
Spurzem Lake	21.2	9.6
Half Moon Lake	8.6	3.9
Ardmore Lake	3.5	1.6
Whaletail South	41.7	18.9
Whaletail North	99.2	45.0

Appendix C4
BATHTUB Model Nutrient Mass Balance

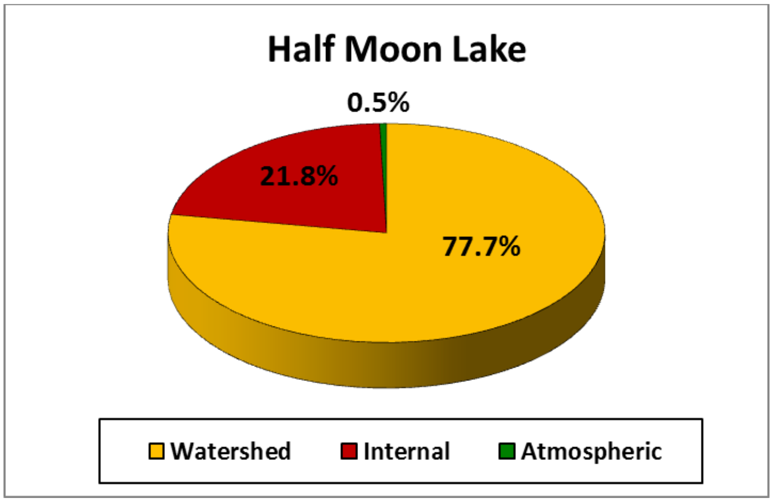
Peter Lake			
	Annual Total Phosphorus Load		
Load	kg/yr	lbs/yr	%
Watershed	75.2	165.8	35.1%
Internal	132.3	291.7	61.7%
Atmospheric	6.9	15.2	3.2%
Total	214.4	472.7	100.0



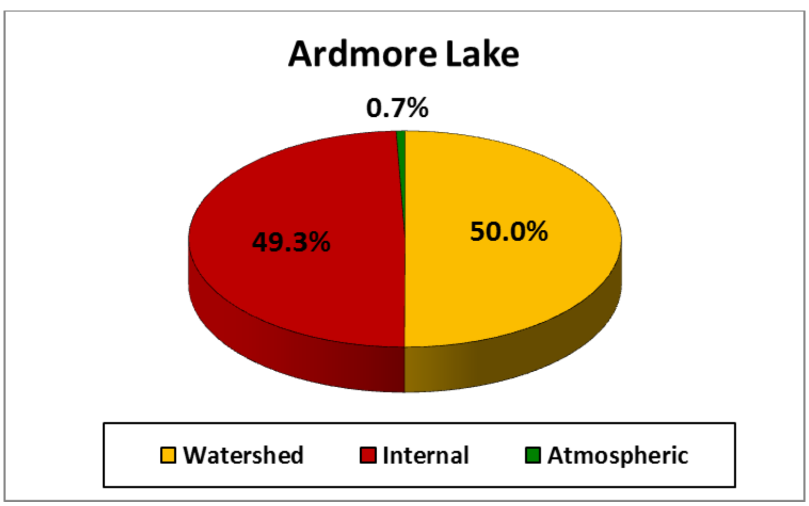
Spurzem Lake			
	Annual Total Phosphorus Load		
Load	kg/yr	lbs/yr	%
Watershed	616.2	1358.5	62.1%
Internal	367.0	809.1	37.0%
Atmospheric	9.6	21.2	1.0%
Total	992.8	2188.7	100.0



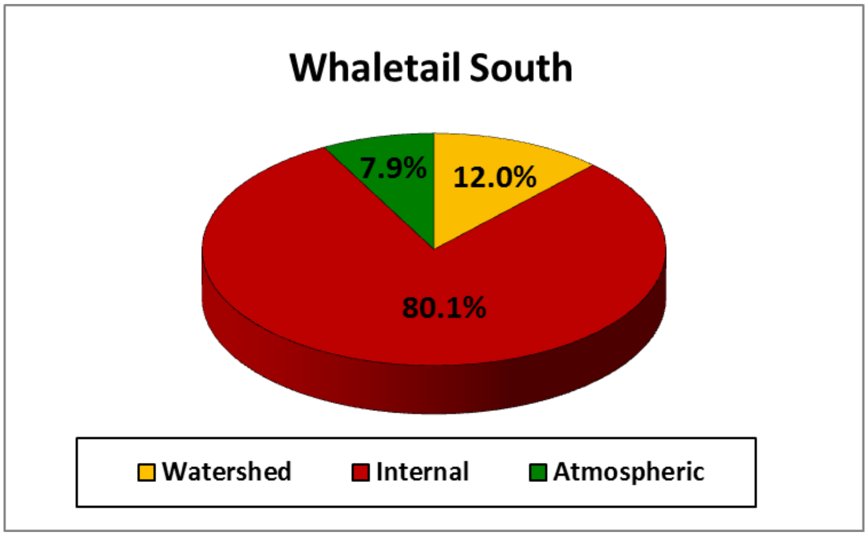
Half Moon Lake			
	Annual Total Phosphorus Load		
Load	kg/yr	lbs/yr	%
Watershed	603.5	1330.5	77.7%
Internal	169.5	373.7	21.8%
Atmospheric	3.9	8.6	0.5%
Total	776.9	1712.8	100.0



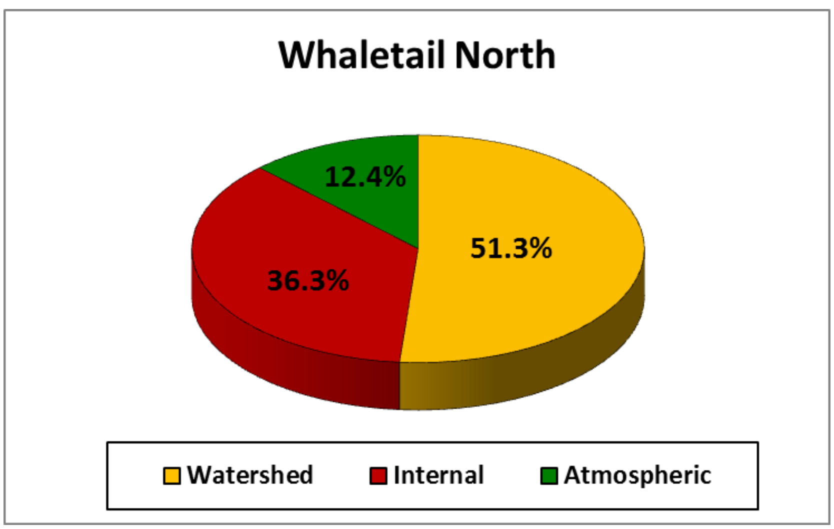
Ardmore			
	Annual Total Phosphorus Load		
Load	kg/yr	lbs/yr	%
Watershed	122.1	269.2	50.0%
Internal	120.2	265.0	49.3%
Atmospheric	1.7	3.7	0.7%
Total	244.0	537.9	100.0



Whaletail South			
	Annual Total Phosphorus Load		
Load	kg	lbs	%
Watershed	28.9	63.7	12.0%
Internal	192.1	423.5	80.1%
Atmospheric	18.9	41.7	7.9%
Total	239.9	528.9	100.0



Whaletail North			
	Annual Total Phosphorus Load		
Load	kg/yr	lbs/yr	%
Watershed	186.5	411.2	51.3%
Internal	132	291.0	36.3%
Atmospheric	45.0	99.2	12.4%
Total	363.5	801.4	100.0



Appendix C5
BATHTUB Model Calibration (Predicted versus Observed)

Peter Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	43.8	43.8	2nd Order, Fixed
Chlorophyll-a (µg/L)	18.6	18.6	P, Light, T
Secchi (m)	3.0	3.0	Chlorophyll-a & Turbidity

Spurzem Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	161.3	161.3	Canf & Bach, Lakes
Chlorophyll-a (µg/L)	52.3	52.3	P, Light, T
Secchi (m)	1.4	1.4	Chlorophyll-a vs Turbidity

Half Moon Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	127.9	127.9	Canf & Bach, General
Chlorophyll-a (µg/L)	48.1	48.1	P, Light, T
Secchi (m)	1.2	1.2	Chlorophyll-a & Turbidity

Ardmore Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	227.9	227.9	Canf & Bach, Lakes
Chlorophyll-a (µg/L)	83.4	83.4	P, Light, T
Secchi (m)	0.6	0.6	Chlorophyll-a & Turbidity

Whaletail South Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	49.9	49.9	Canfield & Bachman, General
Chlorophyll-a (µg/L)	22.6	22.6	P, Light, T
Secchi (m)	1.4	1.4	Chlorophyll-a & Turbidity

Whaletail North Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	71.2	71.2	2nd Order, Available P
Chlorophyll-a (µg/L)	28.3	28.3	P, Linear
Secchi (m)	0.8	0.8	Total P

Appendix C6
BATHTUB Model Load Response Curves

Peter Lake
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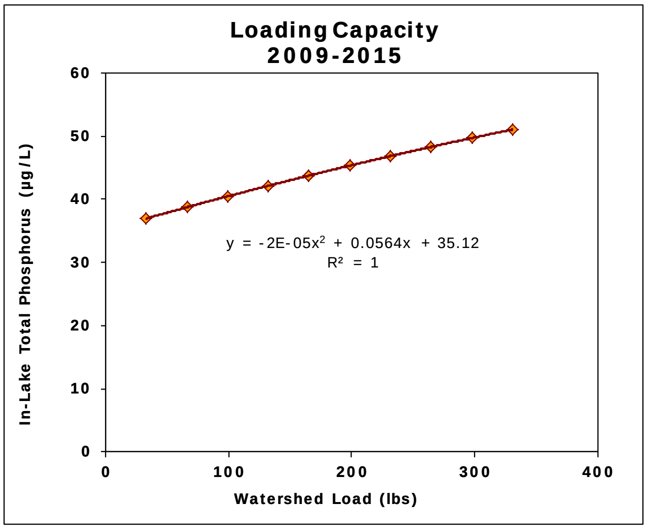
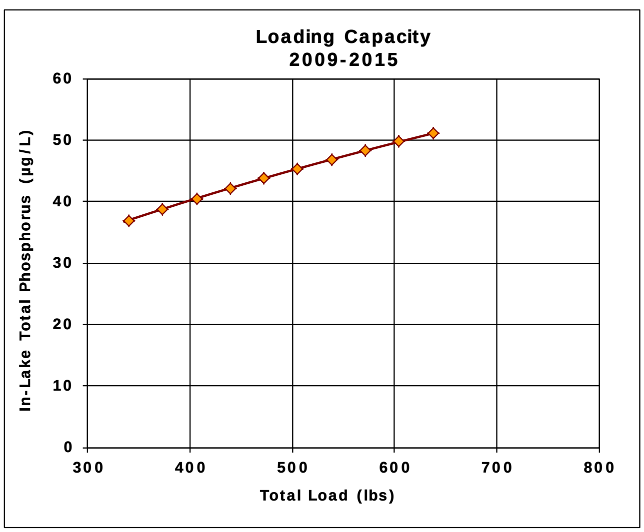
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m³	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	0.3	75.2	273.4	43.8	0.21	36.1	53.1	165.41	472.31
0.20	0.3	15.0	54.7	36.9	0.21	30.4	44.8	33.08	339.98
0.40	0.3	30.1	109.4	38.8	0.21	31.9	47.0	66.17	373.07
0.60	0.3	45.1	164.0	40.5	0.21	33.4	49.1	99.25	406.15
0.80	0.3	60.2	218.7	42.2	0.21	34.7	51.2	132.33	439.23
1.00	0.3	75.2	273.4	43.8	0.21	36.1	53.1	165.41	472.31
1.20	0.3	90.2	328.1	45.3	0.21	37.3	55.0	198.50	505.40
1.40	0.3	105.3	382.8	46.8	0.21	38.6	56.9	231.58	538.48
1.60	0.3	120.3	437.5	48.3	0.21	39.8	58.6	264.66	571.56
1.80	0.3	135.3	492.1	49.7	0.21	40.9	60.4	297.74	604.64
2.00	0.3	150.4	546.8	51.1	0.21	42.0	62.0	330.83	637.73

Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
80.0	39.5	386.9
85.0	39.8	391.9
90.0	40.0	396.9
95.0	40.3	401.9
100.0	40.6	406.9
105.0	40.8	411.9
110.0	41.1	416.9
115.0	41.3	421.9
120.0	41.6	426.9
125.0	41.9	431.9
130.0	42.1	436.9
135.0	42.4	441.9
140.0	42.6	446.9
145.0	42.9	451.9
150.0	43.1	456.9
155.0	43.4	461.9
160.0	43.6	466.9
165.0	43.9	471.9
170.0	44.1	476.9
175.0	44.4	481.9
180.0	44.6	486.9
185.0	44.9	491.9
190.0	45.1	496.9
195.0	45.4	501.9
200.0	45.6	506.9
205.0	45.8	511.9
210.0	46.1	516.9
215.0	46.3	521.9
220.0	46.6	526.9
225.0	46.8	531.9
230.0	47.0	536.9
235.0	47.3	541.9
240.0	47.5	546.9
245.0	47.7	551.9
250.0	48.0	556.9
255.0	48.2	561.9
260.0	48.4	566.9
265.0	48.7	571.9
270.0	48.9	576.9
275.0	49.1	581.9
280.0	49.3	586.9
285.0	49.6	591.9
290.0	49.8	596.9
295.0	50.0	601.9
300.0	50.2	606.9
305.0	50.5	611.9
310.0	50.7	616.9
315.0	50.9	621.9
320.0	51.1	626.9
325.0	51.3	631.9

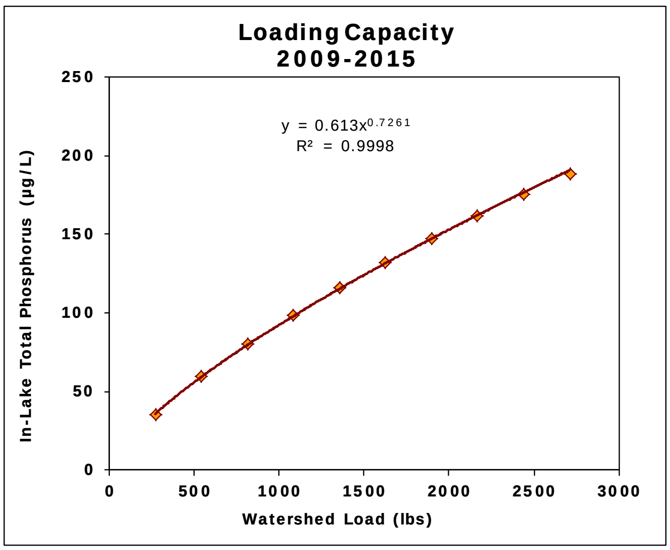


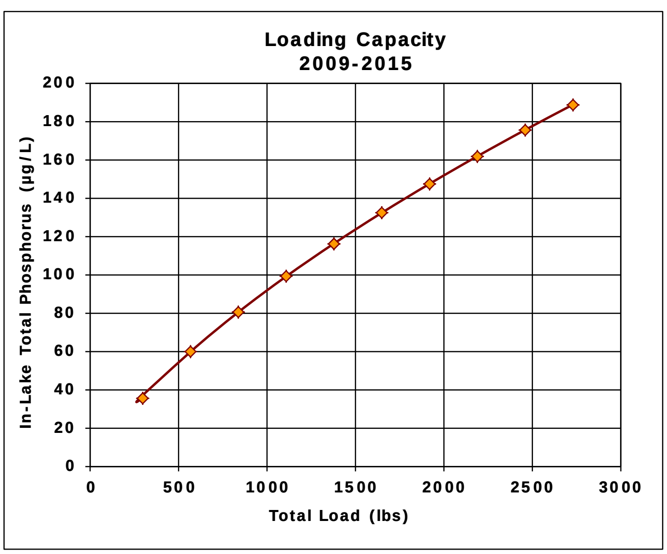


Spurzem Lake
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Pioneer and Sarah Creek\Spurzem\Spurzem Lake 5-20-2016.btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

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	616.1	284.7	116.0	0.26	91.7	146.7	1355.36	1376.56
0.20	2.2	123.2	56.9	35.4	0.19	29.7	42.1	271.07	292.27
0.40	2.2	246.4	113.9	59.4	0.22	48.6	72.6	542.14	563.34
0.60	2.2	369.6	170.8	80.1	0.24	64.6	99.4	813.22	834.42
0.80	2.2	492.9	227.8	98.8	0.25	78.8	123.9	1084.29	1105.49
1.00	2.2	616.1	284.7	116.0	0.26	91.7	146.7	1355.36	1376.56
1.20	2.2	739.3	341.6	132.1	0.27	103.7	168.2	1626.43	1647.63
1.40	2.2	862.5	398.6	147.2	0.28	115.0	188.5	1897.51	1918.71
1.60	2.2	985.7	455.5	161.6	0.29	125.6	207.9	2168.58	2189.78
1.80	2.2	1108.9	512.4	175.4	0.29	135.8	226.5	2439.65	2460.85
2.00	2.2	1232.1	569.4	188.6	0.30	145.5	244.5	2710.72	2731.92

Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
250.0	33.8	271.2
300.0	38.6	321.2
316.0	40.0	337.2
350.0	43.1	371.2
400.0	47.5	421.2
450.0	51.8	471.2
500.0	55.9	521.2
550.0	59.9	571.2
600.0	63.8	621.2
650.0	67.6	671.2
700.0	71.3	721.2
750.0	75.0	771.2
800.0	78.6	821.2
850.0	82.1	871.2
900.0	85.6	921.2
950.0	89.0	971.2
1000.0	92.4	1021.2
1050.0	95.8	1071.2
1100.0	99.0	1121.2
1150.0	102.3	1171.2
1200.0	105.5	1221.2
1250.0	108.7	1271.2
1300.0	111.8	1321.2
1350.0	114.9	1371.2
1400.0	118.0	1421.2
1450.0	121.0	1471.2
1500.0	124.1	1521.2
1550.0	127.0	1571.2
1600.0	130.0	1621.2
1650.0	132.9	1671.2
1700.0	135.9	1721.2
1750.0	138.7	1771.2
1800.0	141.6	1821.2
1850.0	144.5	1871.2
1900.0	147.3	1921.2
1950.0	150.1	1971.2
2000.0	152.9	2021.2
2050.0	155.6	2071.2
2100.0	158.4	2121.2
2150.0	161.1	2171.2
2200.0	163.8	2221.2
2250.0	166.5	2271.2
2300.0	169.2	2321.2
2350.0	171.9	2371.2
2400.0	174.5	2421.2
2450.0	177.1	2471.2
2500.0	179.8	2521.2
2550.0	182.4	2571.2
2600.0	185.0	2621.2
2650.0	187.5	2671.2

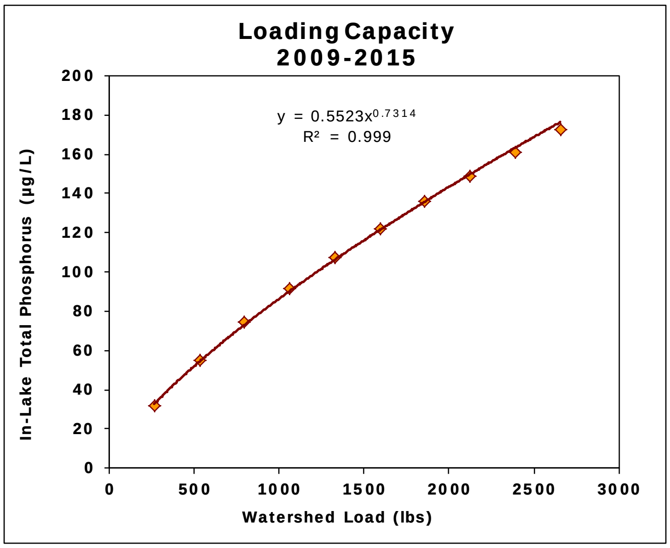


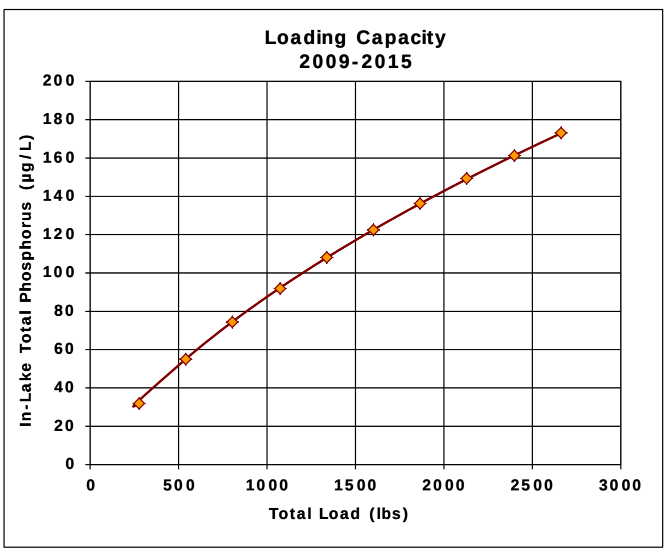


Half Moon
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Pioneer and Sarah Creek\Half Moon\Half Moon 5-23-2016.btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m³	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	2.7	603.5	226.5	107.6	0.23	87.2	132.8	1327.70	1336.30
0.20	2.7	120.7	45.3	31.8	0.14	27.9	36.4	265.54	274.14
0.40	2.7	241.4	90.6	54.8	0.18	46.4	64.7	531.08	539.68
0.60	2.7	362.1	135.9	74.4	0.20	61.8	89.5	796.62	805.22
0.80	2.7	482.8	181.2	91.8	0.22	75.2	112.0	1062.16	1070.76
1.00	2.7	603.5	226.5	107.6	0.23	87.2	132.8	1327.70	1336.30
1.20	2.7	724.2	271.8	122.2	0.24	98.2	152.2	1593.24	1601.84
1.40	2.7	844.9	317.2	135.9	0.25	108.4	170.4	1858.78	1867.38
1.60	2.7	965.6	362.5	148.8	0.26	118.0	187.7	2124.33	2132.93
1.80	2.7	1086.3	407.8	161.0	0.27	127.0	204.1	2389.87	2398.47
2.00	2.7	1207.0	453.1	172.6	0.27	135.5	219.9	2655.41	2664.01

Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
250.0	31.3	258.6
275.0	33.6	283.6
300.0	35.8	308.6
325.0	38.0	333.6
349.0	40.0	357.6
375.0	42.2	383.6
400.0	44.2	408.6
425.0	46.2	433.6
450.0	48.2	458.6
475.0	50.1	483.6
500.0	52.0	508.6
525.0	53.9	533.6
550.0	55.8	558.6
575.0	57.6	583.6
600.0	59.4	608.6
625.0	61.2	633.6
650.0	63.0	658.6
675.0	64.8	683.6
700.0	66.5	708.6
725.0	68.3	733.6
750.0	70.0	758.6
775.0	71.7	783.6
800.0	73.4	808.6
825.0	75.0	833.6
850.0	76.7	858.6
875.0	78.3	883.6
900.0	80.0	908.6
925.0	81.6	933.6
950.0	83.2	958.6
975.0	84.8	983.6
1000.0	86.4	1008.6
1025.0	87.9	1033.6
1050.0	89.5	1058.6
1075.0	91.1	1083.6
1100.0	92.6	1108.6
1125.0	94.1	1133.6
1150.0	95.7	1158.6
1175.0	97.2	1183.6
1200.0	98.7	1208.6
1225.0	100.2	1233.6
1250.0	101.7	1258.6
1275.0	103.2	1283.6
1300.0	104.6	1308.6
1325.0	106.1	1333.6
1350.0	107.6	1358.6
1375.0	109.0	1383.6
1400.0	110.5	1408.6
1425.0	111.9	1433.6
1450.0	113.3	1458.6
1475.0	114.8	1483.6

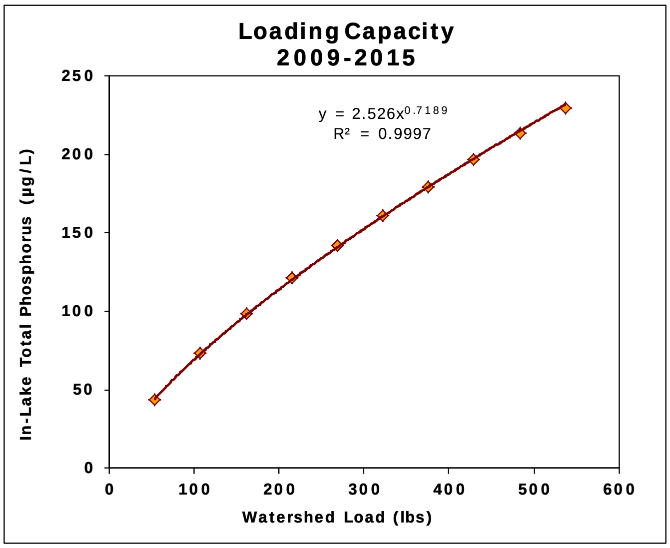


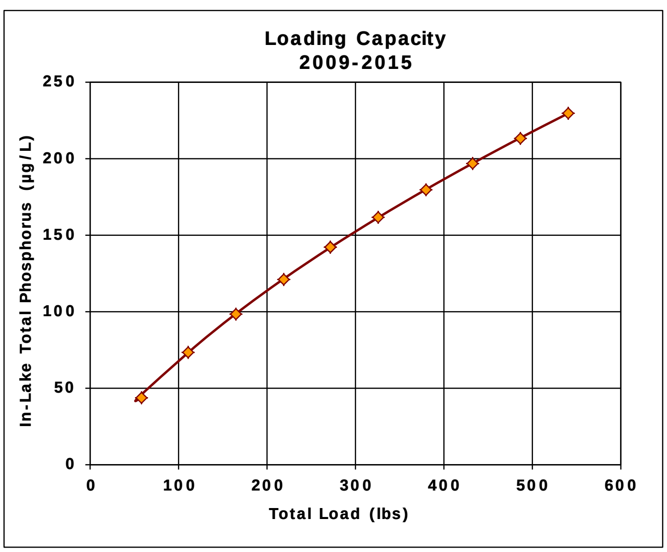


Ardmore Lake
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Pioneer and Sarah Creek\Ardmore Lake 5-25-2016.btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m³	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	0.3	122.0	368.7	141.7	0.27	111.2	180.6	268.51	272.01
0.20	0.3	24.4	73.7	43.7	0.20	36.4	52.4	53.70	57.20
0.40	0.3	48.8	147.5	73.1	0.23	59.4	90.0	107.40	110.90
0.60	0.3	73.2	221.2	98.3	0.25	78.6	123.0	161.11	164.61
0.80	0.3	97.6	295.0	121.0	0.26	95.7	152.9	214.81	218.31
1.00	0.3	122.0	368.7	141.7	0.27	111.2	180.6	268.51	272.01
1.20	0.3	146.5	442.5	161.1	0.28	125.6	206.7	322.21	325.71
1.40	0.3	170.9	516.2	179.4	0.29	139.1	231.3	375.91	379.41
1.60	0.3	195.3	590.0	196.7	0.30	151.9	254.8	429.61	433.11
1.80	0.3	219.7	663.7	213.2	0.30	164.0	277.3	483.32	486.82
2.00	0.3	244.1	737.5	229.1	0.30	175.6	299.0	537.02	540.52

Watershed Load lbs / yr	TP µg / L	Total Load lbs / yr
40.0	35.8	43.6
46.7	40.0	50.3
50.0	42.1	53.6
55.0	45.0	58.6
60.0	47.9	63.6
65.0	50.8	68.6
70.0	53.6	73.6
75.0	56.3	78.6
80.0	59.0	83.6
85.0	61.6	88.6
90.0	64.2	93.6
95.0	66.7	98.6
100.0	69.2	103.6
105.0	71.7	108.6
110.0	74.1	113.6
115.0	76.5	118.6
120.0	78.9	123.6
125.0	81.3	128.6
130.0	83.6	133.6
135.0	85.9	138.6
140.0	88.2	143.6
145.0	90.4	148.6
150.0	92.6	153.6
155.0	94.9	158.6
160.0	97.0	163.6
165.0	99.2	168.6
170.0	101.4	173.6
175.0	103.5	178.6
180.0	105.6	183.6
185.0	107.7	188.6
190.0	109.8	193.6
195.0	111.9	198.6
200.0	113.9	203.6
205.0	116.0	208.6
210.0	118.0	213.6
215.0	120.0	218.6
220.0	122.0	223.6
225.0	124.0	228.6
230.0	126.0	233.6
235.0	127.9	238.6
240.0	129.9	243.6
245.0	131.8	248.6
250.0	133.8	253.6
255.0	135.7	258.6
260.0	137.6	263.6
265.0	139.5	268.6
270.0	141.4	273.6
275.0	143.2	278.6
280.0	145.1	283.6
285.0	147.0	288.6





Whaletail South
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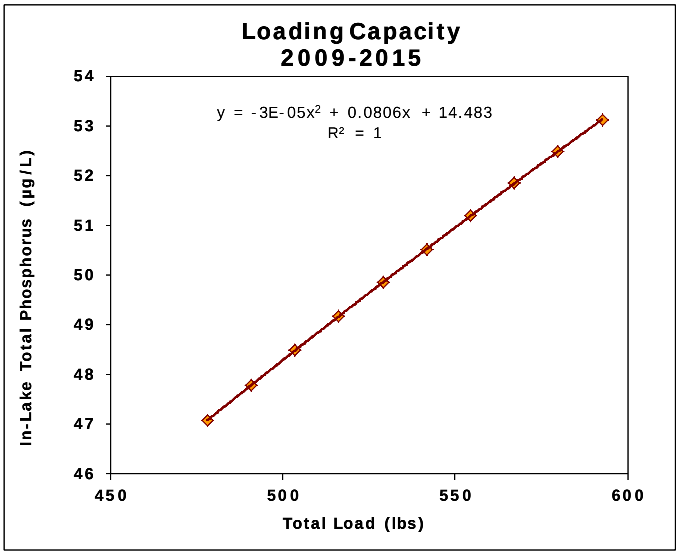
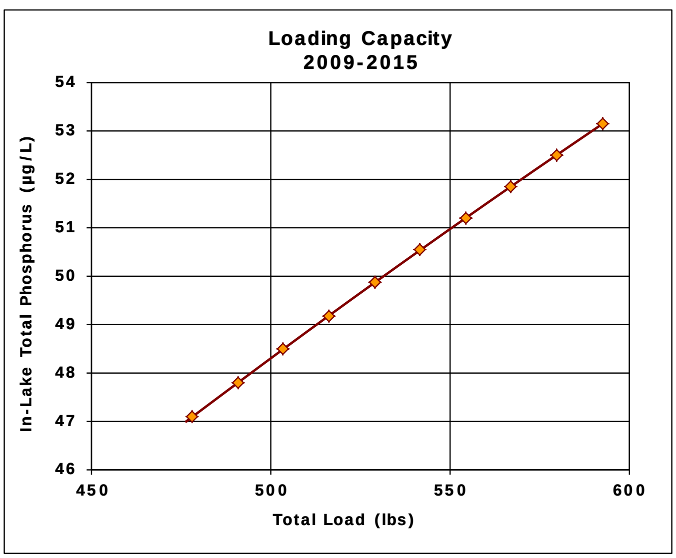
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

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
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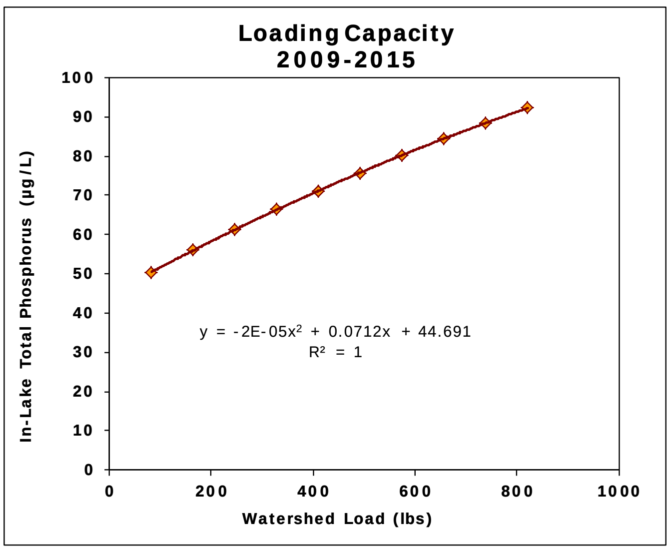
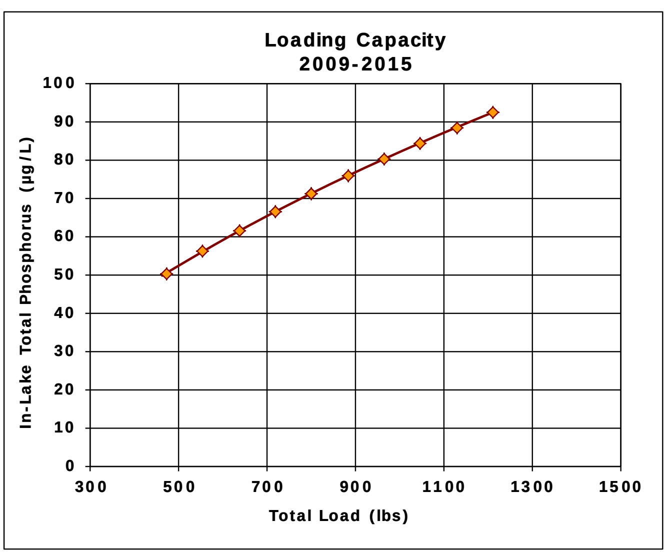
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

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:	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
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 C7
BATHTUB Model Inputs and Outputs

Peter Lake

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Description:

Model used to estimate watershed load

Water Quality is the May-Sept average from 2009 through 2015.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	3	2ND ORDER, FIXED
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Peter Lake	0	1	0.23	4.59	0.79	4.3	0.12	3.12	0	0.08	0.2	0	0	1.575	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	43.8	0	0	0	18.6	0	3	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	0.955	0	1.65	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km²	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Peter Lake	1	1	1.21	0.275	0	0	0	273.41	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Peter Lake

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Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Peter Lake	1.21	0.275	0.00E+00	0.00	0.227
PRECIPITATION				0.23	0.164	1.07E-03	0.20	0.711
TRIBUTARY INFLOW				1.21	0.275	0.00E+00	0.00	0.227
***TOTAL INFLOW				1.44	0.439	1.07E-03	0.07	0.305
ADVECTIVE OUTFLOW				1.44	0.278	3.40E-03	0.21	0.193
***TOTAL OUTFLOW				1.44	0.278	3.40E-03	0.21	0.193
***EVAPORATION					0.161	2.33E-03	0.30	

Overall Mass Balance Based Upon **Predicted** **Outflow & Reservoir Concentrations**

Component: **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Peter Lake	75.19	35.1%	0.00E+00		0.00	273.4	62.14
PRECIPITATION				6.90	3.2%	1.19E+01	100.0%	0.50	42.2	30.00
INTERNAL LOAD				132.31	61.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				75.19	35.1%	0.00E+00		0.00	273.4	62.14
***TOTAL INFLOW				214.40	100.0%	1.19E+01	100.0%	0.02	488.9	148.89
ADVECTIVE OUTFLOW				12.15	5.7%	1.29E+01		0.30	43.8	8.44
***TOTAL OUTFLOW				12.15	5.7%	1.29E+01		0.30	43.8	8.44
***RETENTION				202.25	94.3%	2.41E+01		0.02		

Overflow Rate (m/yr)	1.207	Nutrient Resid. Time (yrs)	0.2155
Hydraulic Resid. Time (yrs)	3.8033	Turnover Ratio	4.6
Reservoir Conc (mg/m3)	43.8	Retention Coef.	0.943

Peter Lake

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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment:	**1**	**Peter Lake**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	43.8	0.21	46.0%	43.8		46.0%
CHL-A MG/M3	18.6	0.32	81.3%	18.6		81.3%
SECCHI M	3.0	0.28	91.2%	3.0		91.1%
ORGANIC N MG/M3	587.9	0.26	66.4%			
TP-ORTHO-P MG/M3	31.0	0.37	51.3%			
HOD-V MG/M3-DAY	332.1	0.22	97.5%			
MOD-V MG/M3-DAY	204.7	0.31	94.0%			
ANTILOG PC-1	170.6	0.56	39.1%	171.5		39.3%
ANTILOG PC-2	23.1	0.08	99.2%	22.9		99.2%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.3	0.23	0.2%	0.3	0.23	0.2%
ZMIX / SECCHI	1.4	0.29	1.9%	1.4	0.12	1.9%
CHL-A * SECCHI	56.3	0.11	99.2%	55.8		99.2%
CHL-A / TOTAL P	0.4	0.27	88.9%	0.4		88.8%
FREQ(CHL-a>10) %	75.6	0.21	81.3%	75.5		81.3%
FREQ(CHL-a>20) %	33.6	0.55	81.3%	33.5		81.3%
FREQ(CHL-a>30) %	14.0	0.81	81.3%	14.0		81.3%
FREQ(CHL-a>40) %	6.2	1.02	81.3%	6.1		81.3%
FREQ(CHL-a>50) %	2.9	1.18	81.3%	2.8		81.3%
FREQ(CHL-a>60) %	1.4	1.32	81.3%	1.4		81.3%
CARLSON TSI-P	58.6	0.05	46.0%	58.7		46.0%
CARLSON TSI-CHLA	59.3	0.05	81.3%	59.3		81.3%
CARLSON TSI-SEC	44.1	0.09	8.8%	44.2		8.9%

Spurzem Lake

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Description:

Model used to estimate watershed load

Water Quality is the May-Sept average from 2009 through 2015.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day): Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Spurzem Lake	0	1	0.32	3.38	0.86	2.71	0.12	1.86	0	0.08	0.2	0	0	3.14	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	161.3	0	0	0	52.3	0	1.4	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	0.985	0	1.9	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km²	Flow (hm³/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Spurzem Direct Watershed	1	1	10.66	1.886	0	0	0	320.2	0	0	0	0	0	0	0
2	Upstream Lake (Peter)	1	1	1.44	0.278	0	0	0	43.8	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Spurzem Lake

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Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Spurzem Direct Watershe	10.66	1.886	0.00E+00	0.00	0.177
2	1	1	Upstream Lake (Peter)	1.44	0.278	0.00E+00	0.00	0.193
PRECIPITATION				0.32	0.228	2.07E-03	0.20	0.711
TRIBUTARY INFLOW				12.10	2.164	0.00E+00	0.00	0.179
***TOTAL INFLOW				12.42	2.392	2.07E-03	0.02	0.193
ADVECTIVE OUTFLOW				12.42	2.168	6.59E-03	0.04	0.175
***TOTAL OUTFLOW				12.42	2.168	6.59E-03	0.04	0.175
***EVAPORATION					0.224	4.52E-03	0.30	

Overall Mass Balance Based Upon Predicted — Outflow & Reservoir Concentrations

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Spurzem Direct Watershe	603.90	60.8%	0.00E+00		0.00	320.2	56.65
2	1	1	Upstream Lake (Peter)	12.18	1.2%	0.00E+00		0.00	43.8	8.46
PRECIPITATION				9.60	1.0%	2.30E+01	100.0%	0.50	42.2	30.00
INTERNAL LOAD				367.00	37.0%	0.00E+00		0.00		
TRIBUTARY INFLOW				616.07	62.1%	0.00E+00		0.00	284.7	50.92
***TOTAL INFLOW				992.68	100.0%	2.30E+01	100.0%	0.00	415.1	79.93
ADVECTIVE OUTFLOW				349.68	35.2%	1.01E+04		0.29	161.3	28.15
***TOTAL OUTFLOW				349.68	35.2%	1.01E+04		0.29	161.3	28.15
***RETENTION				643.00	64.8%	1.01E+04		0.16		

Overflow Rate (m/yr)	6.774	Nutrient Resid. Time (yrs)	0.1758
Hydraulic Resid. Time (yrs)	0.4990	Turnover Ratio	5.7
Reservoir Conc (mg/m3)	161.3	Retention Coef.	0.648

Spurzem Lake

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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Spurzem Lake**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	161.3	0.29	91.1%	161.3		91.1%
CHL-A MG/M3	52.3	0.29	98.7%	52.3		98.7%
SECCHI M	1.4	0.29	62.3%	1.4		63.4%
ORGANIC N MG/M3	1355.6	0.29	98.0%			
TP-ORTHO-P MG/M3	90.9	0.34	87.8%			
HOD-V MG/M3-DAY	933.2	0.21	100.0%			
MOD-V MG/M3-DAY	472.6	0.30	99.7%			
ANTILOG PC-1	950.1	0.55	85.0%	930.5		84.6%
ANTILOG PC-2	24.9	0.08	99.5%	25.3		99.5%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.2	0.23	0.0%	0.2	0.23	0.0%
ZMIX / SECCHI	2.0	0.28	6.5%	1.9	0.12	6.1%
CHL-A * SECCHI	71.6	0.10	99.7%	73.2		99.7%
CHL-A / TOTAL P	0.3	0.33	78.6%	0.3		78.6%
FREQ(CHL-a>10) %	99.1	0.01	98.7%	99.1		98.7%
FREQ(CHL-a>20) %	89.3	0.10	98.7%	89.3		98.7%
FREQ(CHL-a>30) %	72.1	0.22	98.7%	72.1		98.7%
FREQ(CHL-a>40) %	54.9	0.34	98.7%	54.9		98.7%
FREQ(CHL-a>50) %	40.6	0.45	98.7%	40.6		98.7%
FREQ(CHL-a>60) %	29.8	0.55	98.7%	29.7		98.7%
CARLSON TSI-P	77.5	0.05	91.1%	77.5		91.1%
CARLSON TSI-CHLA	69.4	0.04	98.7%	69.4		98.7%
CARLSON TSI-SEC	55.5	0.08	37.7%	55.2		36.6%

Half Moon

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Description:

Model used to estimate watershed load

Water Quality is the May-Sept average from 2009 through 2015.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	9	CANF& BACH, GENERAL
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Half Moon	0	1	0.13	4.08	0.53	2.65	0.12	1.63	0	0.08	0.2	0	0	3.57	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	127.9	0	0	0	48.1	0	1.2	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.911	0	1	0	1.022	0	1.5	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Half Moon Direct Watershe	1	1	1.5	0.496	0	0	0	511.7	0	0	0	0	0	0	0
2	Upstream Lake (Spurzem)	1	1	12.42	2.168	0	0	0	161.3	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Half Moon

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Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Half Moon Direct Watersh	1.50	0.496	0.00E+00	0.00	0.331
2	1	1	Upstream Lake (Spurzem)	12.42	2.168	0.00E+00	0.00	0.175
PRECIPITATION				0.13	0.092	3.42E-04	0.20	0.711
TRIBUTARY INFLOW				13.92	2.664	0.00E+00	0.00	0.191
***TOTAL INFLOW				14.05	2.756	3.42E-04	0.01	0.196
ADVECTIVE OUTFLOW				14.05	2.665	1.09E-03	0.01	0.190
***TOTAL OUTFLOW				14.05	2.665	1.09E-03	0.01	0.190
***EVAPORATION					0.091	7.45E-04	0.30	

Overall Mass Balance Based Upon **Predicted** **Outflow & Reservoir Concentrations**

Component: **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Half Moon Direct Watersh	253.80	32.7%	0.00E+00		0.00	511.7	169.20
2	1	1	Upstream Lake (Spurzem)	349.70	45.0%	0.00E+00		0.00	161.3	28.16
PRECIPITATION				3.90	0.5%	3.80E+00	100.0%	0.50	42.2	30.00
INTERNAL LOAD				169.51	21.8%	0.00E+00		0.00		
TRIBUTARY INFLOW				603.50	77.7%	0.00E+00		0.00	226.5	43.35
***TOTAL INFLOW				776.91	100.0%	3.80E+00	100.0%	0.00	281.9	55.30
ADVECTIVE OUTFLOW				340.87	43.9%	7.17E+03		0.25	127.9	24.26
***TOTAL OUTFLOW				340.87	43.9%	7.17E+03		0.25	127.9	24.26
***RETENTION				436.05	56.1%	7.18E+03		0.19		

Overflow Rate (m/yr)	20.504	Nutrient Resid. Time (yrs)	0.0873
Hydraulic Resid. Time (yrs)	0.1990	Turnover Ratio	11.5
Reservoir Conc (mg/m3)	127.9	Retention Coef.	0.561

Half Moon

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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Half Moon**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	127.9	0.25	86.2%	127.9		86.2%
CHL-A MG/M3	48.1	0.29	98.3%	48.1		98.3%
SECCHI M	1.2	0.29	54.1%	1.2		55.5%
ORGANIC N MG/M3	1260.3	0.28	97.2%			
TP-ORTHO-P MG/M3	83.5	0.34	85.9%			
HOD-V MG/M3-DAY	1021.5	0.21	100.0%			
MOD-V MG/M3-DAY	491.9	0.30	99.7%			
ANTILOG PC-1	1017.3	0.55	86.1%	992.3		85.7%
ANTILOG PC-2	20.8	0.08	98.7%	21.2		98.8%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.2	0.23	0.0%	0.2	0.23	0.0%
ZMIX / SECCHI	2.3	0.28	10.1%	2.2	0.12	9.3%
CHL-A * SECCHI	56.3	0.10	99.2%	57.7		99.3%
CHL-A / TOTAL P	0.4	0.31	84.7%	0.4		84.7%
FREQ(CHL-a>10) %	98.7	0.02	98.3%	98.7		98.3%
FREQ(CHL-a>20) %	86.6	0.12	98.3%	86.6		98.3%
FREQ(CHL-a>30) %	67.5	0.25	98.3%	67.4		98.3%
FREQ(CHL-a>40) %	49.5	0.38	98.3%	49.5		98.3%
FREQ(CHL-a>50) %	35.5	0.50	98.3%	35.5		98.3%
FREQ(CHL-a>60) %	25.3	0.60	98.3%	25.2		98.3%
CARLSON TSI-P	74.1	0.05	86.2%	74.1		86.2%
CARLSON TSI-CHLA	68.6	0.04	98.3%	68.6		98.3%
CARLSON TSI-SEC	57.8	0.07	45.9%	57.4		44.5%

Ardmore Lake

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Description:

Observed in-lake water quality conditions are an average from 2009-2015.

Tributary Load is GLFW Modeling results averaged from 2009-2015.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Ardmore Lake	0	1	0.055	2.87	0.36	2.38	0.12	1.39	0	0.08	0.2	0	0	5.983	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	227.9	0	0	0	83.4	0	0.6	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1.273	0	1.3	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Ardmore Watershed	1	1	2.09	0.331	0	0	0	368.73	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Ardmore Lake

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Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Ardmore Watershed	2.09	0.331	0.00E+00	0.00	0.158
PRECIPITATION				0.05	0.039	6.12E-05	0.20	0.711
TRIBUTARY INFLOW				2.09	0.331	0.00E+00	0.00	0.158
***TOTAL INFLOW				2.14	0.370	6.12E-05	0.02	0.173
ADVECTIVE OUTFLOW				2.14	0.332	1.95E-04	0.04	0.155
***TOTAL OUTFLOW				2.14	0.332	1.95E-04	0.04	0.155
***EVAPORATION					0.038	1.33E-04	0.30	

Overall Mass Balance Based Upon — **Predicted** — **Outflow & Reservoir Concentrations**

Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	Load %Total	Load Variance (kg/yr)²	Load Variance %Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Ardmore Watershed	122.05	50.0%	0.00E+00		0.00	368.7	58.40
PRECIPITATION				1.65	0.7%	6.81E-01	100.0%	0.50	42.2	30.00
INTERNAL LOAD				120.19	49.3%	0.00E+00		0.00		
TRIBUTARY INFLOW				122.05	50.0%	0.00E+00		0.00	368.7	58.40
***TOTAL INFLOW				243.89	100.0%	6.81E-01	100.0%	0.00	659.0	113.70
ADVECTIVE OUTFLOW				75.58	31.0%	5.34E+02		0.31	227.9	35.24
***TOTAL OUTFLOW				75.58	31.0%	5.34E+02		0.31	227.9	35.24
***RETENTION				168.31	69.0%	5.34E+02		0.14		

Overflow Rate (m/yr)	6.029	Nutrient Resid. Time (yrs)	0.1475
Hydraulic Resid. Time (yrs)	0.4760	Turnover Ratio	6.8
Reservoir Conc (mg/m3)	227.9	Retention Coef.	0.690

Ardmore Lake

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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Ardmore Lake

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	227.9	0.30	95.8%	227.9		95.8%
CHL-A MG/M3	83.4	0.29	99.8%	83.4		99.8%
SECCHI M	0.6	0.29	22.0%	0.6		22.0%
ORGANIC N MG/M3	2065.2	0.29	99.8%			
TP-ORTHO-P MG/M3	146.3	0.33	95.2%			
HOD-V MG/M3-DAY	1577.1	0.21	100.0%			
MOD-V MG/M3-DAY	714.9	0.30	100.0%			
ANTILOG PC-1	3191.3	0.55	97.5%	3191.7		97.5%
ANTILOG PC-2	17.9	0.08	97.4%	17.9		97.4%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.2	0.23	0.0%	0.2	0.23	0.0%
ZMIX / SECCHI	4.0	0.28	37.5%	4.0	0.12	37.6%
CHL-A * SECCHI	50.1	0.10	98.8%	50.0		98.8%
CHL-A / TOTAL P	0.4	0.36	83.7%	0.4		83.7%
FREQ(CHL-a>10) %	99.9	0.00	99.8%	99.9		99.8%
FREQ(CHL-a>20) %	97.7	0.03	99.8%	97.7		99.8%
FREQ(CHL-a>30) %	91.0	0.08	99.8%	91.0		99.8%
FREQ(CHL-a>40) %	80.9	0.15	99.8%	80.9		99.8%
FREQ(CHL-a>50) %	69.7	0.23	99.8%	69.7		99.8%
FREQ(CHL-a>60) %	58.8	0.31	99.8%	58.8		99.8%
CARLSON TSI-P	82.4	0.05	95.8%	82.4		95.8%
CARLSON TSI-CHLA	74.0	0.04	99.8%	74.0		99.8%
CARLSON TSI-SEC	67.4	0.06	78.0%	67.4		78.0%

Whaletail South

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Description:

Model used to estimate watershed load

Water Quality is the May-Sept average from 2009 through 2015.

Tributary Load from GFLW Modeling with 0.7 drainage.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	9	CANF& BACH, GENERAL
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Whaletail South	0	1	0.63	3.7	1.1	3.6	0.12	1.69	0	0.08	0.2	0	0	0.835	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	49.9	0	0	0	22.6	0	1.4	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	0.96	0	0.93	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km²	Flow (hm³/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Whaletail South	1	1	2.71	0.977	0	0	0	29.55	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Whaletail South

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Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Whaletail South	2.71	0.977	0.00E+00	0.00	0.361
PRECIPITATION				0.63	0.448	8.03E-03	0.20	0.711
TRIBUTARY INFLOW				2.71	0.977	0.00E+00	0.00	0.361
***TOTAL INFLOW				3.34	1.425	8.03E-03	0.06	0.427
ADVECTIVE OUTFLOW				3.34	0.984	2.55E-02	0.16	0.295
***TOTAL OUTFLOW				3.34	0.984	2.55E-02	0.16	0.295
***EVAPORATION					0.441	1.75E-02	0.30	

Overall Mass Balance Based Upon — **Predicted** — **Outflow & Reservoir Concentrations**

Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Whaletail South	28.87	12.0%	0.00E+00		0.00	29.5	10.65
PRECIPITATION				18.90	7.9%	8.93E+01	100.0%	0.50	42.2	30.00
INTERNAL LOAD				192.14	80.1%	0.00E+00		0.00		
TRIBUTARY INFLOW				28.87	12.0%	0.00E+00		0.00	29.5	10.65
***TOTAL INFLOW				239.91	100.0%	8.93E+01	100.0%	0.04	168.4	71.83
ADVECTIVE OUTFLOW				49.06	20.4%	3.36E+02		0.37	49.9	14.69
***TOTAL OUTFLOW				49.06	20.4%	3.36E+02		0.37	49.9	14.69
***RETENTION				190.85	79.6%	4.04E+02		0.11		

Overflow Rate (m/yr)	1.562	Nutrient Resid. Time (yrs)	0.4844
Hydraulic Resid. Time (yrs)	2.3688	Turnover Ratio	2.1
Reservoir Conc (mg/m3)	49.9	Retention Coef.	0.796

Whaletail South

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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment:	**1**	**Whaletail South**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	49.9	0.35	51.8%	49.9		51.8%
CHL-A MG/M3	22.6	0.39	87.3%	22.6		87.3%
SECCHI M	1.4	0.35	64.9%	1.4		63.4%
ORGANIC N MG/M3	677.7	0.32	75.8%			
TP-ORTHO-P MG/M3	38.0	0.43	59.8%			
HOD-V MG/M3-DAY	674.7	0.24	99.8%			
MOD-V MG/M3-DAY	329.4	0.33	98.7%			
ANTILOG PC-1	407.4	0.69	65.1%	419.7		65.9%
ANTILOG PC-2	14.7	0.08	94.3%	14.4		93.8%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.3	0.23	0.1%	0.3	0.23	0.1%
ZMIX / SECCHI	2.5	0.35	13.3%	2.6	0.12	14.4%
CHL-A * SECCHI	32.6	0.11	95.0%	31.6		94.5%
CHL-A / TOTAL P	0.5	0.28	90.6%	0.5		90.6%
FREQ(CHL-a>10) %	84.2	0.18	87.3%	84.3		87.3%
FREQ(CHL-a>20) %	45.4	0.54	87.3%	45.5		87.3%
FREQ(CHL-a>30) %	22.1	0.83	87.3%	22.2		87.3%
FREQ(CHL-a>40) %	10.9	1.07	87.3%	10.9		87.3%
FREQ(CHL-a>50) %	5.6	1.26	87.3%	5.6		87.3%
FREQ(CHL-a>60) %	3.0	1.42	87.3%	3.0		87.3%
CARLSON TSI-P	60.5	0.08	51.8%	60.5		51.8%
CARLSON TSI-CHLA	61.2	0.06	87.3%	61.2		87.3%
CARLSON TSI-SEC	54.7	0.09	35.1%	55.2		36.6%

Whaletail North

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Description:

Model used to estimate watershed load
Water Quality is the May-Sept average from 2009 through 2015.
Tributary Loads GFLW with 0.7 drainage using 100 cm soil.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	1	2ND ORDER, AVAIL P
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	4	P, LINEAR
Secchi Depth	3	VS. TOTAL P
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Whaletail North	0	1	1.5	1.57	2.01	1.5	0.12	0	0	0.08	0.2	0	0	0.241	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	71.2	0	0	0	28.3	0	0.8	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1.42	0	1.1	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km²	Flow (hm³/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Whaletail North Direct Wat	1	1	3.72	1.234	0	0	0	111.4	0	0	0	0	0	0	0
2	Upstream Lake (Whaletail S	1	1	3.34	0.984	0	0	0	49.9	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Whaletail North

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Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Whaletail North Direct W	3.72	1.234	0.00E+00	0.00	0.332
2	1	1	Upstream Lake (Whaletai	3.34	0.984	0.00E+00	0.00	0.295
PRECIPITATION				1.50	1.067	4.55E-02	0.20	0.711
TRIBUTARY INFLOW				7.06	2.218	0.00E+00	0.00	0.314
***TOTAL INFLOW				8.56	3.285	4.55E-02	0.06	0.384
ADVECTIVE OUTFLOW				8.56	2.235	1.45E-01	0.17	0.261
***TOTAL OUTFLOW				8.56	2.235	1.45E-01	0.17	0.261
***EVAPORATION					1.050	9.92E-02	0.30	

Overall Mass Balance Based Upon — **Predicted** — **Outflow & Reservoir Concentrations**

Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	Load Variance %Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Whaletail North Direct W	137.47	37.8%	0.00E+00		0.00	111.4	36.95
2	1	1	Upstream Lake (Whaletai	49.10	13.5%	0.00E+00		0.00	49.9	14.70
PRECIPITATION				45.00	12.4%	5.06E+02	100.0%	0.50	42.2	30.00
INTERNAL LOAD				132.04	36.3%	0.00E+00		0.00		
TRIBUTARY INFLOW				186.57	51.3%	0.00E+00		0.00	84.1	26.43
***TOTAL INFLOW				363.61	100.0%	5.06E+02	100.0%	0.06	110.7	42.48
ADVECTIVE OUTFLOW				159.13	43.8%	7.97E+02		0.18	71.2	18.59
***TOTAL OUTFLOW				159.13	43.8%	7.97E+02		0.18	71.2	18.59
***RETENTION				204.48	56.2%	1.02E+03		0.16		

Overflow Rate (m/yr)	1.490	Nutrient Resid. Time (yrs)	0.4612
Hydraulic Resid. Time (yrs)	1.0538	Turnover Ratio	2.2
Reservoir Conc (mg/m3)	71.2	Retention Coef.	0.562

Whaletail North

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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment:	**1**	**Whaletail North**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	71.2	0.19	67.0%	71.2		67.0%
CHL-A MG/M3	28.3	0.32	92.4%	28.3		92.4%
SECCHI M	0.8	0.18	32.5%	0.8		34.6%
ORGANIC N MG/M3	808.5	0.29	85.2%			
TP-ORTHO-P MG/M3	48.2	0.37	69.1%			
ANTILOG PC-1	912.4	0.41	84.2%	875.3		83.4%
ANTILOG PC-2	10.5	0.19	82.3%	10.8		84.0%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.1	0.23	0.0%	0.1	0.23	0.0%
ZMIX / SECCHI	2.0	0.21	6.3%	1.9	0.12	5.4%
CHL-A * SECCHI	21.7	0.28	85.6%	22.6		87.0%
CHL-A / TOTAL P	0.4	0.26	86.7%	0.4		86.7%
FREQ(CHL-a>10) %	91.4	0.09	92.4%	91.4		92.4%
FREQ(CHL-a>20) %	59.9	0.33	92.4%	59.9		92.4%
FREQ(CHL-a>30) %	34.3	0.56	92.4%	34.3		92.4%
FREQ(CHL-a>40) %	19.3	0.75	92.4%	19.3		92.4%
FREQ(CHL-a>50) %	11.0	0.90	92.4%	11.0		92.4%
FREQ(CHL-a>60) %	6.4	1.04	92.4%	6.4		92.4%
CARLSON TSI-P	65.7	0.04	67.0%	65.7		67.0%
CARLSON TSI-CHLA	63.4	0.05	92.4%	63.4		92.4%
CARLSON TSI-SEC	63.9	0.04	67.5%	63.2		65.4%

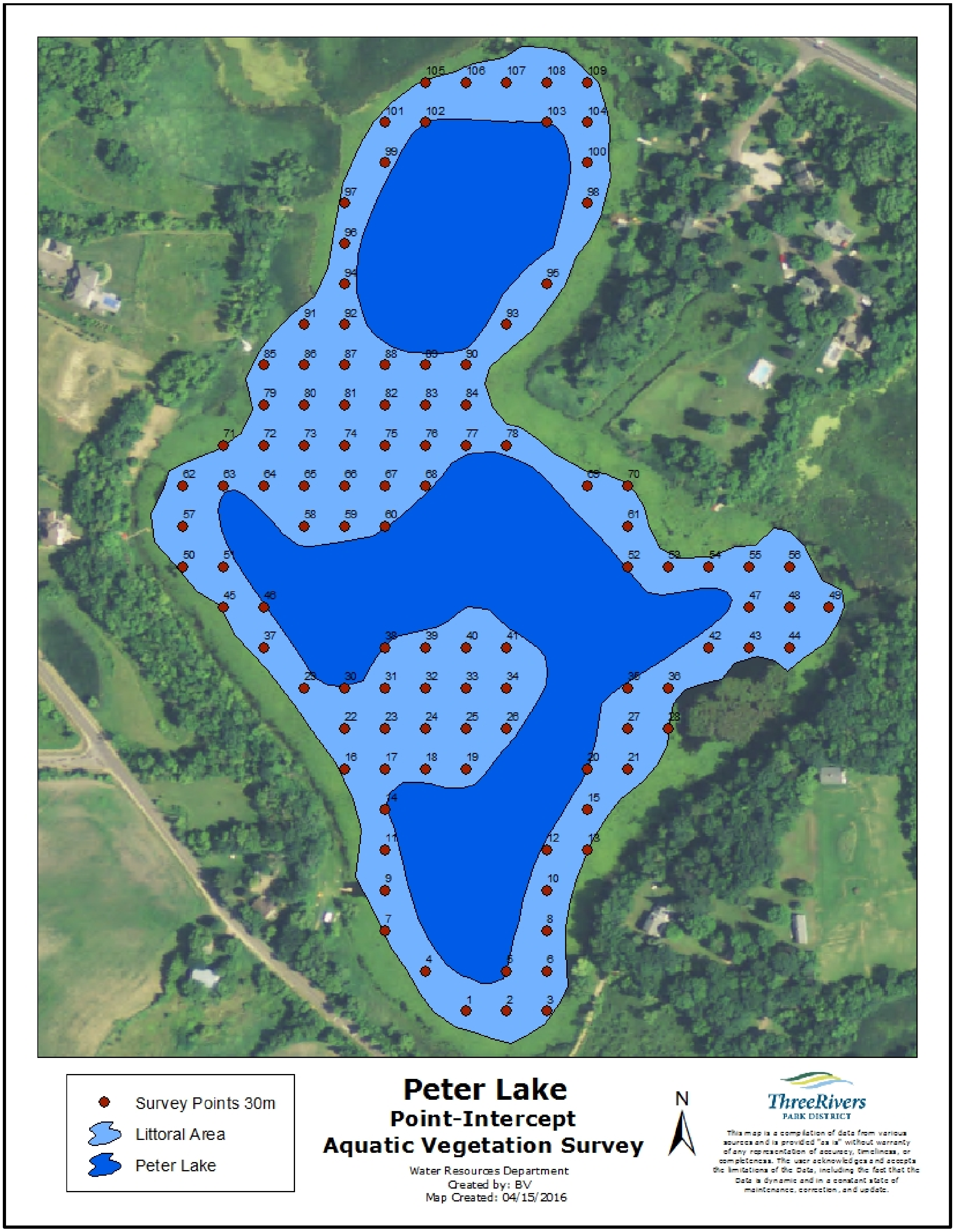
Appendix D: Point-Intercept Aquatic Vegetation Survey Data

Point-Intercept Survey

Methods

Point intercept surveys were conducted to assess the plant community for each impaired lake within the Pioneer and Sarah Creek TMDL. A point-sampling grid was developed for each lake using geo-spatial analysis techniques. The number of points and the distance between point-grid transects were adjusted accordingly to ensure an accurate assessment of the plant community. Each point was sampled by tossing a double-sided rake and assigning a rake density value ranging from zero (no plants present) to five (rake completely covered by a plant species) for each plant species observed. Rake densities are often subjectively based on the percent rake coverage for a particular species. The point-intercept data were summarized and analyzed for the percent frequency of occurrence for each plant species. In cases when a lake had a significant amount of CLPW, the point-intercept rake density data were imported into ArcMap for further spatial analysis. The Spatial analyst extension was used to perform Kriging analysis on the CLPW point intercept rake density data to interpolate the area between the sampling points. The Kriging analysis raster was used for calculating the surface of CLPW with different rake densities.

Peter Lake


Survey Points 30m
Littoral Area
Peter Lake
Peter Lake
Point-Intercept
Aquatic Vegetation Survey
Water Resources Department
Created by: BV
Map Created: 04/15/2016
N
ThreeRivers
PARK DISTRICT
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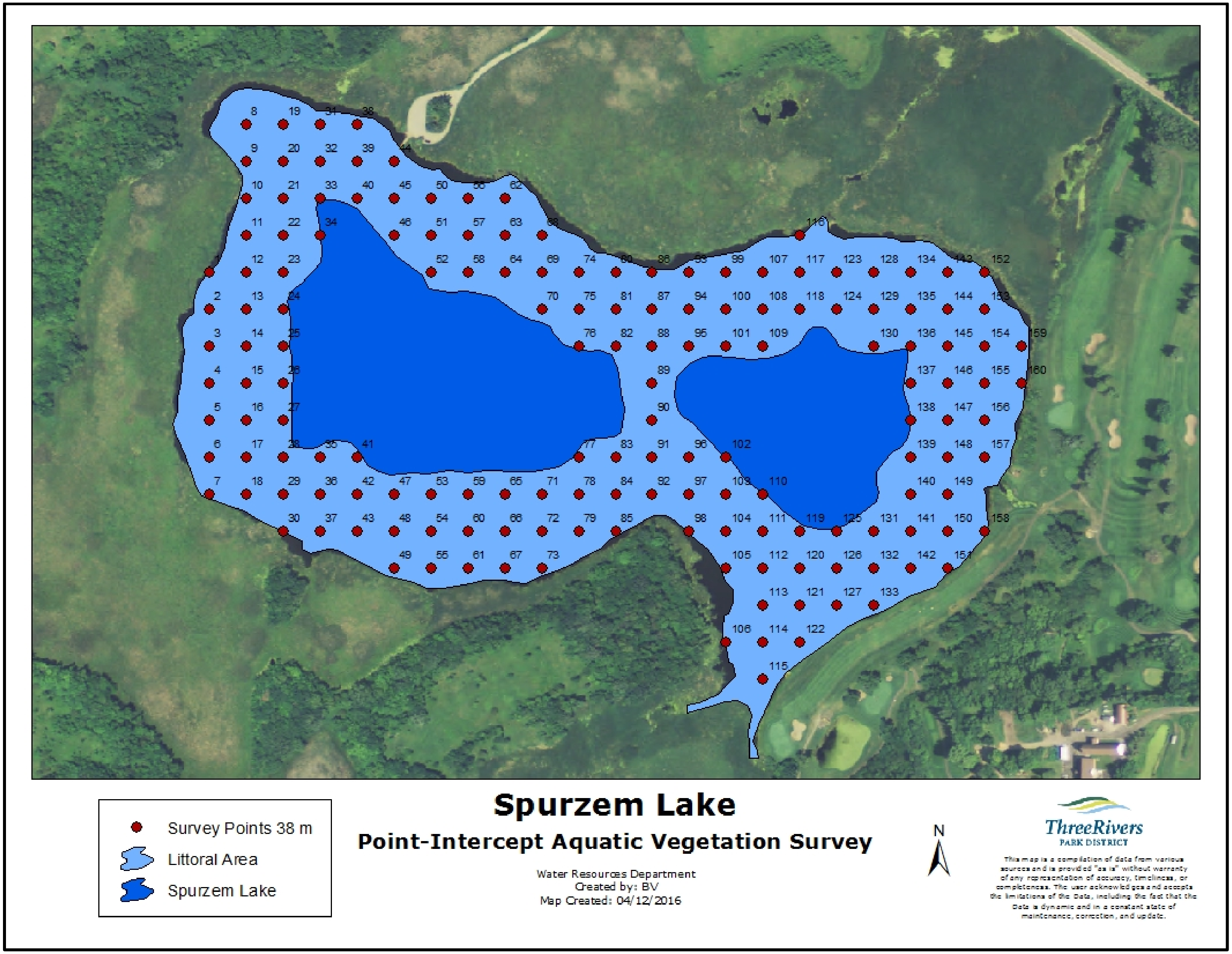
Peter Lake											
Year	Month	Day	Max Depth Sampled (m)	Max Depth of Submerged Plant Growth (m)	Vegetated Depth Range Sampled (m)	Number of Points Sampled	Number of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Submersed Vegetation	Average Number of Native Submersed Taxa per Sample Point	Submersed Species Richness (Number of Submerged Species)
2013	7	12	10	10	0.3-10.0	103	82	79.6	79.6	2	10
2013	9	13	9.8	6.5	0.3-6.5	109	76	69.7	69.7	1.4	8
2015	6	24	9.5	6.3	0.4-6.3	92	66	71.7	71.7	1.41	10
2015	9	15	10.8	5.5	0.1-5.5	109	73	66.9	66.9	0.91	6

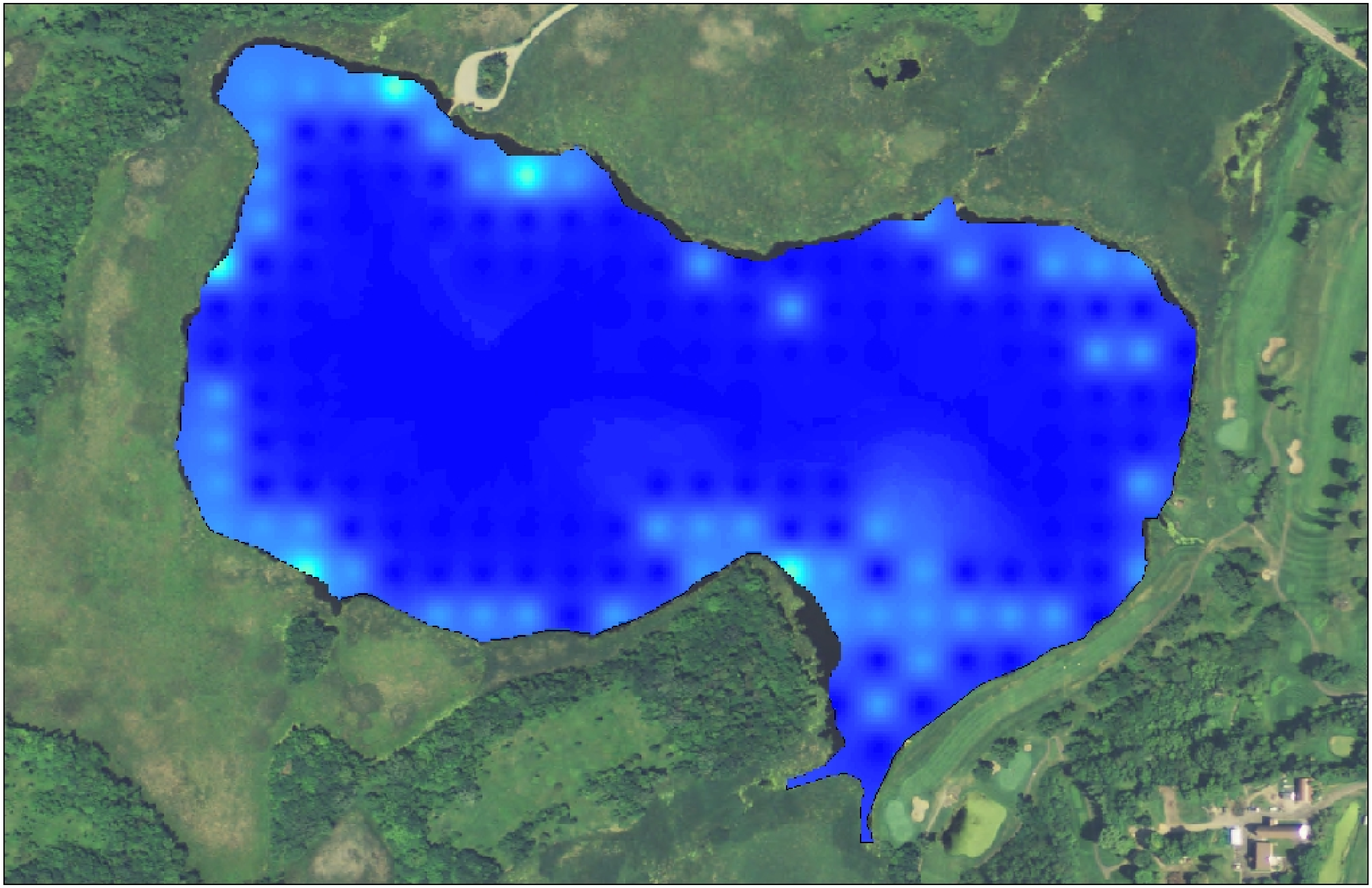
Peter Lake Point-intercept Surveys					Dicots			Monocots											Macroalgae	Dicots	
					Non-native	Native		Non-native	Native										Native	Native	
Year	Month	Numbers of Sample Points in Littoral	Surveyor	**Frequency of Occurrence %**	*Myriophyllum spicatum* (Eurasian Water Milfoil)	*Myriophyllum sibiricum* (Northern Water Milfoil)	*Ceratophyllum demersum (Coontail)*	*Potamogeton crispus* (Curly-leaf Pondweed)	*Elodea canadensis* (Canada Waterweed)	*Potamogeton foliosus* (Leafy Pondweed)	*Potamogeton zosteriformis* (Flat-stem Pondweed)	*Potamogeton amplifolius* (Large-leaf Pondweed)	*(Potamogeton filiformis* (Slender-leaved Pondweed)	*Potamogeton friesii (Fries' Pondweed)*	*Stuckenia pectinata* (Sago Pondweed)	*Potamogeton natans* (Floating Leaf Pondweed)	*Utricularia vulgaris* (Common Bladderwort)	*Potamogeton pusilis* (Small Pondweed)	*Chara spp* (Chara)	*Nuphar variegata* (Spatterdock)	*Nymphaea odorata* (White Water Lilly)
2013	Jul-12	103	TRPD			31	78	10	2	14	57	9	1	7	2					41	50
2013	Sep-13	109	TRPD		3	20	70		1		39	2				3	6			30	37
2015	Jun-24	92	TRPD			11	72	4	5	2	39	7				1		2	2	21	32
2015	Sep-13	109	TRPD			5	67		3		13	2					2			15	39

Spurzem Lake



Spurzem Lake											
Year	Month	Day	Max Depth Sampled (m)	Max Depth of Submerged Plant Growth (m)	Vegetated Depth Range Sampled (m)	Number of Points Sampled	Number of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Submersed Vegetation	Average Number of Native Submersed Taxa per Sample Point	Submersed Species Richness (Number of Submerged Species)
2006	6	1	N/A	N/A	N/A	160	0	0	46	0	1
2006	10	2	N/A	N/A	N/A	160	1	1	3	0.01	2
2007	6	13	N/A	N/A	N/A	160	2	1	8	0.01	2
2008	5	23	8.3	1.8	0.6-1.8	160	1	1	6	0.01	2
2008	9	5	9.2	1.1	0.3-1.1	160	12	8	8	0.09	3
2009	6	4	N/A	N/A	N/A	160	12	8	32	0.09	4
2013	6	21	9	3.8	0.4-3.8	160	27	17	61	0.19	6
2013	8	9	7.7	2.1	0.4-7.7	160	14	9	9	0.09	2
2014	6	11	9.4	2.6	0.5-9.4	160	6	4	50	0.04	4
2014	8	20	8.5	2.3	0.4-8.5	160	29	19	20	0.29	4
2015	6	19	8.4	4	0.4-8.4	160	95	59	64	0.91	5
2015	8	20	10.9	3.1	0.4-10.9	160	89	56	56	0.88	2

Spurzem Lake Point-intercept Surveys					Dicots Native	Monocots Non-native	Native				Dicots Native	
Year	Month	Numbers of Sample Points in Littoral	Surveyor	**Frequency of Occurrence %**	*Ceratophyllum demersum (Coontail)*	*Potamogeton crispus* (Curly-leaf Pondweed)	*Elodea canadensis* (Canada Waterweed)	*Potamogeton foliosus* (Leafy Pondweed)	*Potamogeton zosteriformis* (Flat-stem Pondweed)	*Stuckenia pectinata* (Sago Pondweed)	*Nuphar variegata* (Spatterdock)	*Nymphaea odorata* (White Water Lilly)
2006	Jun-1	160	TRPD			46						
2006	Oct-2	160	TRPD			2		1				
2007	Jun-13	160	TRPD		1	7						
2008	May-23	160	TRPD		1	6						
2008	Sep-5	160	TRPD		6	1	2					1
2009	Jun-4	160	TRPD		8	32	1			1		
2013	Jun-21	160	TRPD		13	58	3	1	1	1		
2013	Aug-9	160	TRPD		9		1					
2014	Jun-1	160	TRPD			46						
2014	Aug-20	160	TRPD		18	4	10			2		
2015	Jun-19	160	TRPD		33	55	58	1		1		
2015	Aug-20	160	TRPD		33		55					



Spurzem Lake

Curly-leaf Pondweed 2009

Spurzem Lake

CLP Rake Density 2009

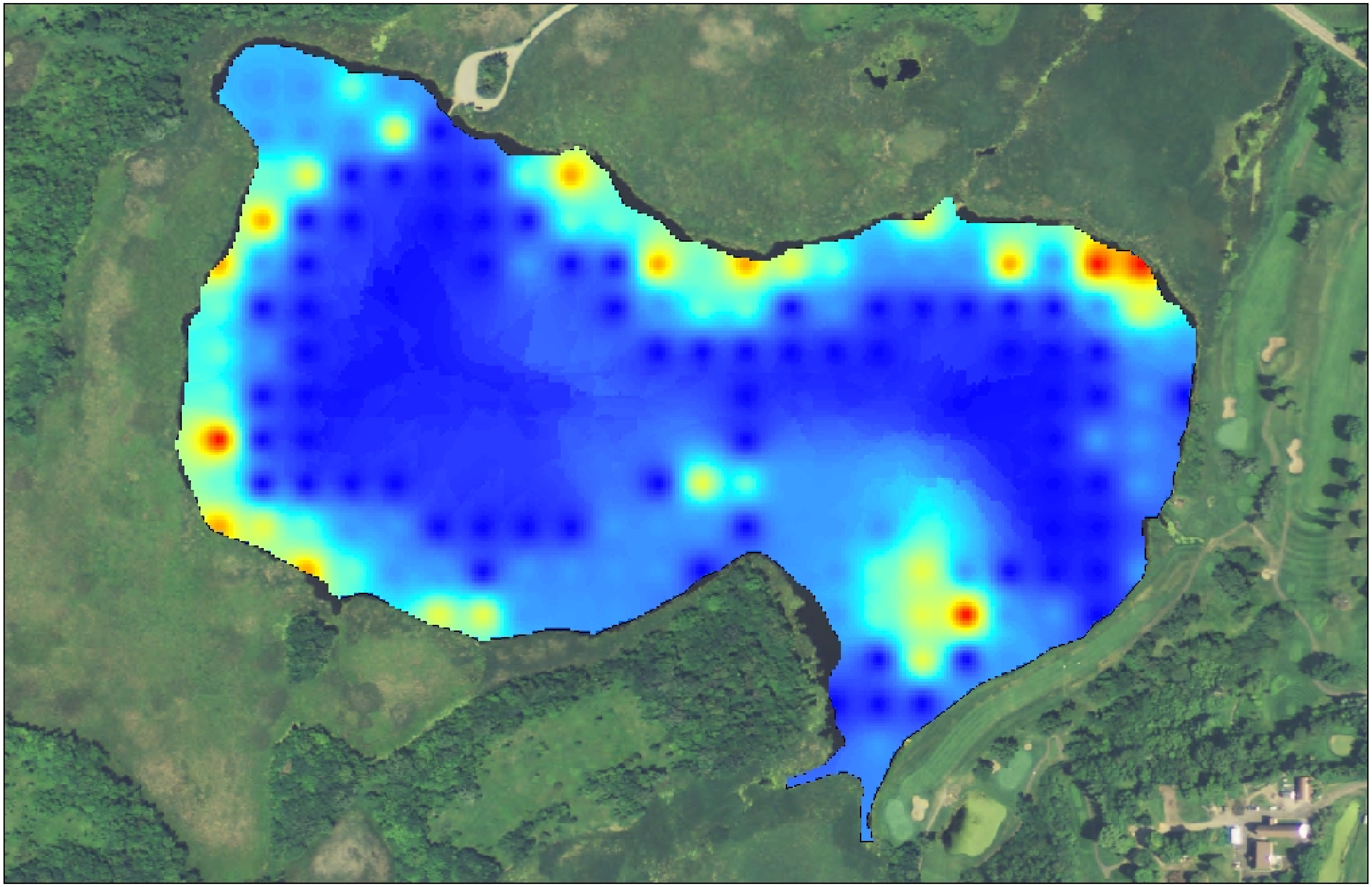
High : 5

Low : 0

N

Water Resources Department
Created by: BV
Map Created: 04/12/2016

ThreeRivers
PARK DISTRICT



Spurzem Lake

Curly-leaf Pondweed 2013

Spurzem Lake

CLP Rake Density 2013

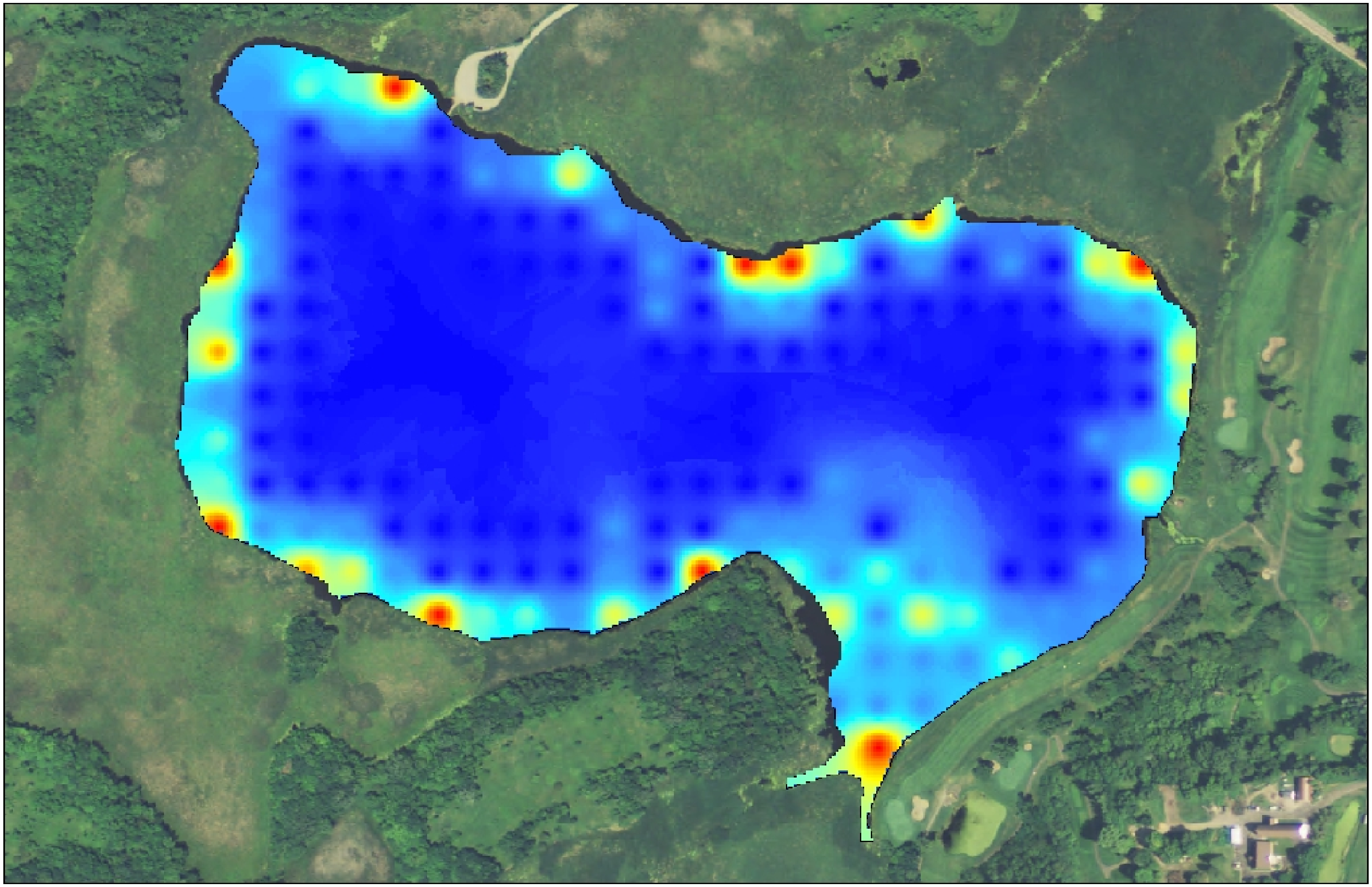
High : 5

Low : 0

N

Water Resources Department
Created by: BV
Map Created: 04/12/2016

ThreeRivers
PARK DISTRICT



Spurzem Lake

CLP Rake Density 2014

High : 5

Low : 0

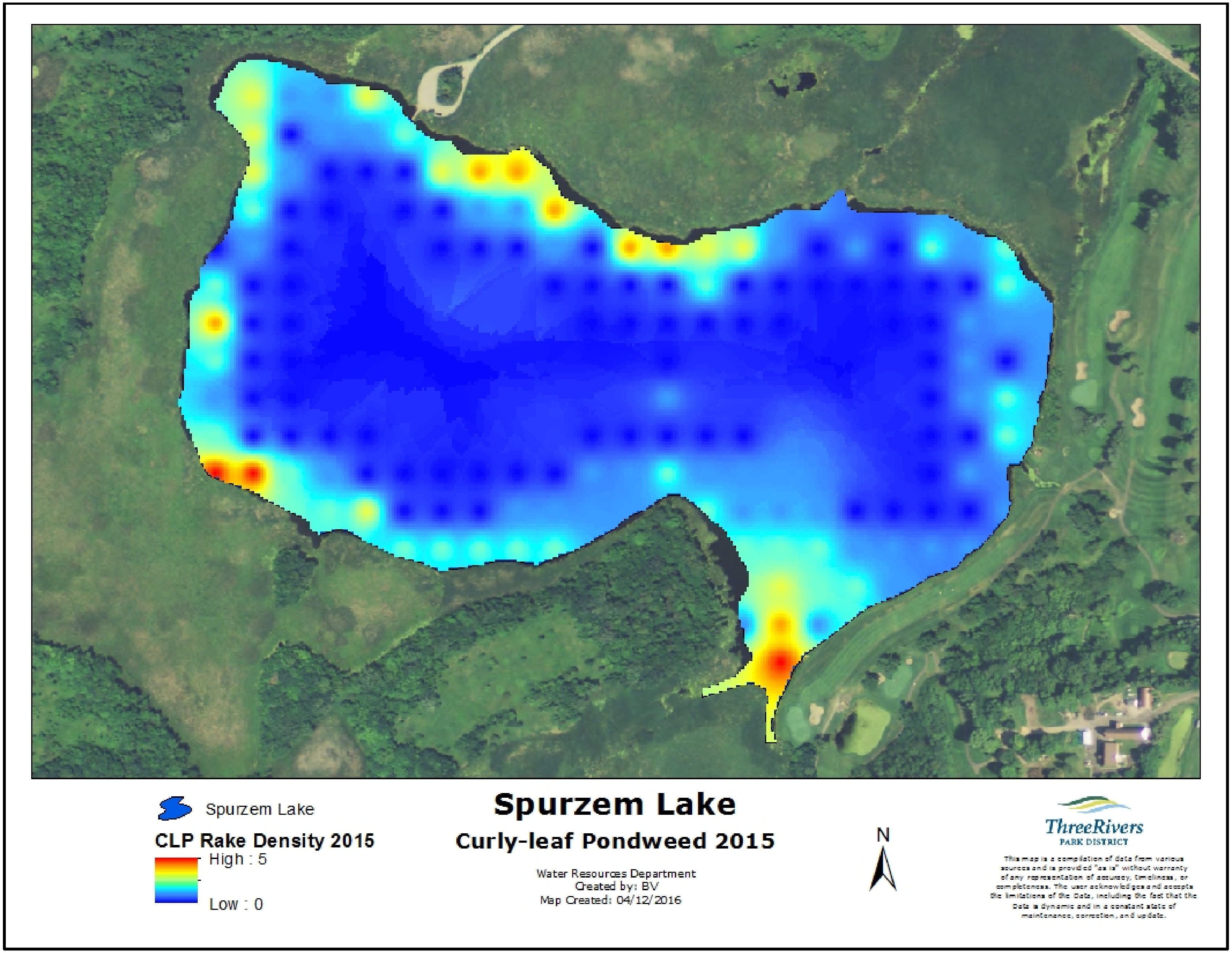
Spurzem Lake

Curly-leaf Pondweed 2014

Water Resources Department
Created by: BV
Map Created: 04/12/2016

N

ThreeRivers
PARK DISTRICT


Spurzem Lake
CLP Rake Density 2015
High : 5
Low : 0
Spurzem Lake
Curly-leaf Pondweed 2015
Water Resources Department
Created by: BV
Map Created: 04/12/2016
N
ThreeRivers
PARK DISTRICT
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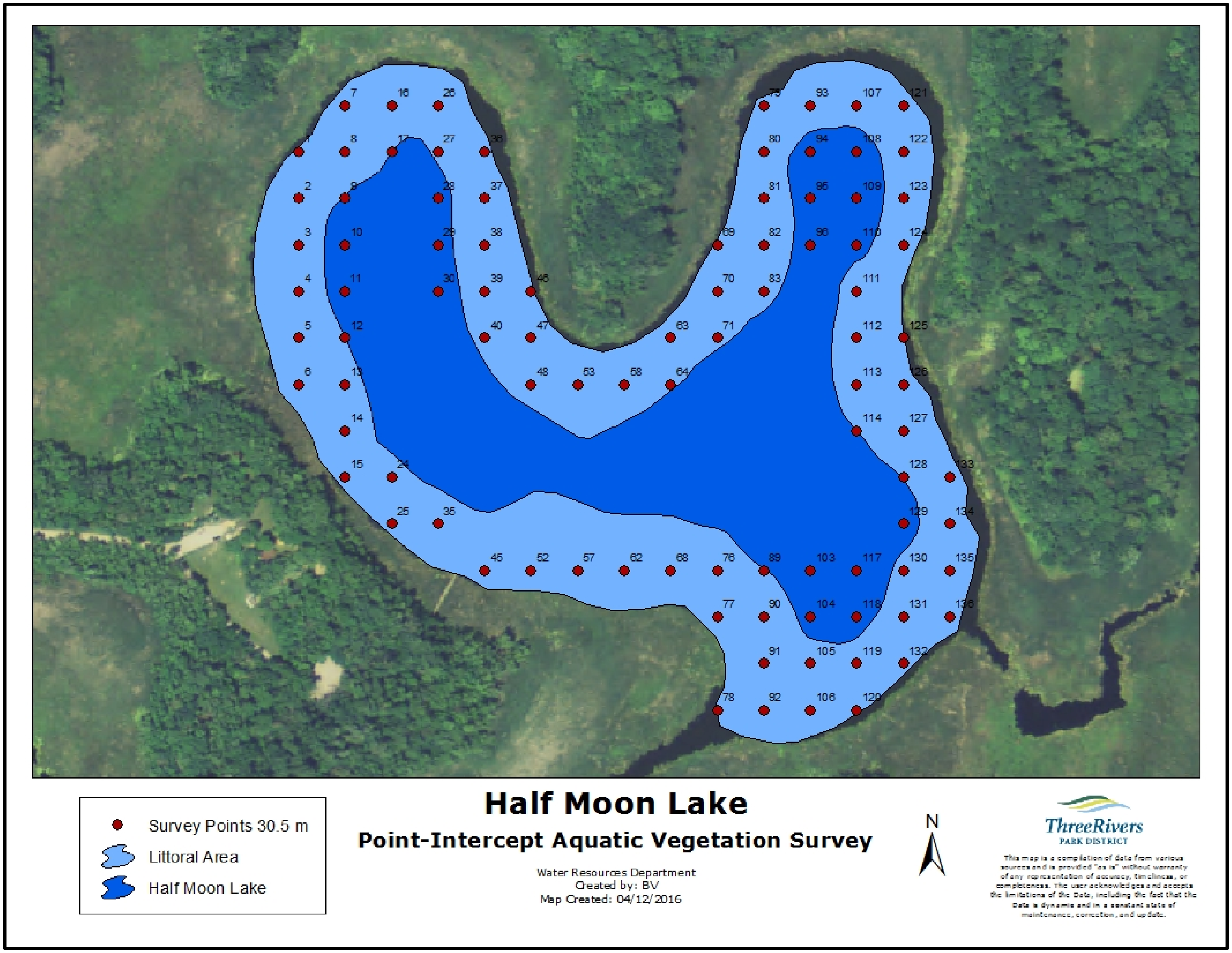
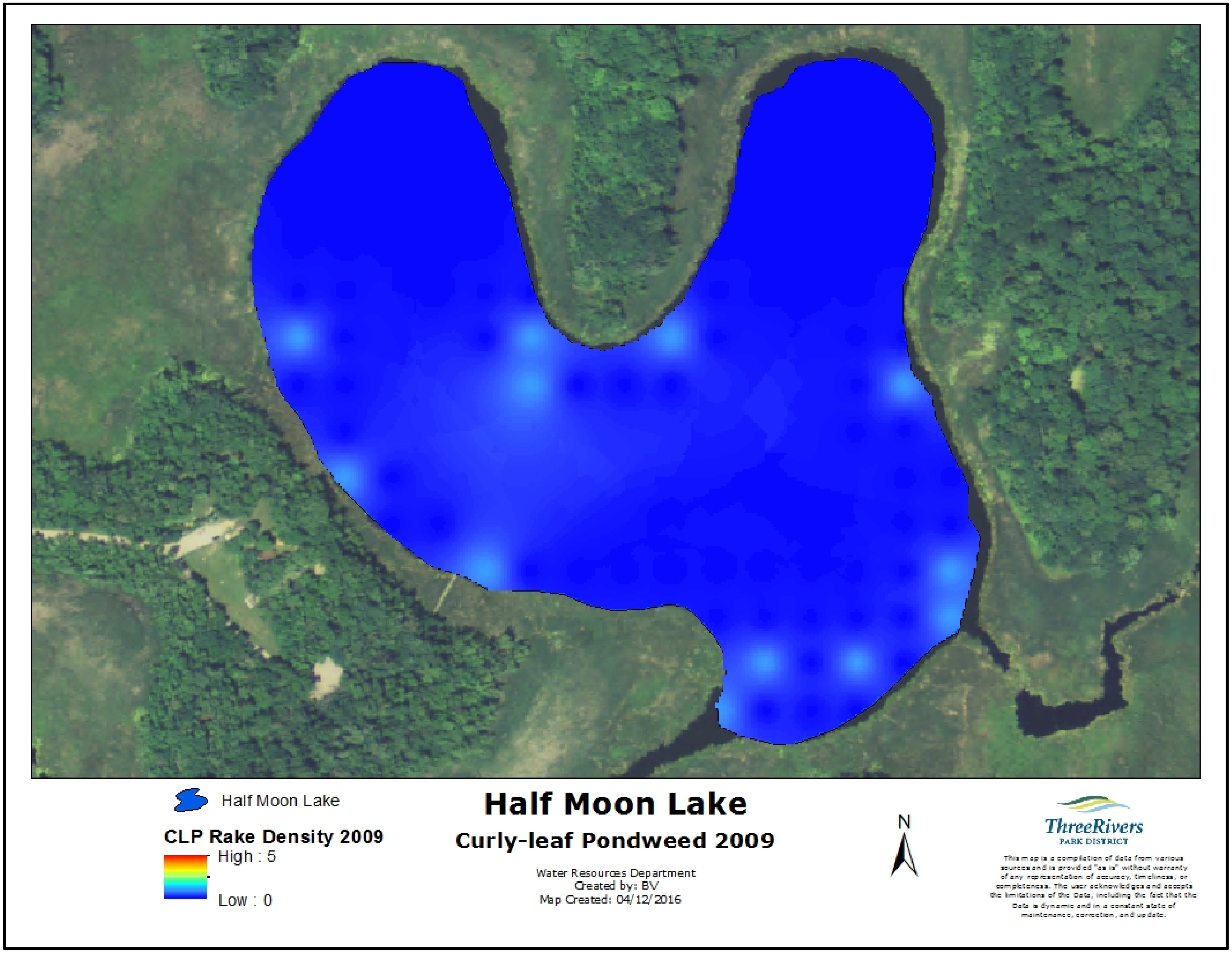
Half Moon Lake



Half Moon Lake											
Year	Month	Day	Max Depth Sampled (m)	Max Depth of Submerged Plant Growth (m)	Vegetated Depth Range Sampled (m)	Number of Points Sampled	Number of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Submersed Vegetation	Average Number of Native Submersed Taxa per Sample Point	Submersed Species Richness (Number of Submerged Species)
2006	6	7	N/A	N/A	N/A	136	41	30.1	34.6	0.53	4
2006	10	15	N/A	N/A	N/A	136	29	21.3	21.3	0.27	2
2009	6	18	N/A	N/A	N/A	95	43	45.3	47.4	0.49	3
2009	9	30	N/A	N/A	N/A	93	34	36.6	36.6	0.36	1
2013	6	20	8.5	2.6	0.6-8.5	93	16	17.2	40.8	0.13	6
2013	8	8	8	1.7	0.6-8.0	93	8	8.6	8.6	0.05	1
2014	6	12	8.2	3.4	1.0-8.2	93	8	7.5	25	0.07	4
2014	8	15	7.9	2.7	1.2-7.9	93	7	7.5	8.6	0.05	4
2015	6	18	N/A	N/A	N/A	93	22	23.7	41.9	0.21	4
2015	8	26	7	2	0.6-7.0	93	12	12.9	12.9	0.1	3

Half Moon Lake Point-intercept Surveys					Native	Non-native	Native					Native	Native	
					Dicots	Monocots						Macroalgae	Dicots	
Year	Month	Numbers of Sample Points in Littoral	Surveyor	**Frequency of Occurrence %**	*Ceratophyllum demersum (Coontail)*	*Potamogeton crispus* (Curly-leaf Pondweed)	*Elodea canadensis* (Canada Waterweed)	*Potamogeton foliosus* (Leafy Pondweed)	*Potamogeton zosteriformis* (Flat-stem Pondweed)	*Stuckenia pectinata* (Sago Pondweed)	*Potamogeton pusilis* (Small Pondweed)	*Chara spp* (Chara)	*Nuphar variegata* (Spatterdock)	*Nymphaea odorata* (White Water Lilly)
2006	Jun-7	136	TRPD		24	16		4	26					
2006	Oct-15	136	TRPD		20				7					
2009	Jun-18	95	TRPD		44	13			5					
2009	Sep-30	93	TRPD		37									
2013	Jun-20	93	TRPD		14	32		1	2	1	1			
2013	Aug-8	93	TRPD		9									
2014	Jun-12	93	TRPD		4	35		1	5					
2014	Aug-15	93	TRPD		5	1	1					1	1	
2015	Jun-18	93	TRPD		14	40		13	3				1	
2015	Aug-26	93	TRPD		13	1			2					


Half Moon Lake
CLP Rake Density 2009
High : 5
Low : 0
Half Moon Lake
Curly-leaf Pondweed 2009
Water Resources Department
Created by: BV
Map Created: 04/12/2016
N
ThreeRivers
PARK DISTRICT
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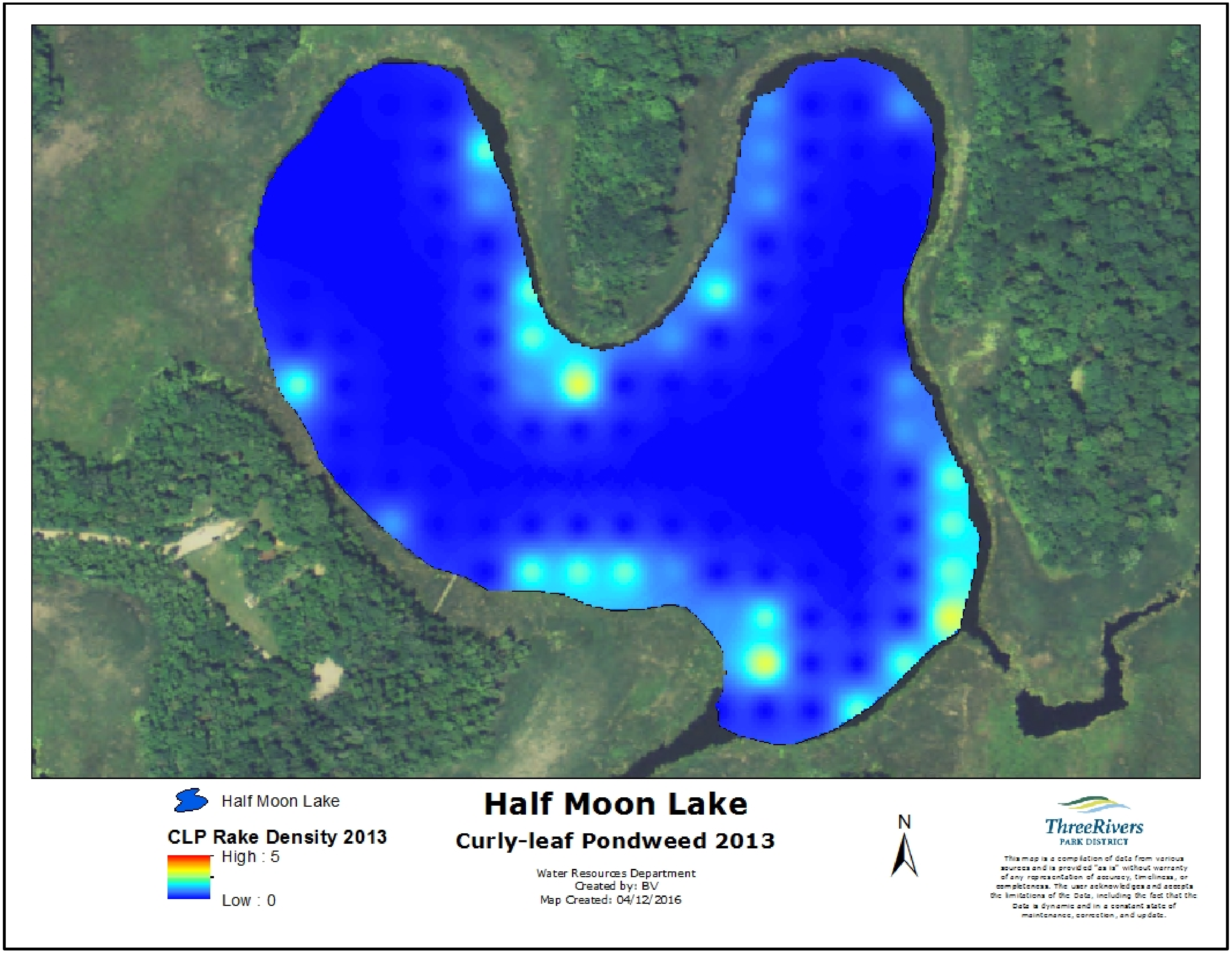
Half Moon Lake
CLP Rake Density 2013
High : 5
Low : 0
Half Moon Lake
Curly-leaf Pondweed 2013
Water Resources Department
Created by: BV
Map Created: 04/12/2016
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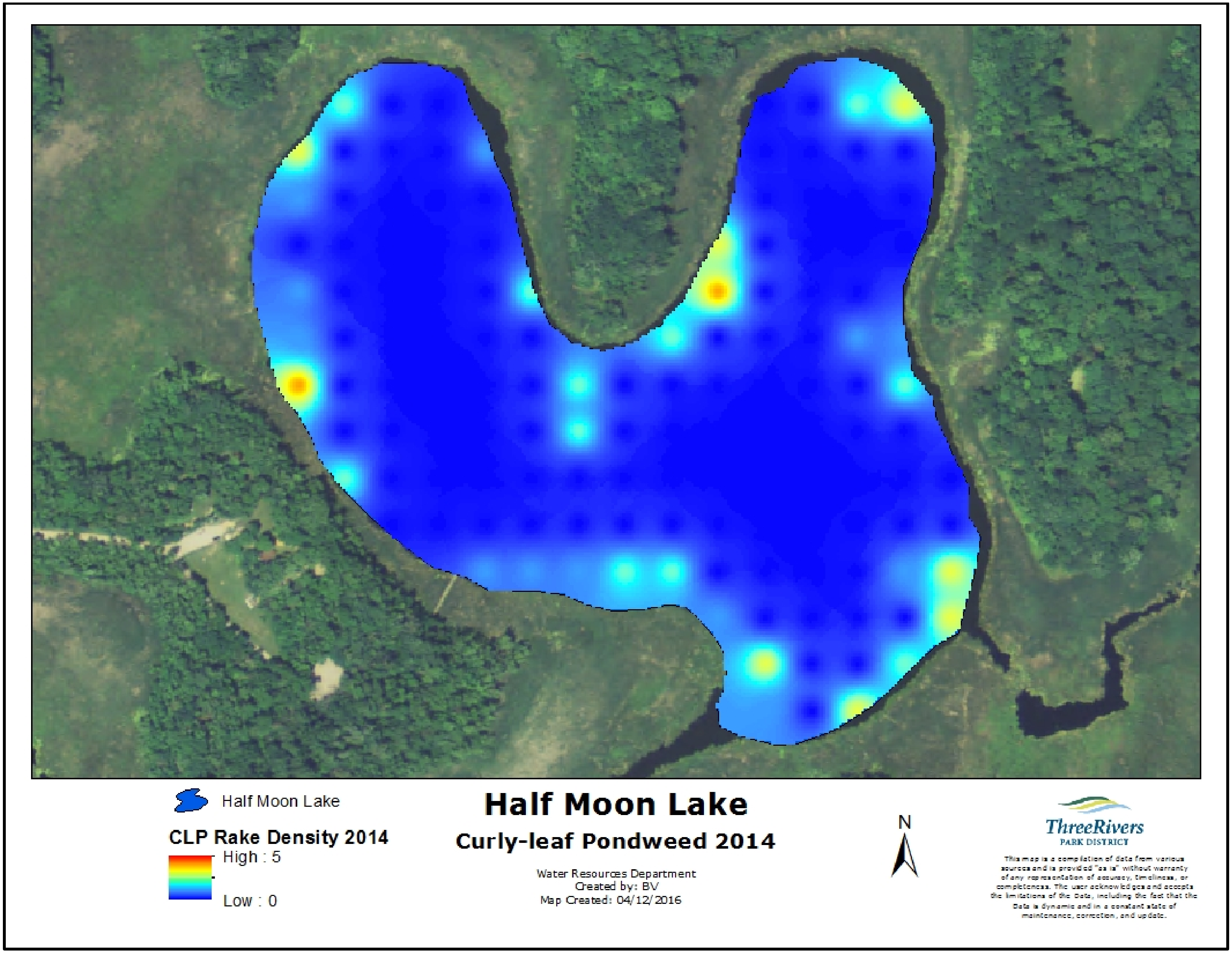

Half Moon Lake
CLP Rake Density 2014
High : 5
Low : 0
Half Moon Lake
Curly-leaf Pondweed 2014
Water Resources Department
Created by: BV
Map Created: 04/12/2016
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PARK DISTRICT
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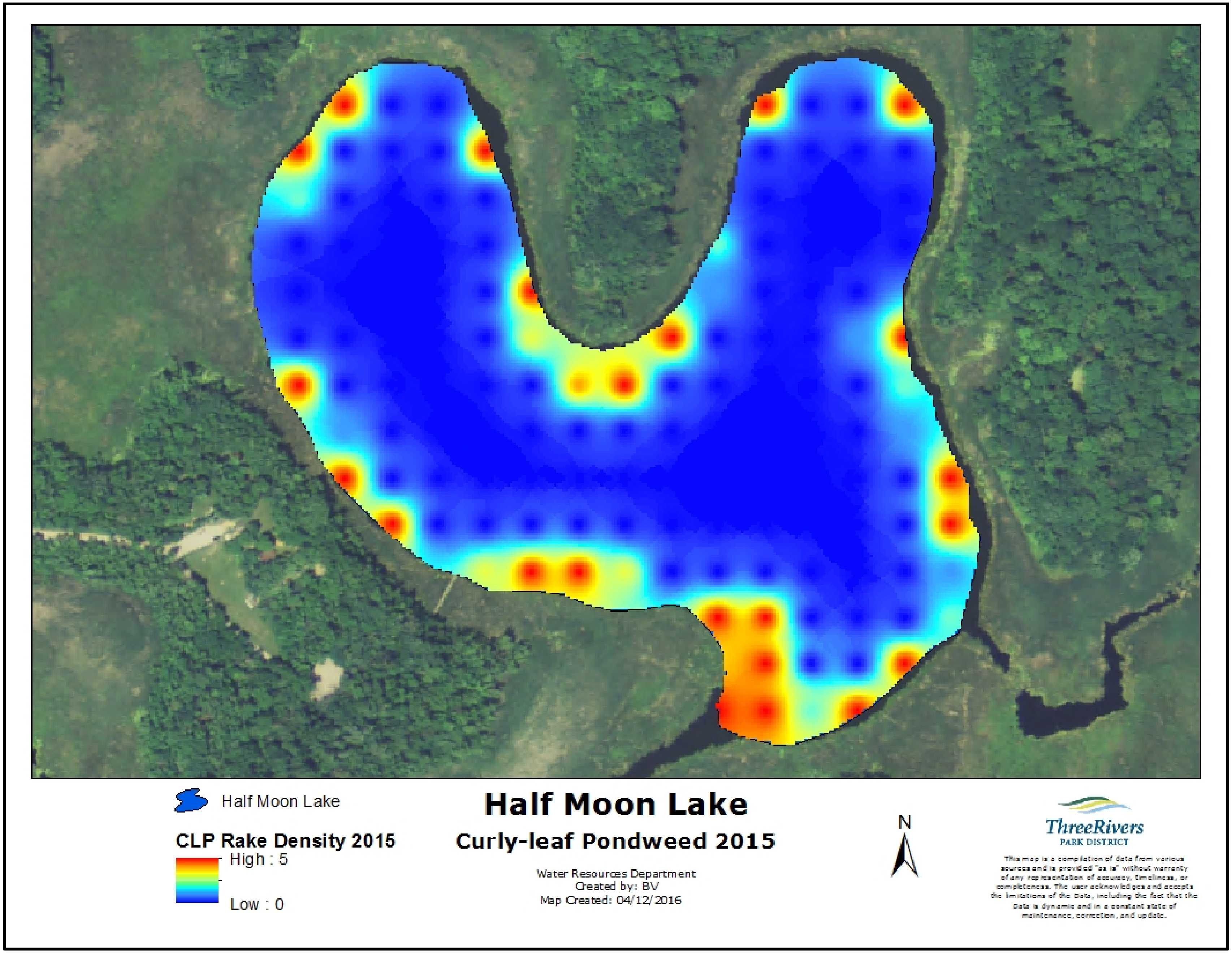

Half Moon Lake
CLP Rake Density 2015
High : 5
Low : 0
Half Moon Lake
Curly-leaf Pondweed 2015
Water Resources Department
Created by: BV
Map Created: 04/12/2016
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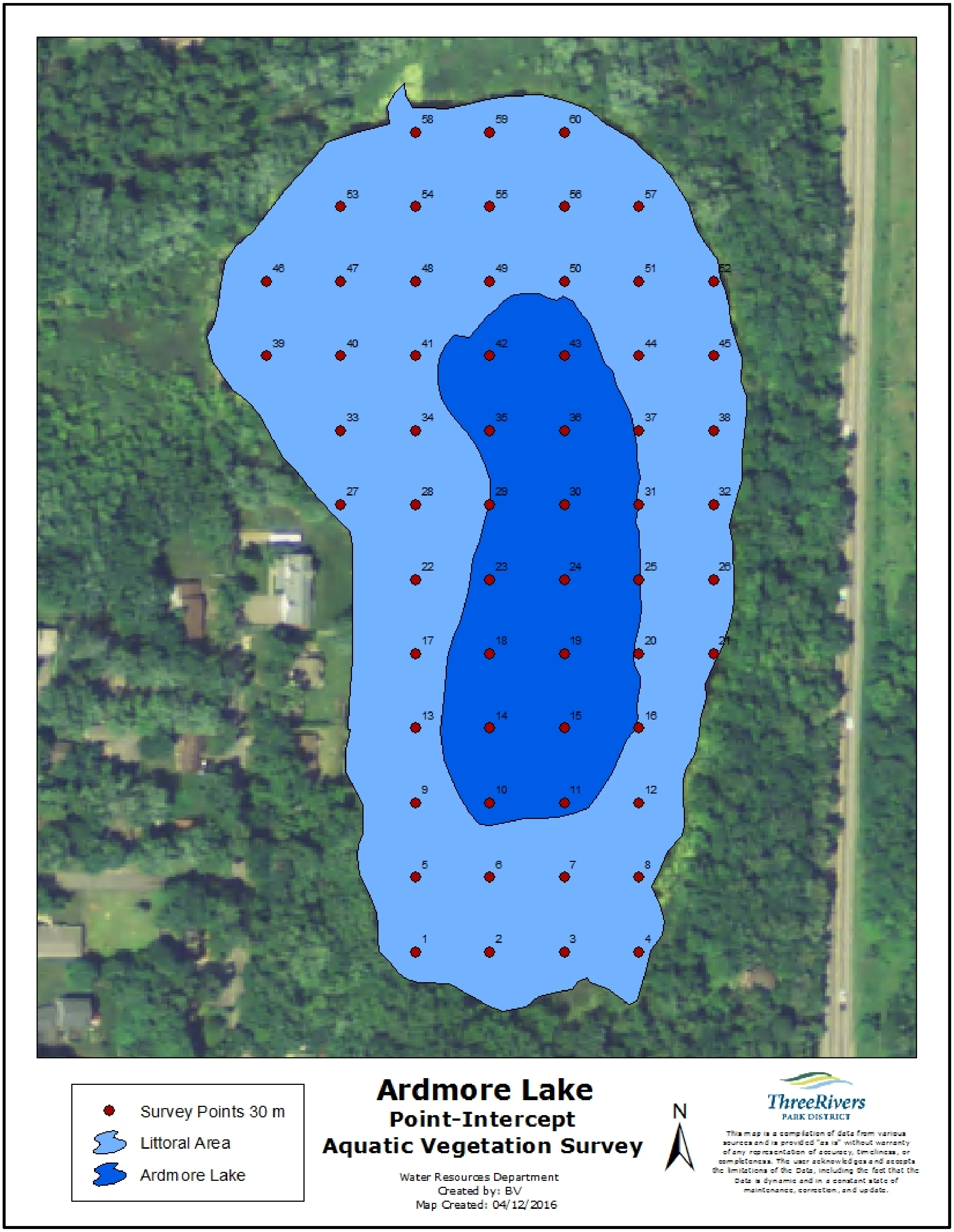
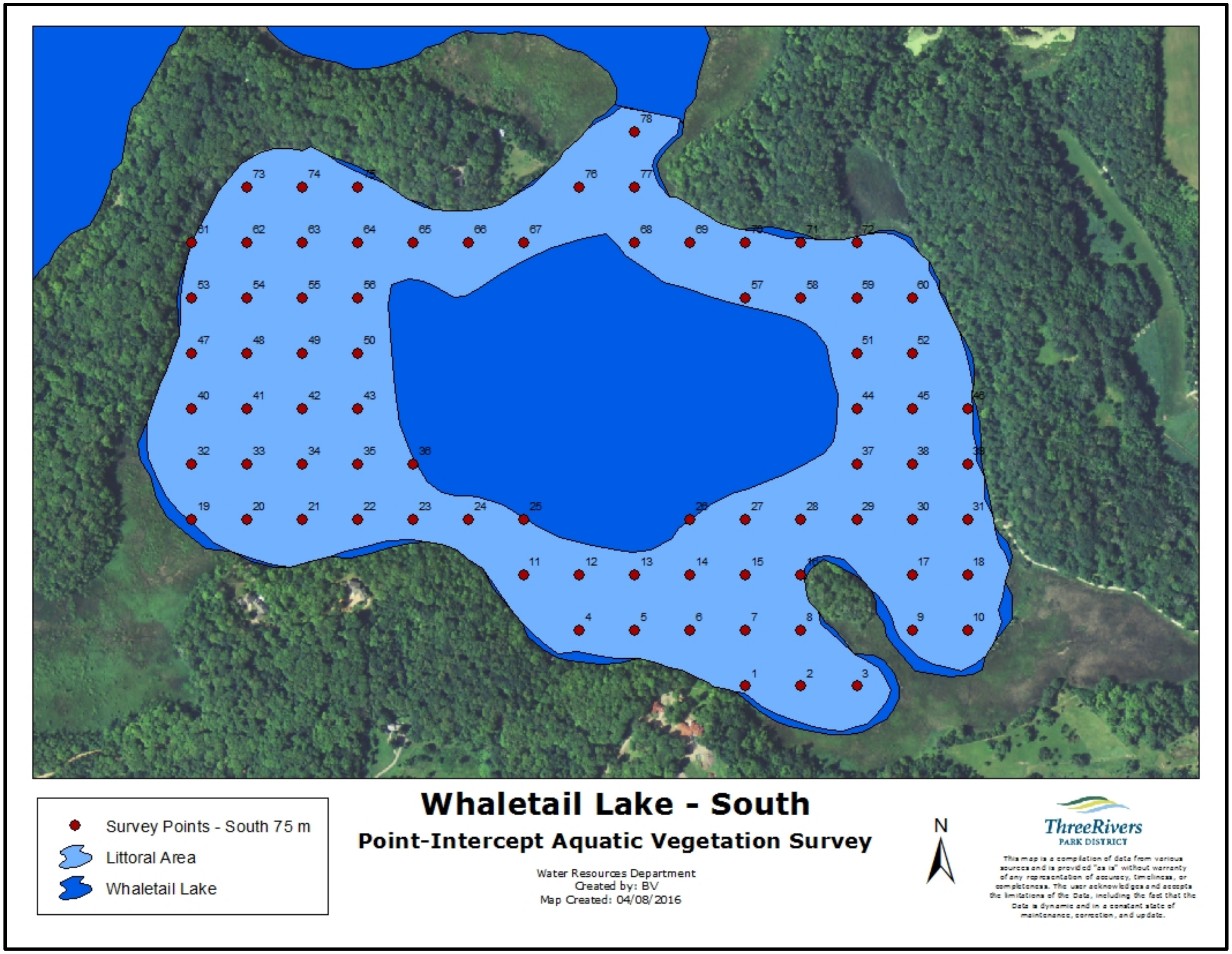
Ardmore Lake



Ardmore Lake											
Year	Month	Day	Max Depth Sampled (m)	Max Depth of Submerged Plant Growth (m)	Vegetated Depth Range Sampled (m)	Number of Points Sampled	Number of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Submersed Vegetation	Average Number of Native Submersed Taxa per Sample Point	Submersed Species Richness (Number of Submerged Species)
2013	6	28	7.4	4.3	0.6-7.7	60	8	13	13	0.15	2
2013	8	8	6.5	0.4	0.4-6.5	60	10	17	17	0.17	1
2014	6	12	6.6	1.1	0.5-6.6	60	15	25	27	0.25	2
2014	8	15	6.8	2.5	0.4-6.8	60	3	5	5	0.06	2
2015	6	19	6.4	0.9	0.4-6.4	60	6	10	10	0.11	2
2015	8	26	6.4	1.1	0.3-6.4	60	3	5	5	0.05	1

Ardmore Lake Point-intercept Surveys					Native	Non-native	Native	Native	
					Dicots	Monocots		Dicots	
Year	Month	Numbers of Sample Points in Littoral	Surveyor	**Frequency of Occurrence %**	*Ceratophyllum demersum (Coontail)*	*Potamogeton crispus* (Curly-leaf Pondweed	*Stuckenia pectinata* (Sago Pondweed)	*Nuphar variegata* (Spatterdock)	*Nymphaea odorata* (White Water Lilly)
2013	Jun-28	60	TRPD		2		13		
2013	Aug-8	60	TRPD				17		
2014	Jun-12	60	TRPD			2	25		
2014	Aug-15	60	TRPD		2		5		
2015	Jun-19	60	TRPD		3		8		
2015	Aug-26	60	TRPD		5				

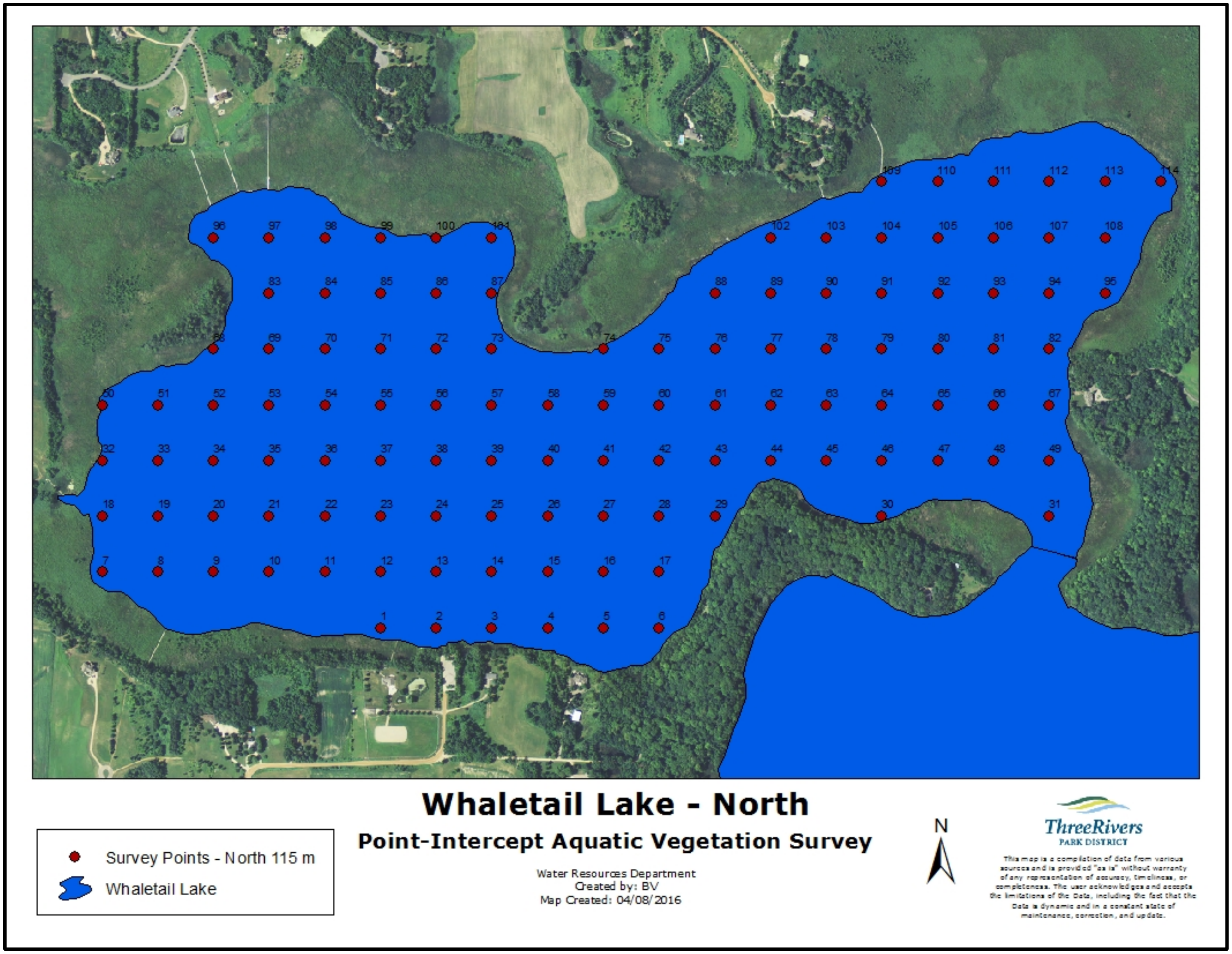
Whaletail Lake – South



Whaletail Lake (South)											
Year	Month	Day	Max Depth Sampled (m)	Max Depth of Submerged Plant Growth (m)	Vegetated Depth Range Sampled (m)	Number of Points Sampled	Number of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Submersed Vegetation	Average Number of Native Submersed Taxa per Sample Point	Submersed Species Richness (Number of Submerged Species)
2013	7	9	5.2	3.9	0.4-5.2	78	28	36	38	0.56	6
2013	8	20	5.2	2.7	0.4-5.2	78	28	36	41	0.51	7

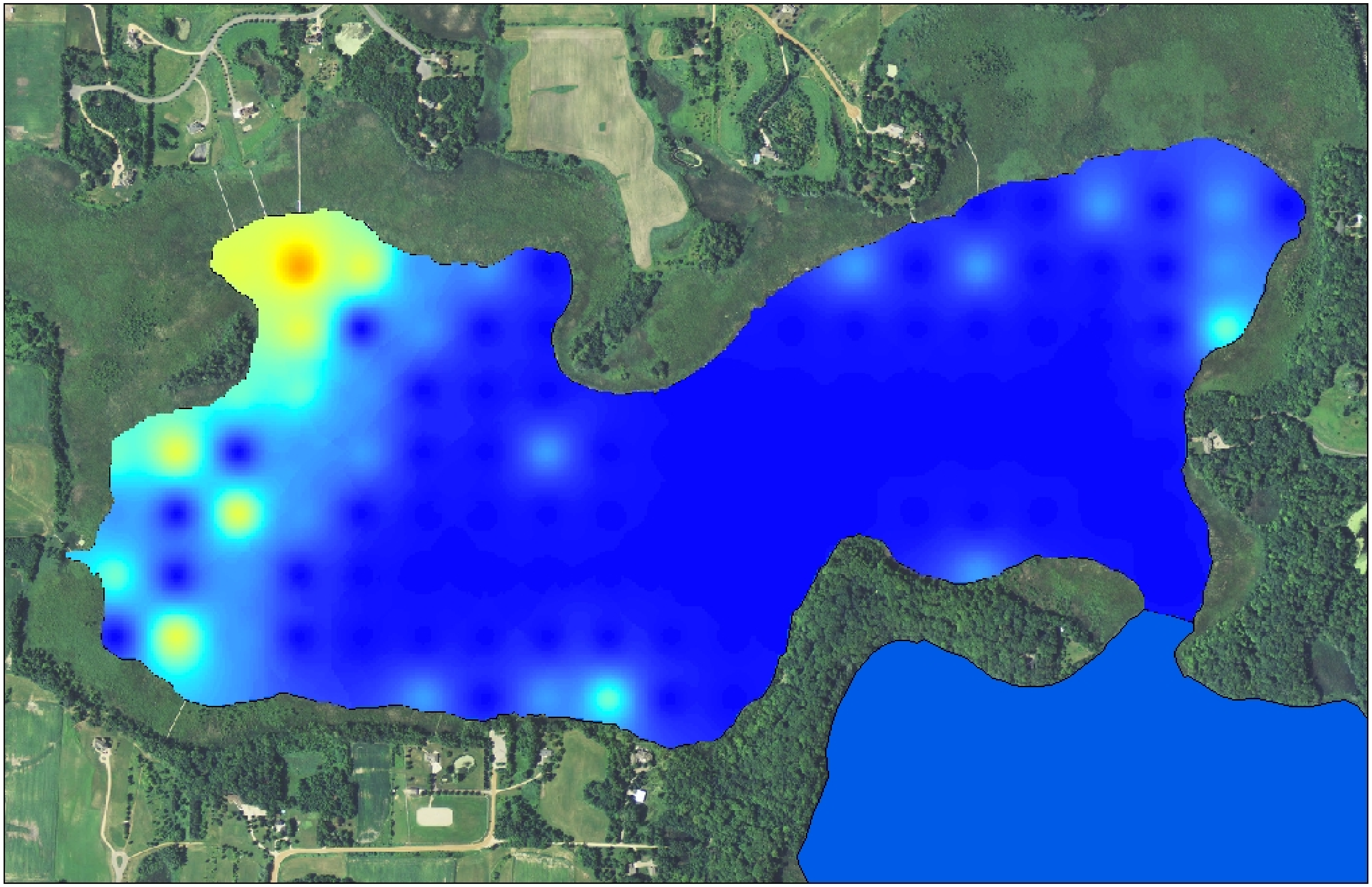
Whaletail Lake (South) Point-intercept Surveys					Non-native	Native		Non-native	Native				Native		
					Dicots			Monocots					Dicots		
Year	Month	Numbers of Sample Points in Littoral	Surveyor	**Frequency of Occurrence %**	*Myriophyllum spicatum* (Eurasian Water Milfoil)	*Myriophyllum sibiricum* (Northern Water Milfoil)	*Ceratophyllum demersum (Coontail)*	*Potamogeton crispus* (Curly-leaf Pondweed)	*Potamogeton zosteriformis* (Flat-stem Pondweed)	*Potamogeton amplifolius* (Large-leaf Pondweed)	*Stuckenia pectinata* (Sago Pondweed)	*Potamogeton natans* (Floating Leaf Pondweed)	*Nuphar variegata* (Spatterdock)	*Nelumbo lutea* (American Lotus)	*Nymphaea odorata* (White Water Lilly)
2013	Jul-9	78	TRPD		24		35	3	15	4	3		3		23
2013	Aug-20	78	TRPD		22	1	33		9	3	4	1	3	8	21

Whaletail Lake – North



Whaletail Lake (North)											
Year	Month	Day	Max Depth Sampled (m)	Max Depth of Submerged Plant Growth (m)	Vegetated Depth Range Sampled (m)	Number of Points Sampled	Number of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Native Submersed Vegetation	Percentage of Points Sampled with Submersed Vegetation	Average Number of Native Submersed Taxa per Sample Point	Submersed Species Richness (Number of Submerged Species)
2013	7	9	2.7	2.1	0.5-2.7	114	71	62	65	1.07	8
2013	8	21	2.6	2.1	0.5-2.6	114	72	63	71	1.24	9

Whaletail Lake (North) Point-intercept Surveys					Non-native	Native		Non-native	Native						Native	Native	
					Dicots			Monocots							Macroalgae	Dicots	
Year	Month	Numbers of Sample Points in Littoral	Surveyor	**Frequency of Occurrence %**	*Myriophyllum spicatum* (Eurasian Water Milfoil)	*Myriophyllum sibiricum* (Northern Water Milfoil)	*Ceratophyllum demersum (Coontail)*	*Potamogeton crispus* (Curly-leaf Pondweed)	*Potamogeton zosteriformis* (Flat-stem Pondweed)	*Potamogeton amplifolius* (Large-leaf Pondweed)	*Potamogeton praelongus (White Stem Pondweed)*	*Stuckenia pectinata* (Sago Pondweed)	*Potamogeton natans* (Floating Leaf Pondweed)	*Potamogeton pusilis* (Small Pondweed)	*Chara spp* (Chara)	*Nuphar variegata* (Spatterdock)	*Nymphaea odorata* (White Water Lilly)
2013	Jul-9	114	TRPD		42		12	28	55	10	11	6	9		6	1	11
2013	Aug-21	114	TRPD		48	27	11	1	54	10		17		1	5	4	18



Whaletail Lake

CLP Rake Density 2013

High : 5

Low : 0

Whaletail Lake - North

Curly-leaf Pondweed 2013

Water Resources Department
Created by: BV
Map Created: 04/12/2016

N

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PARK DISTRICT

Appendix E: Internal Phosphorus Loading and Sediment Phosphorus Fractionation Reports

Internal Phosphorus Loading and Sediment Characteristics for Peter Lake, Minnesota

Aerial view of Peter Lake, MN (Google maps)

18 January, 2016

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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 Peter 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 two stations (North and South) in Peter Lake for determination of rates of P release under aerobic and anaerobic conditions. 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, 2016. 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 °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 °C for determination of moisture content, wet and dry bulk density, and burned at 500 °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. As with earlier studies, sediment was very flocculent with the potential for becoming unconsolidated and separated during incubation, necessitating 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 1). P concentration increases were slightly higher for sediment cores collected at the south station in Peter Lake. Mean SRP concentrations in the overlying water column at the end of the incubation period were moderately high at 0.534 mg/L (±0.091 standard error; SE) and 0.611 mg/L (± 0.082 SE; Table 4). Overall, mean anaerobic P release rates were moderately high and similar at both Peter Lake stations, ranging between 5.29 mg/m^2 d and 6.37 mg/m^2 d for the north and south station, respectively (Table 4). These rates fell near the median compared to other Minnesota lakes in the metropolitan region (Fig. 2).

Not surprisingly, soluble phosphorus accumulation in the overlying water column was lower under aerobic versus anaerobic conditions (Figure 3). However, both P mass and concentration increased linearly over the 10-day incubation period. Mean P concentrations at the end of the incubation period were relatively high at 0.129 mg/L (± 0.021 SE) and 0.122 mg/L (± 0.032 SE; Table 4) for the north and south station sediments, respectively, and could represent an important available P source for assimilation by algae. The mean aerobic P release rate was also substantial at 1.25 to 1.44 mg/m^2 d (Table 4) and fell well above the upper 25% quartile compared to Minnesota Lakes in the region (Fig. 2).

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). Organic matter content was also moderately high at 24% and 29% for north and south station sediments, respectively (Table 5).

Total P concentrations in the upper 10-cm sediment layer were relatively high at both stations due to high concentrations of iron-bound P and aluminum-bound P (Table 6 and 7). The biologically-labile P fraction (i.e., sum of loosely-bound, iron-bound, and labile organic P) was dominated by iron-bound P at ~ 72% (Table 6 and Fig. 4). In addition, loosely-bound, iron-bound, labile organic, and aluminum-bound P concentrations fell above the upper 25% quartile compared to other Minnesota Lakes in the metropolitan region (Fig. 5). In particular, loosely-bound P, which reflects porewater P, was unusually high relative to other Minnesota lakes at ~ 0.190 mg/g. Iron-bound P, which has been empirically related to anaerobic P flux (Nürnberg 1988), was very high at ~ 1.41 to 1.99 mg/g. For Peter Lake, however, anaerobic P flux was low relative to iron-bound P. This pattern may have been related to other factors such as potentially high aluminum (Al) concentrations in the sediment. Although not measured for this study, high Al can play a role in sequestering P under anaerobic conditions. Because aluminum-bound P was also high in Peter Lake sediments, it follows that Al concentrations may also be high.

ACKNOWLEDGMENTS

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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.

Station location	P Flux		P fractions
	Aerobic	Anaerobic	upper 10 cm
North	2	2	1
South	2	2	1

Table 2. Sediment physical-textural characteristics and phosphorus species 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 in Peter Lake, MN.

Station	Sediment P release rate			
	Aerobic		Anaerobic	
	(mg/m^2 d)	(mg/L)	(mg/m^2 d)	(mg/L)
North	1.44 (0.16)	0.129 (0.021)	5.29 (1.22)	0.534 (0.091)
South	1.25 (0.35)	0.122 (0.032)	6.37 (0.74)	0.611 (0.082)

Table 5. Textural characteristics in the upper sediment layer for sediment cores collected in various lakes in Peter Lake, MN.

Lake	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Organic Matter (%)
North	93.8	1.030	0.064	24.0
South	94.9	1.023	0.053	29.1

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 for sediment cores collected in Peter Lake, MN. DW = dry mass.

Lake	Total P	Redox P		Bio-labile P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
North		1.597	#DIV/0!	1.959	#DIV/0!
South		2.181	#DIV/0!	2.723	#DIV/0!

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

Lake	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)
North	0.188	1.409	87	0.362	3.420
South	0.195	1.986	102	0.542	2.662

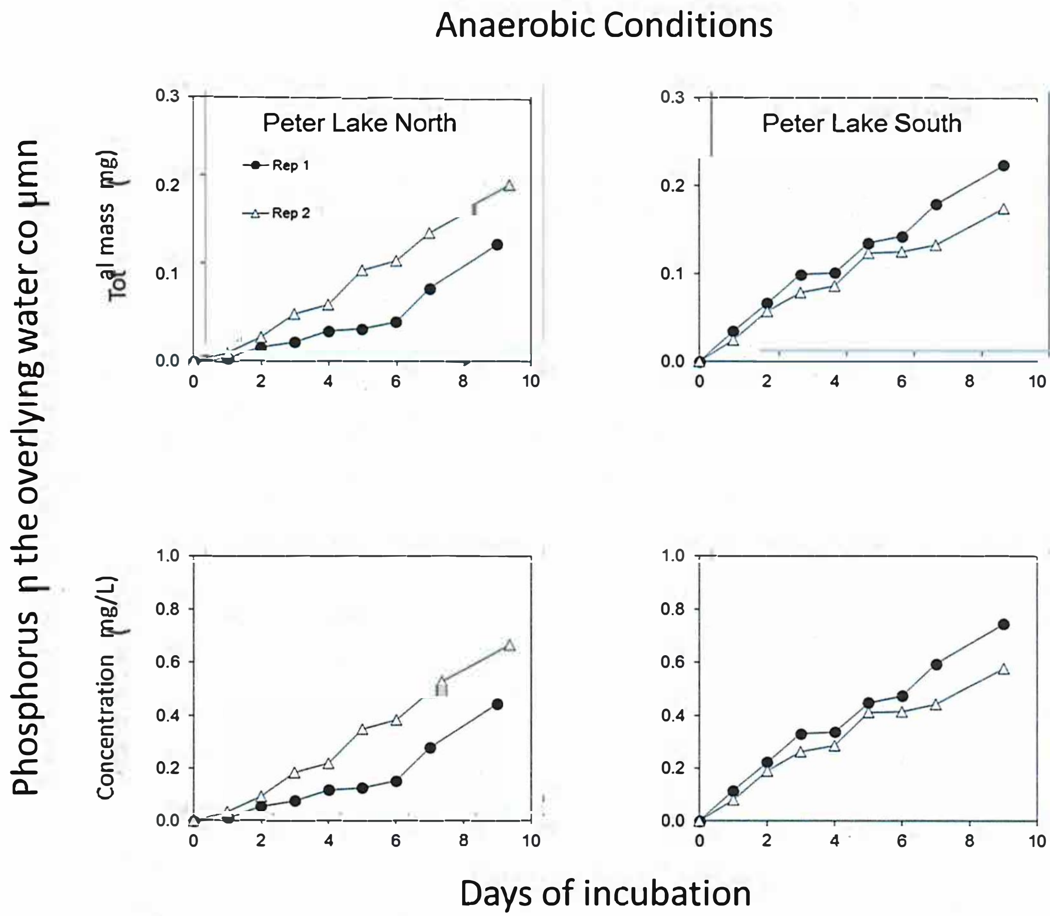

Figure 1. Changes in soluble reactive phosphorus mass (upper panels) and concentration (lower panels) in the overlying water column under anaerobic conditions versus time for sediment cores collected from Peter Lake.

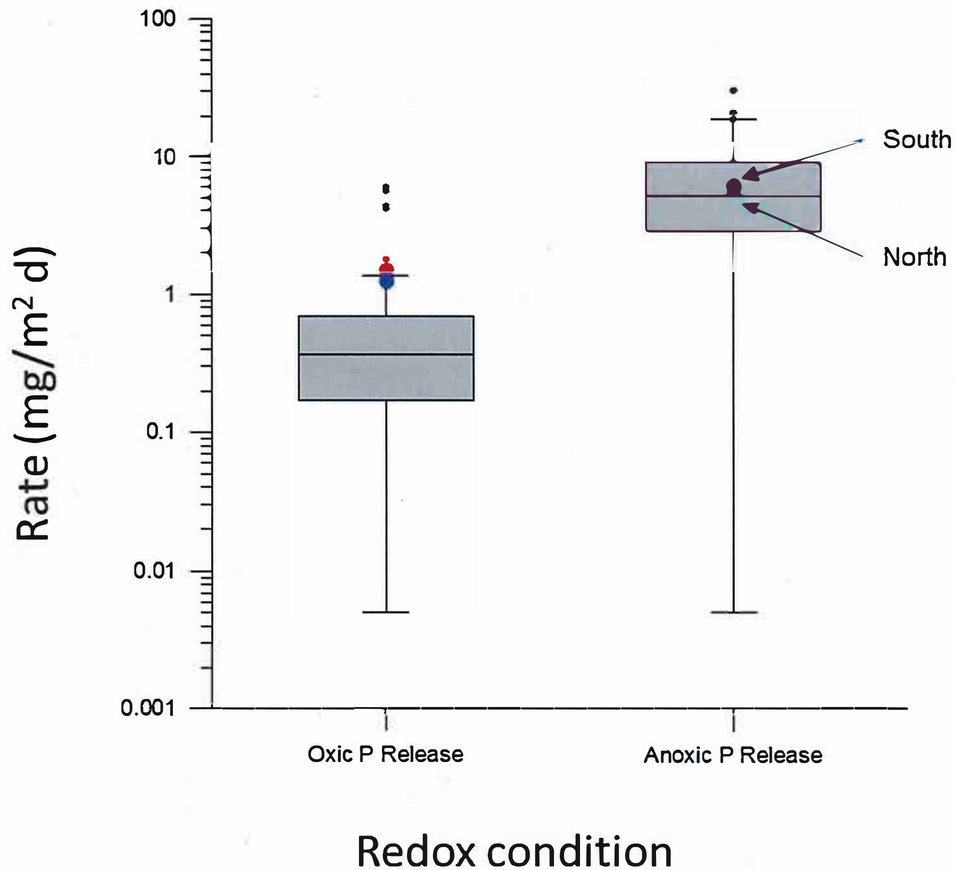

Figure 2. Box and whisker plot comparing the aerobic (i.e., oxic) and anaerobic (i.e., anoxic) phosphorus (P) release rate measured for north and south station sediments collected in Peter Lake with statistical ranges (n=50) for lakes in the State of Minnesota.

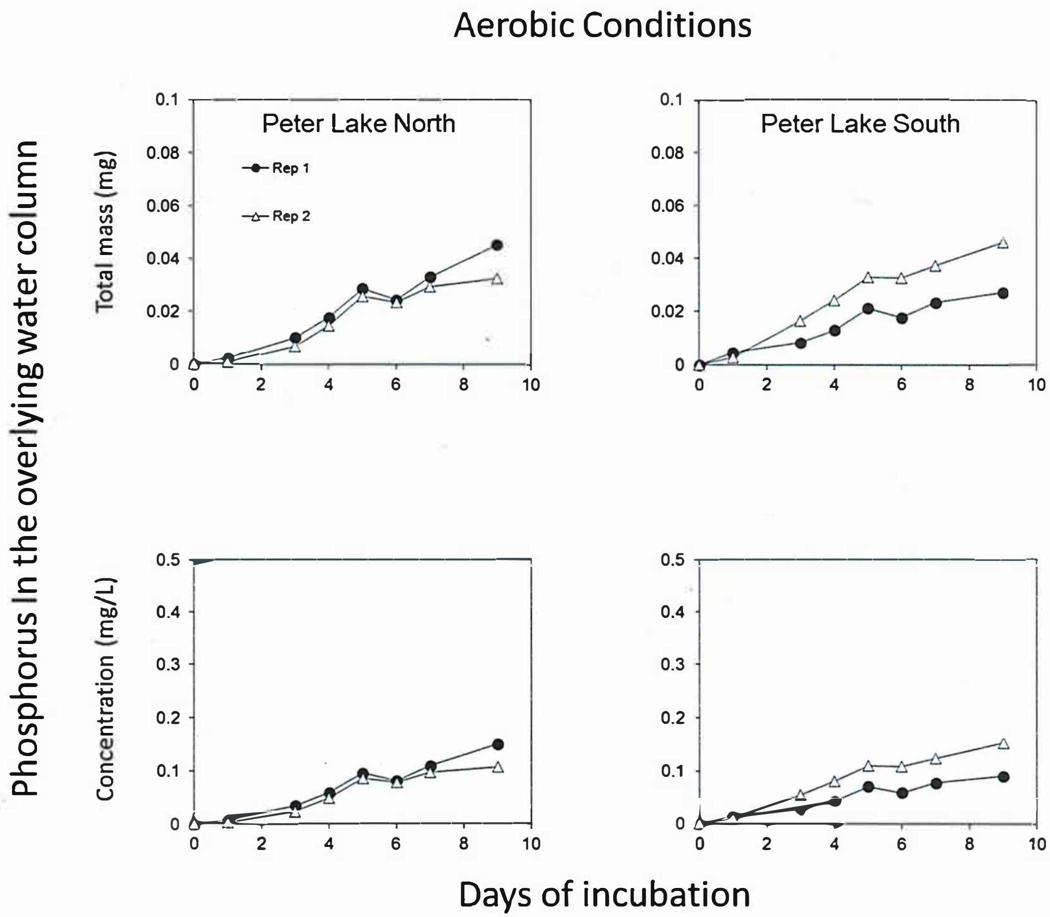

Figure 3. Changes in soluble reactive phosphorus mass (upper panels) and concentration (lower panels) in the overlying water column under aerobic conditions versus time for sediment cores collected from Peter Lake.

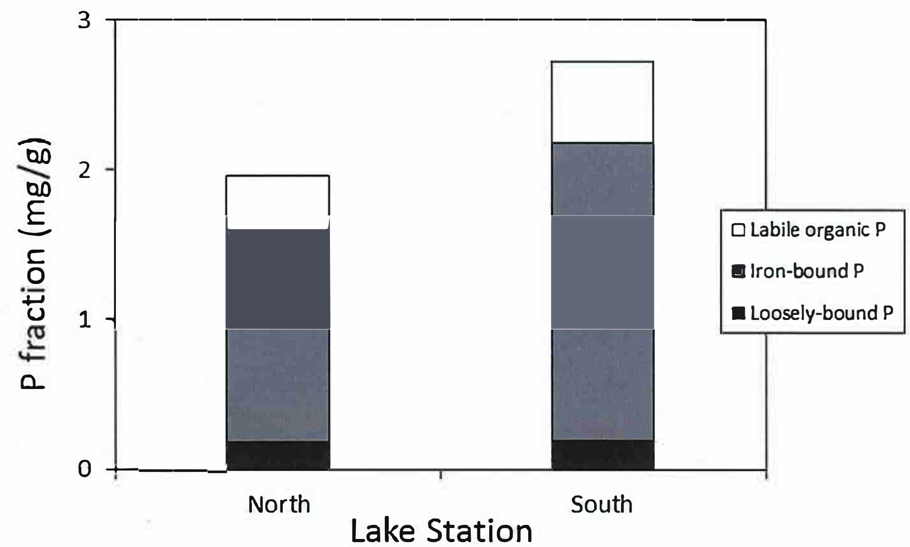

Figure 4. The composition of the biologically-labile phosphorus (P) fraction (i.e., loosely-bound, iron-bound, and labile organic P) for the upper 10-cm sediment section.

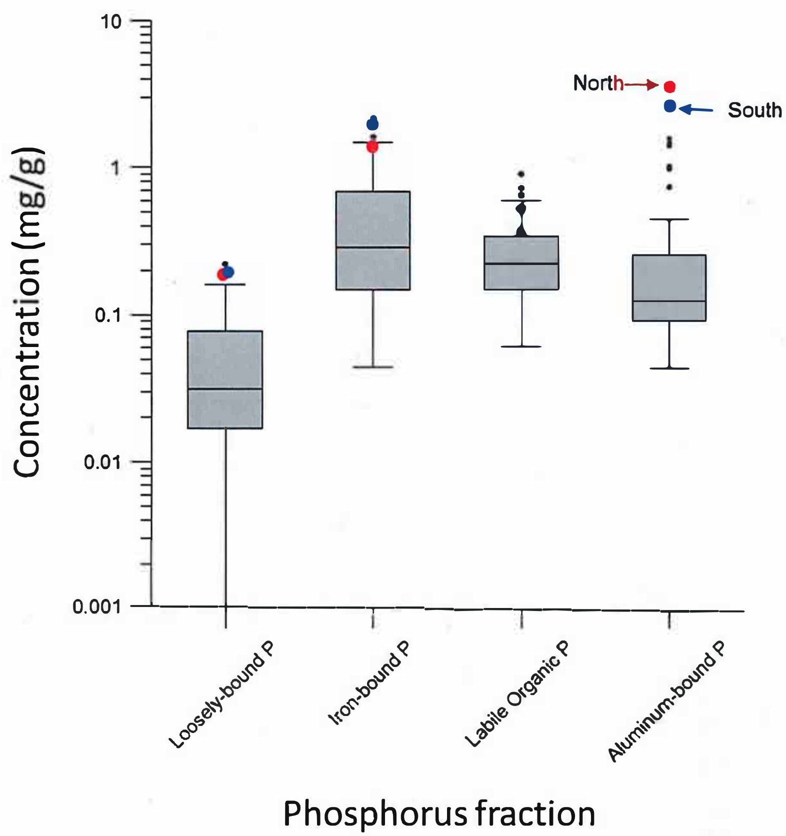

Figure 5. Box and whisker plots comparing various sediment phosphorus (P) fractions measured in the upper 10-cm section of Peter Lake sediments with statistical ranges (n=50) for lakes in the State of Minnesota.

Internal Phosphorus Loading and Alum Dosage Considerations for Lakes in the Pioneer Creek Watershed, Minnesota

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OBJECTIVES

The objectives of these investigations were to examine rates of phosphorus (P) release, sediment chemistry, and the aluminum sulfate dosage required to sequester mobile P fractions in the upper sediment layer that are contributing to internal P loading in Ardmore, Half Moon, and Spurzum Lake of the Pioneer Creek watershed, Hennepin County, Minnesota . The specific outcomes and deliverables of this research were to,

1. determine rates of P release from intact sediment cores under laboratory-controlled temperature and redox (i.e., aerobic and anaerobic) conditions,
2. examine spatial and vertical variations in biologically-labile (i.e., subject to recycling via Eh, pH, and bacterially-mediated reactions in the sediment; loosely-bound, iron-bound, and labile organic P) P fractions that are potentially active in sediment internal P loading,
3. estimate aluminum sulfate (as aluminum; Al) dosage for binding redox-sensitive P (i.e., the loosely-bound and iron-bound P fractions) in the upper sediment layer of , and,
4. provide a cost estimate for Al treatment based on susceptible areas in these lakes.

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 one central station in Ardmore and Half Moon Lake and from the east and west lobe of Spurzem Lake for determination of rates of P release under aerobic and anaerobic conditions. Additional sediment cores collected at these stations were sectioned vertically over the upper 10-cm layer to evaluate variations in sediment physical-textural and chemical characteristics for Al dosage estimation. Cores were sectioned at 1-cm intervals over the first 6 cm and at 2-cm intervals between 6 and 10 cm. Additional cores collected at these same lake stations were also analyzed for mean sediment characteristics over the upper 10-cm layer.

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 each 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).

Al dosage determination

Mixed sediment from the upper 10-cm section was subjected to a range of aluminum sulfate (as Al) concentrations to determine the dosage required to inactivate the redox-P fraction (Rydin and Welch 1999). Alum (as aluminum sulfate; $Al_2(SO_4)_3 \cdot 18\ H_2O$) was combined with 0.1 M sodium bicarbonate ($NaHCO_3$) to a concentration of 0.7 g Al/L to form an aluminum hydroxide ($Al(OH)_3$) floc. Aliquots of this solution, diluted to a final volume of 10 mL with distilled water, were added to centrifuge tubes containing the equivalent of 0.025 g dry weight (DW) of fresh sediment to obtain Al concentrations ranging from 0 (i.e., control) to ~ 50 mg Al/g DW sediment. The assay tubes were shaken for a minimum of 2 hours at 20 ^{o}C in a darkened environmental chamber, centrifuged at 500 g to concentrate the sediment, and decanted for redox-P determination (see *Sediment chemistry* above).

Al dosage was estimated as the concentration (g/m^2) required to bind at least 90% of the redox-P. The dry mass concentration of redox-P (mg/g) was converted to an areal concentration (g/m^2) as,

$$\text{Redox-P (g/m}^2) = \text{Redox-P (mg/g)} \cdot \rho\ (\text{g/cm}^3) \cdot \theta \cdot h\ (\text{m}) \cdot 1{,}000{,}000\ (\text{cm}^3/\text{m}^3) \cdot 0.001\ (\text{g/mg}) \qquad 1)$$

where, ρ is sediment bulk density (g/cm^3), θ is the percentage of sediment solids (100 – percent moisture content; dimensionless), and h is sediment thickness (m). The Al concentration (g/m^2) was estimated as,

$$Al\ (g/m^2) = Redox\text{-}P\ (g/m^2) \cdot Al{:}P_{90\%} \tag{2}$$

where, $Al{:}P_{90\%}$ is the binding ratio required to adsorb at least 90% of the redox-P in the sediment.

Maximum allowable Al dosage based on alkalinity and pH

Addition of aluminum sulfate to a lake leads to hydrolysis and the liberation of hydrogen ions which lowers the pH of the water column. Since Al toxicity to the biota can occur if the pH falls below ~4, maintaining a pH ≥ 6.0 as a margin of safety should also be considered in dose determination (Cooke et al. 2005). For situations where alkalinity is low or the required dosage exceeds the maximum allowable dosage to maintain pH ≥ 6.0, a buffered aluminum sulfate-sodium aluminate treatment will be needed to maintain pH near neutrality. Surface water collected from each lake was analyzed for total alkalinity and pH according to APHA (2005). A titration procedure was used to determine the maximum allowable dosage of aluminum sulfate that can be added and yet maintain pH above 6.0 (Cooke et al. 2005). A 1.25 g Al/L solution of $Al_2(SO_4)_3 \cdot 18\ H_2O$ was used as the titrant: 1.0 mL additions to 500 mL of lake water were each equivalent to 2.5 mg Al/L. Lake water was titrated with the Al solution until an endpoint of pH 6 was reached. The total volume (mL) of Al solution needed to titrate lake water to pH 6 was multiplied by 2.5 mg Al/L to estimate the maximum allowable concentration. This calculation was then compared with estimates based on sediment redox-P to ensure that the latter was at or below the maximum allowable dosage. Caution needs to be used because a vertical alkalinity and pH profile over the entire vertical water column needs to be estimated in order to more accurately evaluate the maximum allowable dosage.

RESULTS AND INTERPRETATION

Sediment phosphorus release rates

Sediment cores collected from all lakes were very flocculent. In addition, sediment collected from Ardmore Lake contained benthic algae at the sediment-water interface (Figure 1). Sediment material in Spurzem Lake incubation systems 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 rapidly and linearly in the overlying water column of duplicate sediment incubation systems (Figure 2). Mean SRP concentrations in the overlying water column at the end of the incubation period were high at 2.329 mg/L (±0.125 standard error; SE), 0.684 mg/L (±0.137 SE), 1.585 mg/L (±0.266 SE), and 0.670 mg/L (±0.237 SE) for Ardmore, Half Moon, and Spurzem Lake stations 1 and 2, respectively (Table 4).

Overall, mean anaerobic P release rates were relatively high for lake sediments in the Pioneer Creek watershed (Table 4). The mean rate was greatest for Ardmore Lake sediment at 21.3 mg/m^2 d (±2.3 SE; Figure 3). Sediment cores collected from Spurzem 1 also exhibited a very high anaerobic P release rate of 19.1 mg/m^2 d (±3.0 SE). Half Moon Lake and Spurzem 2 sediments exhibited lower rates compared to the other stations (Figure 3). Nevertheless, these ranges reflected rates measured in eutrophic to hypereutrophic lake systems (Nürnberg 1988). When compared to linear regression relationships developed between iron-bound P or redox-P versus the anaerobic P release rate, Pioneer Creek watershed lakes either fell within or above the overall range of values (Figure 4; Nürnberg 1988), suggesting that iron-phosphorus chemistry was playing a role in anaerobic P release. Ardmore lake sediments were an exception to this general pattern; the anaerobic P release rate was much higher relative to the iron-bound P concentration. This discrepancy may have reflected additional P solubilization or leaching from benthic algal mats that might have decomposed during anaerobic incubation in a dark environment.

Soluble phosphorus accumulation in the overlying water column was lower under aerobic versus anaerobic conditions for all lake stations (Figure 2). However, significant P increases were observed over the course of the incubation period, suggest a strong potential for internal P loading contributions from sediments under aerobic conditions. P concentrations at the end of the incubation period were relatively high at 0.185 mg/L to 0.332 mg/L (Table 4). Mean rates of P release under aerobic conditions were also substantial, ranging between 1.4 mg/m^2 d for sediment cores collected from Spurzem 2 and 4.2 to 5.7 mg/m^2 d for Ardmore, Half Moon, and Spurzem 1 sediment (Table 4). These aerobic P release rate ranges were moderately high and could represent an important available P source for assimilation by algae. However, mechanisms explaining these patterns are not exactly known. Diffusive flux out of aerobic sediment could be occurring as a result of a low sediment Fe:P ratio (i.e., insufficient iron oxyhydroxide to bind P; Jensen et al. 1992). Some breakdown and leaching of soluble P from decomposing benthic algal mats in the incubation systems may also be occurring.

Sediment characteristics

Moisture contents were high, while wet and dry bulk densities low, in 10-cm sections, indicating very flocculent, high porosity (i.e., volume of interstitial spaces in the sediment column) sediment characteristics (Table 5 and Figure 5). In particular, moisture content exceeded ~95% for Half Moon and Spurzem 2 sediment sections. Organic matter contents were high, ranging between 21% and 54% (Table 5 and Figure 5).

Vertical patterns in sediment physical-textural characteristics indicated that moisture content was greater than or equal to 95% in the upper 5 cm to 6 cm of Ardmore, Half

Moon, and Spurzem 1 sediment (Figure 6), suggesting the potential for an Al floc to sink into the surface sediments to sequester P. Although moisture content was slightly lower in Spurzem 2 sediments, values exceeded 93% over the upper 6 cm. Moisture content declined, while wet and dry bulk density increased, at deeper depths in the sediment due to probable compaction. Organic matter content was relatively uniform with sediment depth for all lake sediments (Figure 6).

For all lake stations, total P concentrations in the upper 10-cm sediment layer were relatively high (Table 6 and Figure 7). Redox-P (i.e., the sum of the loosely-bound and iron-bound P fractions) accounted for 27% to 49%, while biologically-labile P (i.e., the sum of redox-P and labile organic P fractions) represented 63% to greater than 75% of this total P (Table 6 and Figure 7). Thus, much of the total P was composed of forms that could be recycled to the overlying water column. Iron-bound P accounted for greater than 90% of the redox-P and concentrations were greatest in Half Moon and Spurzem 1 sediments (Table 7 and Figure 7). In particular, the iron-bound P concentration was unusually high at ~1.60 mg/g in Spurzem 1 sediments. Loosely-bound P concentrations were low relative to other biologically-labile P fractions. This fraction reflects P in the porewater and P that is loosely-adsorbed onto calcium carbonates and is typically the lowest in concentration compared to the other P fractions. Notably, however, loosely-bound P concentrations were highest in Spurzem 1 sediments at 0.13 mg/g (Table 7). In general, redox-P, composed primarily of the iron-bound fraction, represented ~ 53% (range = 43% to 64%), and labile organic P accounted for ~ 47% (range = 36% to 58%), of the biologically-labile P in the upper 10-cm sediment layer.

Vertically in the sediment column, P fractions were approximately homogeneous with sediment depth for Ardmore and Spurzem 1 (Figure 8). In Half Moon Lake sediments, iron-bound P concentrations exhibited a peak in the upper 1-cm section, declined to uniform concentrations between 2 and 5 cm, and increased again at the 7-cm depth (Figure 8). In contrast, iron-bound P concentrations were very high, exceeding 2 mg/g, in the upper 3-cm layer of east basin sediments collected in Spurzem Lake (Figure 8). Concentrations declined below this depth but were high compared to iron-bound P concentrations in the other lakes. Although much lower in concentration compared to iron-bound P, labile organic P exhibited a similar peak in the upper sediment of Spurzem 1 sediments.

Aluminum sulfate dosage and cost

For sediment assay tubes subjected to a range of Al concentrations, the redox-P concentration declined exponentially as a function of increasing Al concentration, due to binding onto the $Al(OH)_3$ floc (Figure 9). Exposure to relatively low concentrations of Al (~ < 10 mg/g sediment dry mass) usually resulted in binding of greater than 50% of the redox-P. However, much more Al was needed to bind and sequester at least 90% or more of the redox- P because other constituents in the sediment (organic compounds and other anions) were also competing with PO_4^{3-} for the same binding sites. The measured $Al{:}P_{90\%}$ binding ratio (i.e., parts of Al required to bind one part of redox-sensitive P) ranged between 18:1 and 65:1 and fell within ranges measured for lake sediment in the regional area (Figure 10).

The Al dosage required to sequester redox-P for various sediment thicknesses is shown in Table 8. The redox-P concentration in Table 8 represents the sediment depth-integrated average for each sediment layer. These averages were relatively constant for Ardmore, Half Moon, and Spurzem 2 sediments because redox-P concentrations were uniform over the 10-cm sediment column. For Spurzem 1 sediments, the depth-integrated average redox-P concentration declined with increasing layer thickness, reflecting the vertical trend in redox-P. The $Al{:}P_{90\%}$ ratio was estimated for each depth-integrated redox P average using the regression relationships shown in Figure 10 to account for vertical variations in the redox-P concentration.

Al dosage can be based on sequestration of *excess* redox-P in the surface sediments. Sediments in eutrophic lakes often exhibit a distinct peak in redox-P concentration near the surface and lower, more uniform, concentrations deeper in the sediment column. This vertical pattern has been attributed to accumulation of redox-P in excess of diagenesis and burial (Carey and Rydin 2011, Rydin et al. 2011, Malmaeus et al. 2012). Since this excess redox-P layer drives internal P loading, it should be targeted for inactivation by Al. However, a distinct peak in excess redox-P was only observed in the Spurzem 1 sediment core; other lake sediments did not exhibit this vertical pattern. Since the excess redox-P layer was ~ 6 to 8-cm thick in the Spurzem 1 sediment core, this thickness range might be considered for all lakes. Because sediment wet and dry bulk densities are very low in the upper 8 cm layer, the formed Al floc will have a higher probability of rapidly sinking through these porous layers to scavenge redox-P. Al dosages needed to scavenge redox-P in the upper 8-cm were 105 g/m^2 for Ardmore, 86 g/m^2 for Half Moon, 130 g/m^2 for the west basin and 95 g/m^2 for the east basin of Spurzem Lake (Table 8).

Recent lake Al dosage estimates have ranged between ~ 95 g Al/m^2 and ~145 g Al/m^2 (Table 9). These more recent Al dosage ranges are generally higher compared to historical ranges (Huser 2012) because they were targeted toward inactivation of the excess P pool in the sediment. The proposed Al dosages to treat the upper 8-cm sediment layer of each lake in the present study generally fell within these recent ranges.

Treatment areas in each lake were based on the extent of summer hypolimnetic anoxia and basin slope. Hypolimnetic anoxia occurred between early May and late October, 2014, and extended to the 2-m depth (i.e., within the lower metalimnion) in Ardmore Lake (Figure 11). Because the littoral slope was relatively steep between the 6 ft and ~ 15 ft contours (Figure 12), the Al floc would be susceptible to sediment focusing and transport to the deep basin. Sediments in this region are probably characteristic of those found in lake erosional zones; course-grained, nutrient-poor, and exhibiting much lower anaerobic P release rates than sediments located in the deeper accumulation zone. Basin slope tends to lessen at depths greater than 15 ft, at least in the northern portion of the lake. Based on these observations, sediments located at depths greater than 4 m were considered for Al treatment in Ardmore Lake (Table 11). Similarly, hypolimnetic anoxia was established between mid-May and early November, 2014, and extended to ~ the 3-m depth in Half Moon Lake (Figure 13). Half Moon Lake has three distinct basins containing sediment exposed to summer anoxic conditions that should be treated with Al

(Figure 14). The 5-m contour (i.e., 16 ft) was chosen for Al treatment in this lake to inactivate sediment P in each sub-basin. Finally, hypolimnetic anoxic conditions occurred between mid-May and later September, 2014, in Spurzem Lake (Figure 15). Anoxia extended to the 4-m depth between June and August. Al application that included the steep slope between the 20- and 30-ft contours in the west basin would likely result in transport to depth greater than 30 ft (Figure 16). Thus, application should be confined to the 7-m contour (~ 23 to 25 ft) in this region of the lake. For the east basin, treatment should be confined to the 4-m contour (~ 15-16 ft).

Al dosage and cost scenarios for each lake are shown in Table 10. Total cost, including a generic setup fee of $7,000 (i.e., costs associated with travel and per diem to the site, transport of alum, application and boat operation) varied between ~ $20,000 for Ardmore Lake, $34,900 for Half Moon Lake, and and $52,100 for Spurzem Lake. Treatment of the west and east basins of Spurzem Lake cost $25,700 and $26,400, respectively.

Total alkalinities at the time of sediment core sampling were moderately high at ~130 to 140 mg $CaCO_3$/L (Ardmore = 138 mg/L, Half Moon = 127 mg/L, Spurzem = 130 mg/L), suggesting sufficient buffering capacity for regulating pH during alum application. Al binding of P is most efficient within a pH range of 6 to 8. As pH declines below 6, Al becomes increasingly soluble (as Al^{3+}) and toxic to biota. The maximum allowable Al dosage that could be applied and yet maintain pH at or above 6, determined via jar tests (Cooke et al. 2005), was high at 19 to 21 mg Al/L (Table 11). While actual Al dosage was below the maximum allowable dose for Half Moon and the west basin of Spurzem Lake, it slightly exceeded the maximum allowable dose for Ardmore Lake and the east basin of Spurzem Lake. However, potential pH issues can be avoided with multiple, lower Al dose applications (see below). Cooke et al. (2005) reported that treatment longevity (i.e., years of successful P control) generally coincided with Al dosages greater than ~ 12 to 18 g/m^3 for stratified lakes (range = 11.7 to 30 g/m^3; Table 11).

The objective of an alum application is to have the $Al(OH)_3$ floc sink through the upper 8-cm sediment layer and bind the redox-sensitive P that is contributing to internal P loading and algal bloom development. In order to meet these objectives, the Al floc needs to be denser than the upper sediment layer and sink through that layer relatively quickly (i.e., within 3 months or less). Recent research has suggested that $Al(OH)_3$ binding efficiency for P decreases significantly (i.e., > 75% decrease) if it has not been exposed to and reacted with sediment redox-sensitive P within 90 days, due to changes in crystalline structure in the absence of adsorbed P (de Vicente et al. 2008a). Furthermore, as binding sites on the $Al(OH)_3$ floc become saturated with redox-sensitive P, additional P diffusing into the alum layer from deeper sediments over time can become re-adsorbed to Fe~(OOH) (i.e., redox-sensitive P; Lewandowski et al. 2003), eventually diffuse out of the sediment under anaerobic and reducing conditions, and again become an important internal P loading source years after alum treatment.

One current unknown is the exact $Al(OH)_3$ floc density after application, reaction with water, and deposition to the sediment. However, preliminary indications are that Al floc density is very low during the first 6 to 12 months after application (W.F. James, personal observation). Thus, surface sediment wet bulk density should ideally be very low and moisture content high, on the order of 95% or greater, in order to promote sinking and exposure of the Al floc to redox-sensitive P. Since Ardmore, Half Moon, and Spurzem sediments exhibited very high moisture contents and low wet bulk densities, the Al floc should sink through and react with redox-P in the upper sediment layers.

To date, there is no universally accepted and proven alum application strategy to maximize P binding effectiveness and longevity. Although there have been instances of multiple applications over a period of years (Lewandowski et al. 2003), generally, lake Al treatments in the upper midwestern United States have been one-time applications. In addition to the density and sinking concerns identified above, input of new sediment from the watershed can accrete over the $Al(OH)_3$ floc over time, reducing treatment effectiveness and longevity (Lewandowski et al. 2003, Cooke et al. 2005). As mentioned earlier, upward diffusion of P through the alum layer from deeper sediments can eventually lead to P flux into the overlying water column, depending on the extent of binding site saturation by P on the $Al(OH)_3$ floc. Although the $Al(OH)_3$ floc continues to adsorb P for years (Lewandowski et al. 2003), its P binding efficiency apparently decreases over time (de Vicente et al. 2008a). If the $Al(OH)_3$ floc does not entirely sink through the excess P layer and, instead, stabilizes on top of sediments with high redox-sensitive P concentration, upward P diffusion from deeper sediment layers could eventually overwhelm the capacity of the $Al(OH)_3$ floc to bind this additional sediment P source. De Vicente et al. (2008b) suggested that smaller doses spread out over several years might maintain higher P binding efficiencies. More research is clearly needed to develop effective application strategies to maximize internal P loading reduction and extend Al treatment success and longevity.

Finally, Al dosage and treatment areas were assessed to control P release from anaerobic profundal sediments in each lake. Possible aerobic and anaerobic P release from shallow sediments might be considered before decisions are made to treat the lakes. Shallow sediments may be a factor in the P budget of each lake if they are fine-grained, soft muds with high moisture content. At a minimum, littoral sediment samples could be analyzed for basic physical-textural characteristics and redox-P as a screening assessment of the potential for P contributions to the epilimnion of each lake.

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Table 1. Lake and station sediment sampling locations and numbers of sediment cores collected for determination of rates of phosphorus (P) flux under aerobic or anaerobic conditions, biologically-labile P fractions (see Table 2), and aluminum sulfate (Al) dosage.

Lake	Station location	P Flux		P fractions		Al dosage
		Aerobic	Anaerobic	upper 10 cm	Vertical profiles	
Ardmore	Central	2	2	1	1	1
Half Moon	East	2	2	1	1	1
Spurzem 1	West	2	2	1	1	1
Spurzem 2	East	2	2	1	1	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 in various lakes in the Pioneer Creek Watershed area.

Lake	Sediment P release rate			
	Aerobic		Anaerobic	
	(mg/m^2 d)	(mg/L)	(mg/m^2 d)	(mg/L)
Ardmore	4.37 (1.83)	0.332 (0.079)	21.3 (2.3)	2.329 (0.125)
Half Moon	5.68 (0.45)	0.185 (0.033)	9.5 (1.4)	0.684 (0.137)
Spurzem 1	4.22 (2.93)	0.276 (0.048)	19.1 (3.0)	1.585 (0.266)
Spurzem 2	1.37 (0.08)	0.241 (0.001)	6.0 (3.5)	0.670 (0.237)

Table 5. Textural characteristics in the upper sediment layer for sediment cores collected in various lakes in the Pioneer Creek Watershed area.

Lake	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Organic Matter (%)
Ardmore	93.5	1.028	0.068	31.4
Half Moon	96.1	1.011	0.040	54.4
Spurzem 1	94.8	1.018	0.054	44.2
Spurzem 2	93.4	1.021	0.069	48.8

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 for various lakes in the Pioneer Creek Watershed area. DW = dry mass.

Lake	Total P (mg/g DW)	Redox P (mg/g DW)	Redox P (% total P)	Bio-labile P (mg/g DW)	Bio-labile P (% total P)
Ardmore	1.341	0.487	36.3%	0.941	70.2%
Half Moon	2.074	0.818	39.4%	1.542	74.4%
Spurzem 1	3.262	1.598	49.0%	2.509	76.9%
Spurzem 2	1.280	0.346	27.0%	0.814	63.6%

Table 7. Concentrations of biologically labile and refractory P in the upper 10-cm sediment layer for various lakes in the Pioneer Creek Watershed area. DW = dry mass, FW = fresh mass.

Lake	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)
Ardmore	0.023	0.464	30	0.454	0.144
Half Moon	0.043	0.775	30	0.724	0.226
Spurzem 1	0.130	1.468	77	0.911	0.445
Spurzem 2	0.032	0.314	21	0.468	0.102

Table 8. Mean redox-sensitive phosphorus (P), the estimated aluminum:phosphorus (Al:P) binding ratio, and the areal Al dosage estimate versus sediment thickness for various lakes in the Pioneer Creek watershed area.

Ardmore				Half Moon				Spurzem 1				Spurzem 2			
Sediment thickness (cm)	Redox-P (mg/g)	Estimated Al:P ratio[1]	Al dose (g/m^2)	Sediment thickness (cm)	Redox-P (mg/g)	Estimated Al:P ratio[1]	Al dose (g/m^2)	Sediment thickness (cm)	Redox-P (mg/g)	Estimated Al:P ratio[1]	Al dose (g/m^2)	Sediment thickness (cm)	Redox-P (mg/g)	Estimated Al:P ratio[1]	Al dose (g/m^2)
2	0.404	53.6	20	2	0.382	55.6	17	2	2.428	17.5	32	2	0.245	73.5	22
4	0.427	51.9	46	4	0.307	63.7	36	4	1.958	20.0	68	4	0.235	75.3	44
6	0.463	49.3	73	6	0.315	62.8	57	6	1.480	23.8	97	6	0.223	77.8	68
8	0.452	50.0	**105**	8	0.388	55.0	**86**	8	1.236	26.6	**130**	8	0.210	80.8	**95**
10	0.424	52.1	148	10	0.378	55.9	113	10	1.229	26.8	168	10	0.206	81.8	125

[1]Based on regression relationships shown in Figure 10

Table 9. Recent alum (as Al) dosages for various lakes.

Lake	Al Dose (g Al m^{-2})	Reference
Ardmore[1]	105	Present study
Half Moon[1]	86	
Spurzem[1]	95 to 130	
Bald Eagle, MN	100	(unpubl. data)
Black Hawk, MN	145	(unpubl. data)
Tiefwarensee, Germany	137	Wauer et al. (2009)
East Alaska, WI	132	Hoyman (2012)
Half Moon, WI[2]	115	James (2011)
Susser See, Germany	100	Lewandowski et al. (2003)
Green, WA	94	Dugopolski et al. (2008)

[1]Over the upper 8-cm sediment layer

[2]West and east arm dosages were 150 and 75 g/m^2, respectively

Table 10. Approximate cost scenario to treat the upper 8-cm sediment layer in each lake with aluminum sulfate.

Variable	Ardmore	Half Moon	Spurzem		
			West basin	East basin	Total
Treatment area (acres)	4.37	11.44	6.02	8.52	13.37
Treatment depth (m)	4	5	7	4	6
Treatment depth (ft)	13	16	23	13	20
Al dosage (g/m^2)	105	86	130	95	95 to 130
Alum ($)	$13,000	$27,859	$22,173	$22,925	$45,098
Setup ($)	$7,000	$7,000	$3,500	$3,500	$7,000
Total ($)	$20,000	$34,859	$25,673	$26,425	$52,098

Table 11. A comparison of the maximum allowable Al dose, based on a titration assay and nomograph estimate presented in (Cooke et al. 2005) and the the areal sediment redox-P based Al dosage converted to a concentration. Al dosages and longevity for other unstratified and stratified lakes are from Cooke et al (2005). Numbers on parentheses denote percent reductions in lake total phosphorus. Longevity = as of publication of Cooke et al. (2005).

Lake		Al Dose ($g\ Al/m^3$)	Observed Longevity (years)
Ardmore	Maximum allowable	20	
	Actual	**23**	
Half Moon	Maximum allowable	19	
	Actual	15	
Spurzem west basin	Maximum allowable	21	
	Actual	17	
Spurzem east basin	Maximum allowable	21	
	Actual	**21**	
Unstratified lakes	Long Kitsap County	5.5	11(30%)
	Pickerel	7.3	<1
	Long Thurston County North	7.7	>8 (56%)
	Pattison North	7.7	7 (29%)
	Wapato	7.8	<1
	Erie	10.9	>8 (75%)
	Campbell	10.9	>8 (46%)
Stratified lakes	Eau Galle	4.5	<2
	Morey	11.7	8 (60%)
	Cochnewagon	18	6 (not reported)
	Dollar	20.9	18 (68%)
	Annabessacook	25	13 (41%)
	West Twin	26	18 (66%)
	Irondoquoit Bay	28.7	5 (24%)
	Kezar	30	9 (37%)

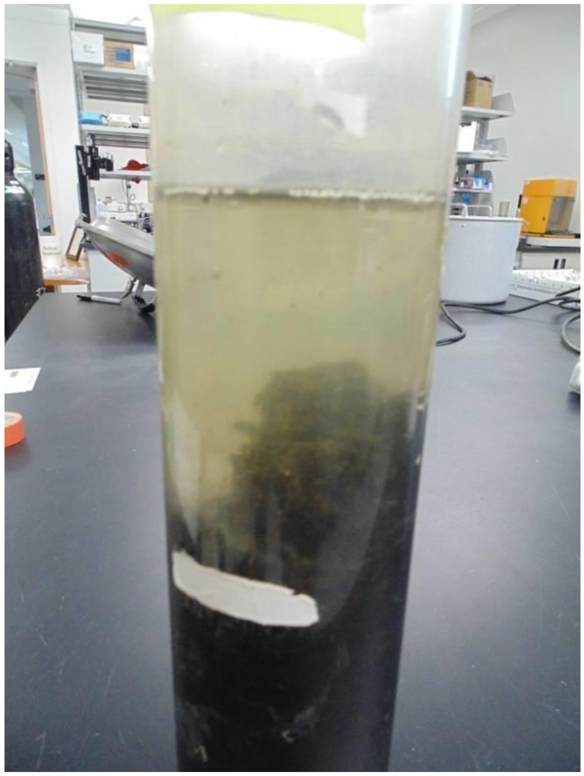

Figure 1. Ardmore Lake sediment incubation system.

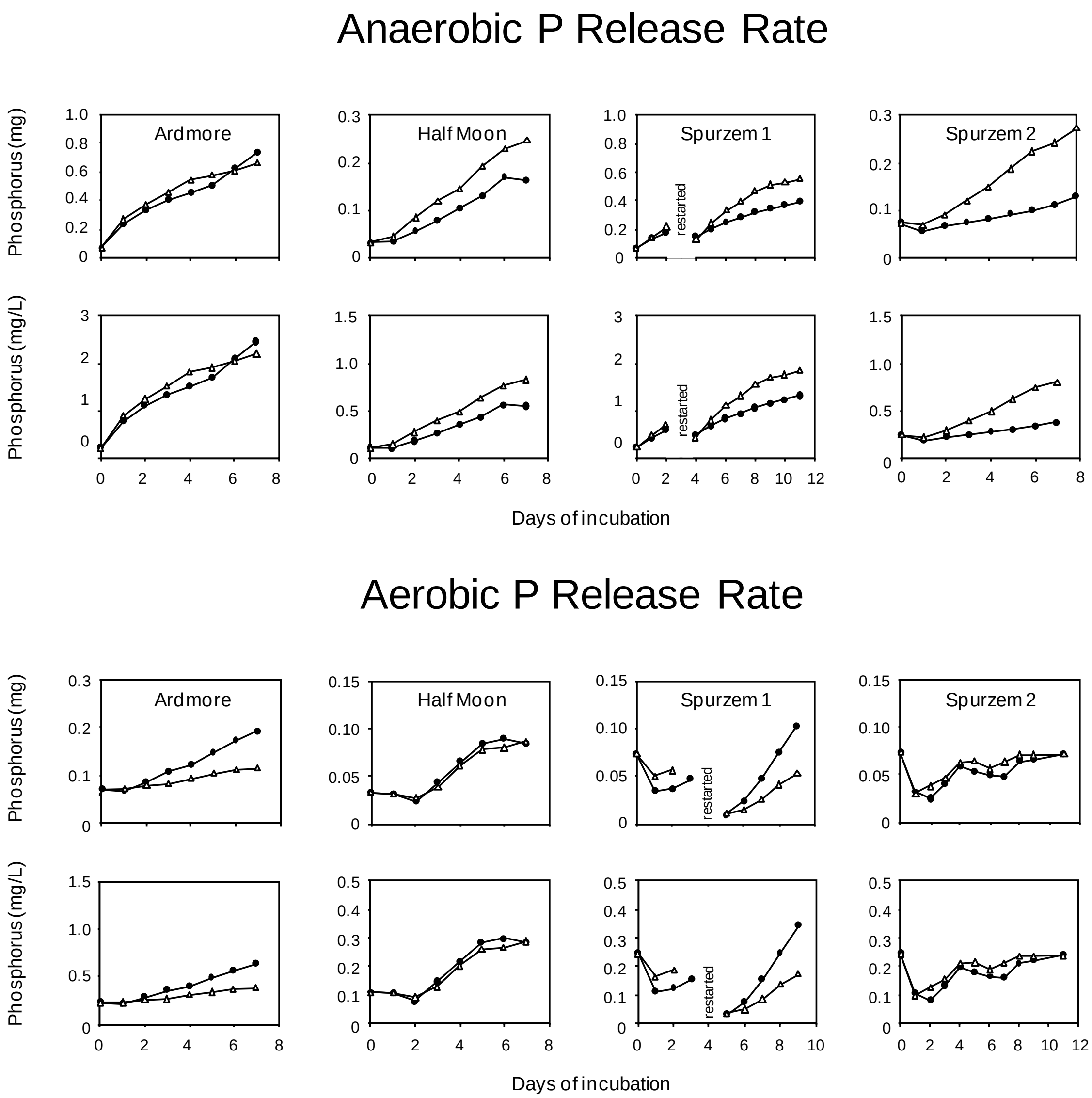

Figure 2. Changes in soluble reactive phosphorus mass and concentration in the overlying water column under anaerobic (upper panels) and aerobic (lower panels) conditions versus time for sediment cores collected from lakes in the Pioneer Creek watershed.

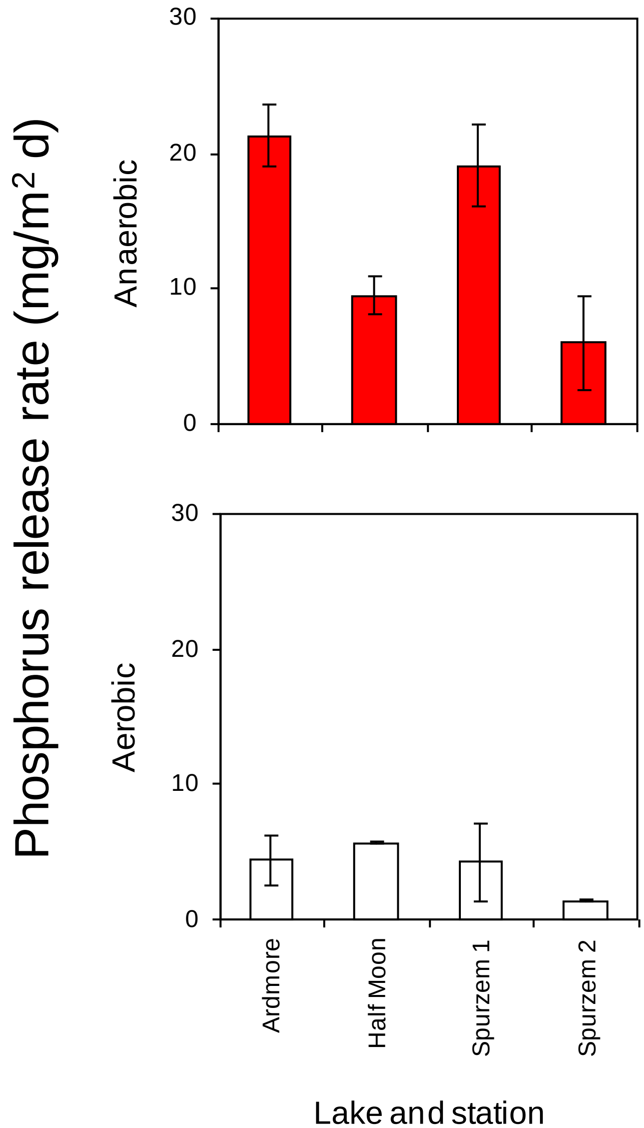

Figure 3. Mean (n=2; ± 1 standard error) anaerobic and aerobic phosphorus (P) release rates for sediment cores collected from lakes in the Pioneer Creek watershed.

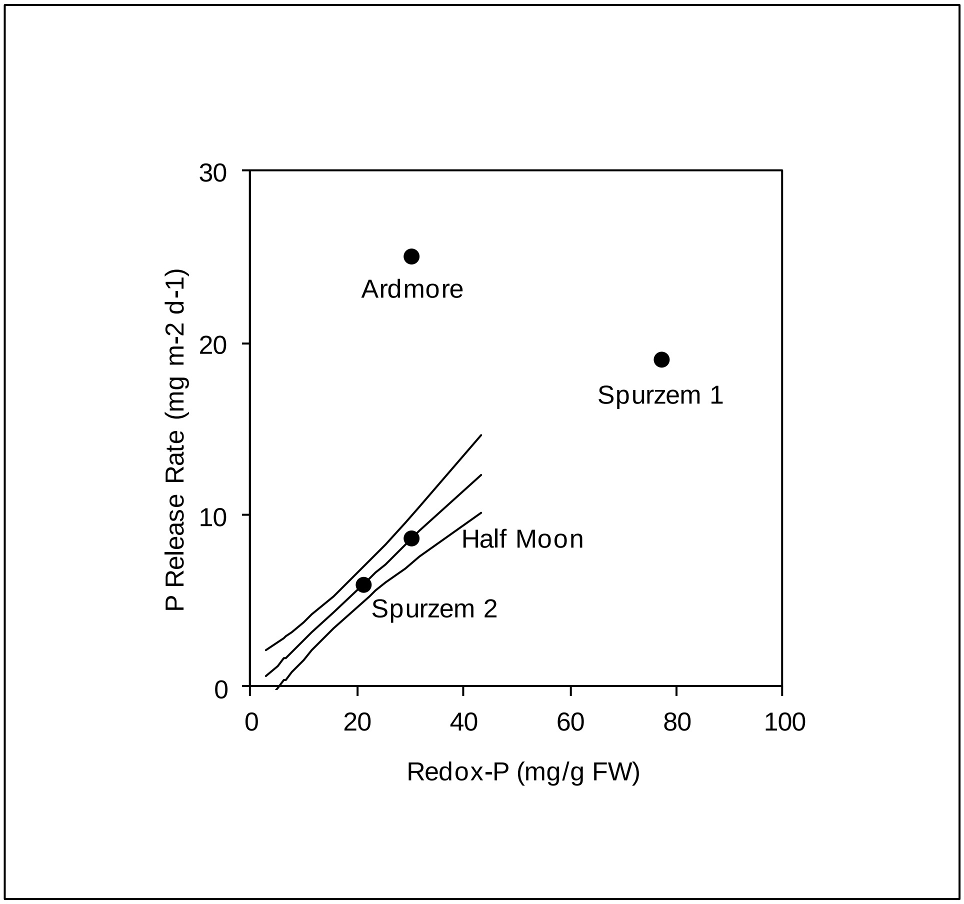

Figure 4. Regression relationships between iron-bound phosphorus (P; mg/g fresh mass) and anaerobic phosphorus (P) release rates (Nürnberg 1988).

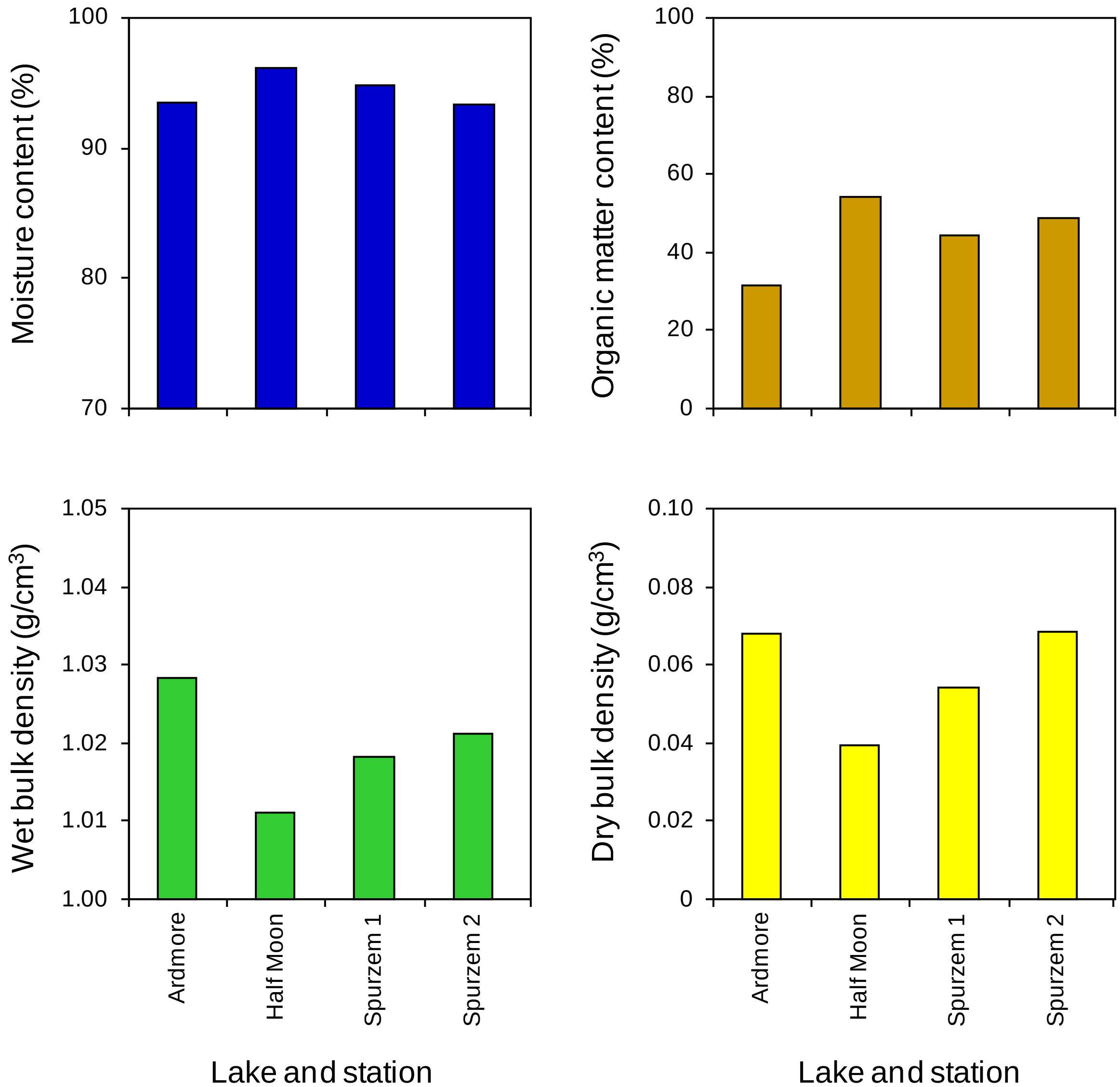

Figure 5. Variations in moisture content, wet and dry bulk density, and organic matter content in the upper 10-cm section of sediment cores collected from lakes in the Pioneer Creek watershed.

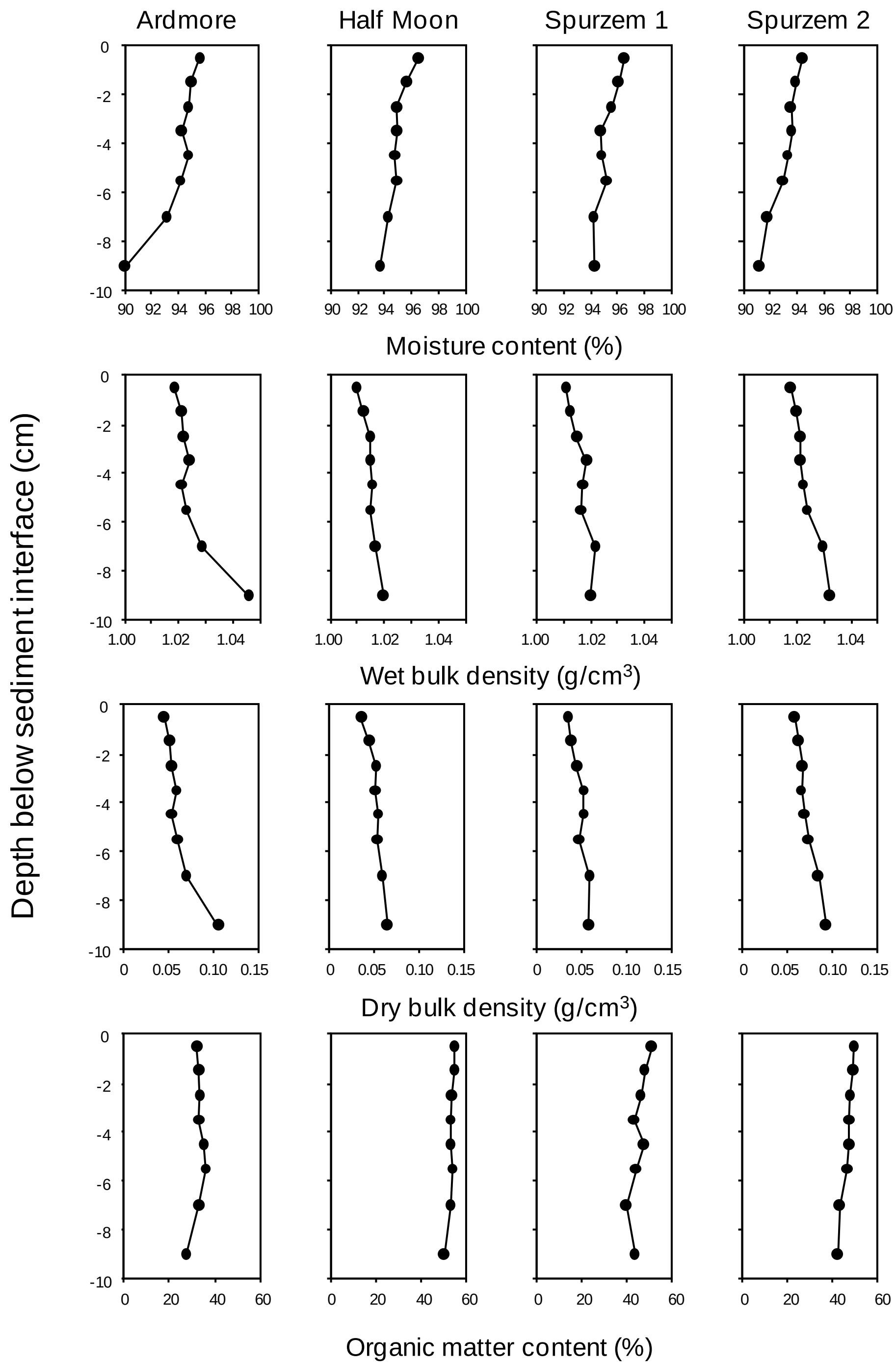

Figure 6. Vertical variations in moisture content, wet and dry bulk density, and organic matter content for sediment cores collected from lakes in the Pioneer Creek watershed.

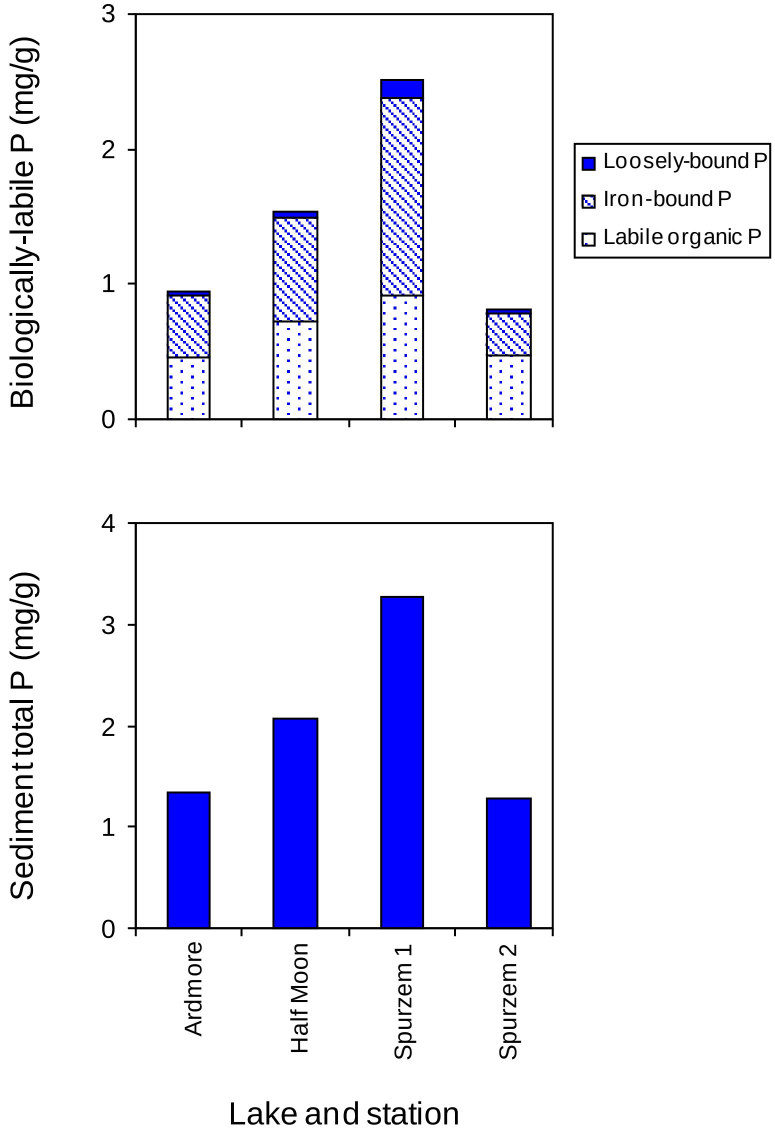

Figure 7. Variations in biologically-labile (i.e., subject to recycling) phosphorus (P) fractions (upper panel) and total P in the upper 10-cm section of sediment cores collected from lakes in the Pioneer Creek watershed.

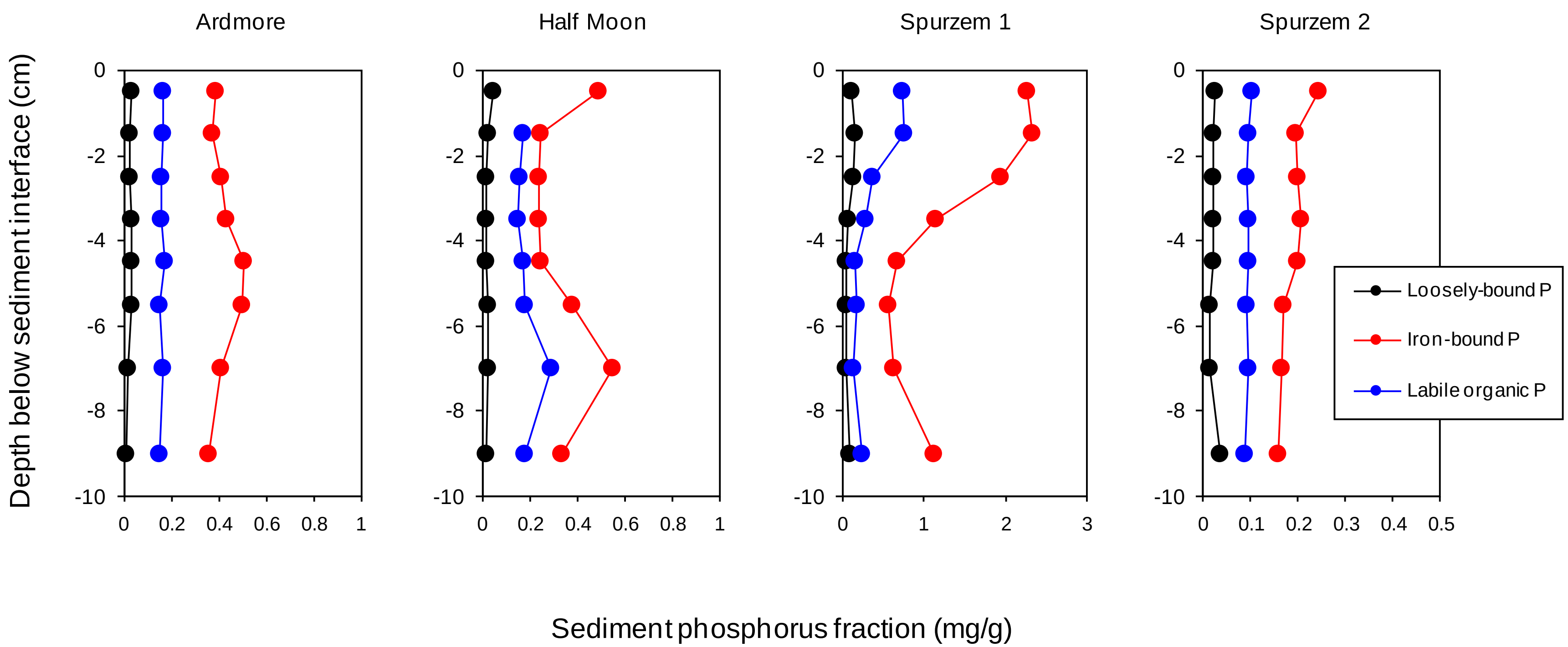

Figure 8. Vertical variations in loosely-bound phosphorus (P), iron-bound P, and labile organic P concentrations for sediment cores collected from lakes in the Pioneer Creek watershed.

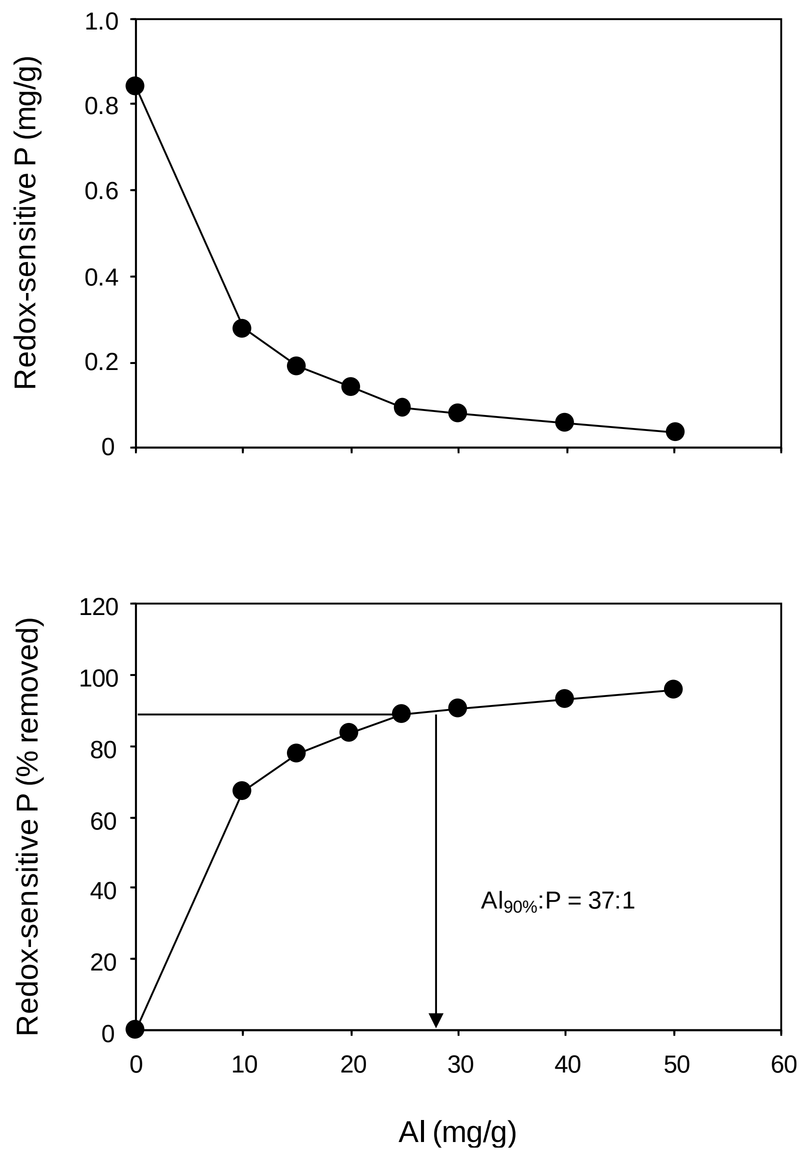

Figure 9. Variations in the concentration of redox-sensitive phosphorus (P; i.e., the loosely-bound and iron-bound phosphorus fractions; upper panel) and percent removed or adsorbed to the aluminum (Al) floc (lower panel) as a function of increasing Al concentration for Half Moon Lake sediment assays.

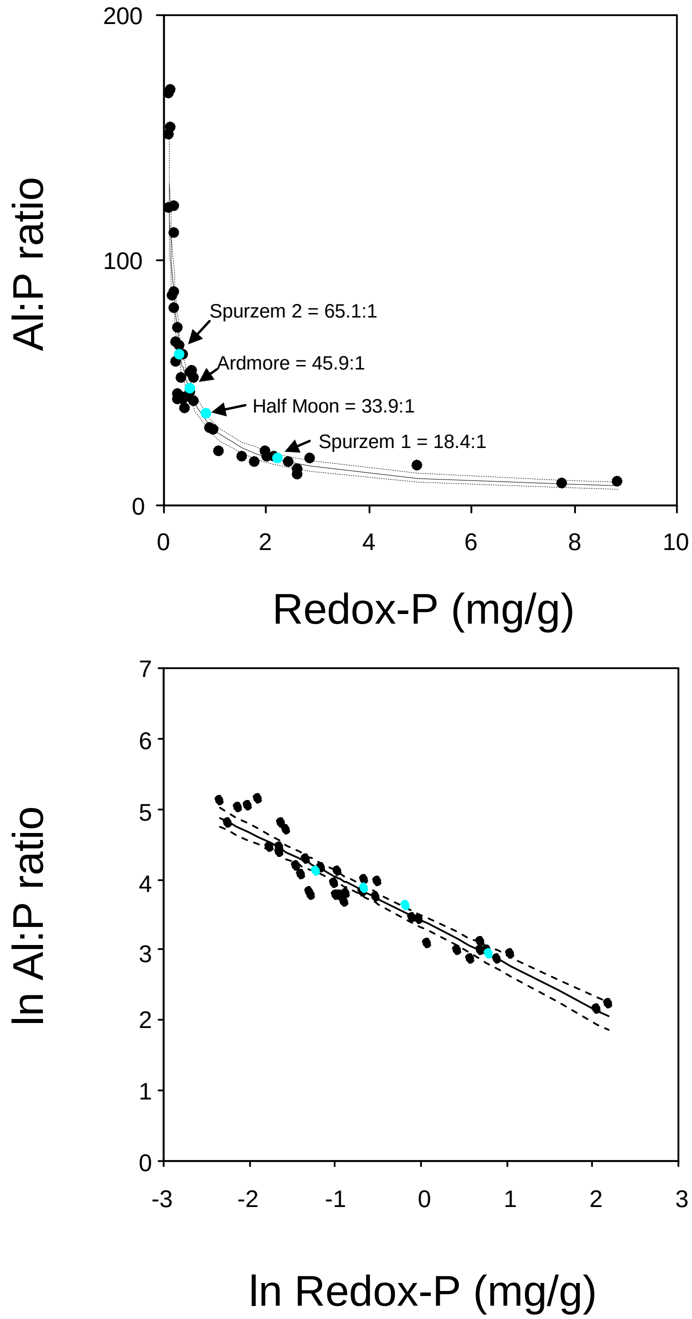

Figure 10. Regression relationships between the redox-sensitive phosphorus (redox-P) concentration and the aluminum:phosphorus (Al:P) ratio for Pioneer Creek watershed lakes and sediments collected from various lakes in the region.

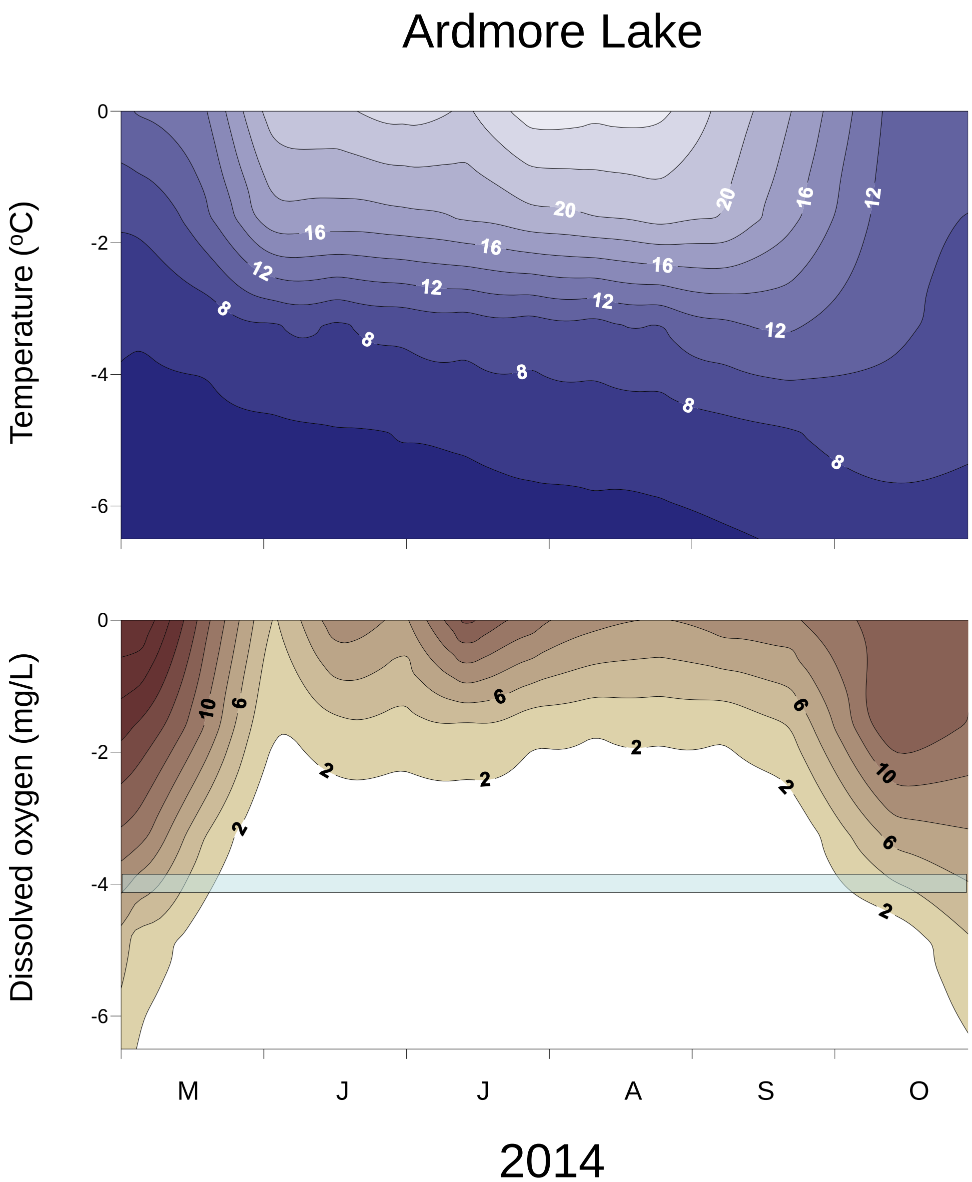

Figure 11. Seasonal and vertical variations in temperature (upper panel) and dissolved oxygen (lower panel) in Ardmore Lake during the summer of 2014. The white contour in the lower panel denotes the extent of hypolimnetic anoxia (DO < 1 mg/L). The transparent blue horizontal bar represents the proposed depth contour for alum treatment.

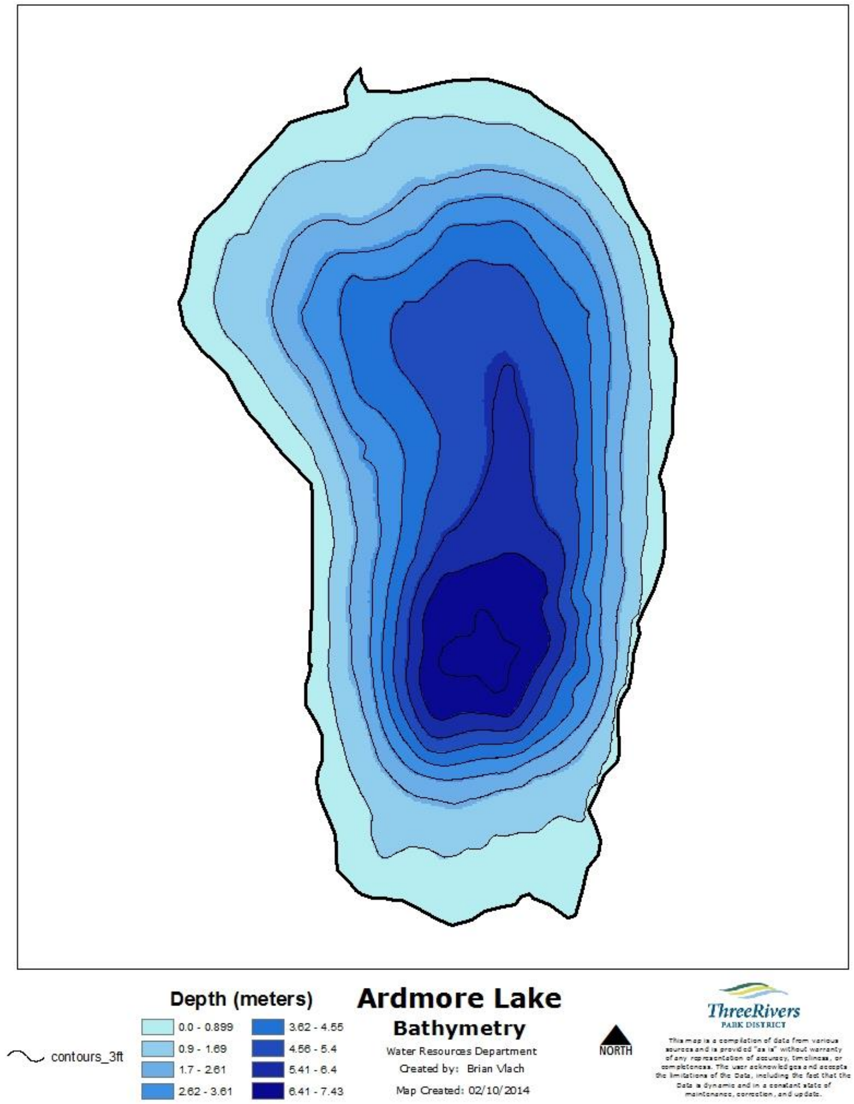

Figure 12. Bathymetry of Ardmore Lake.

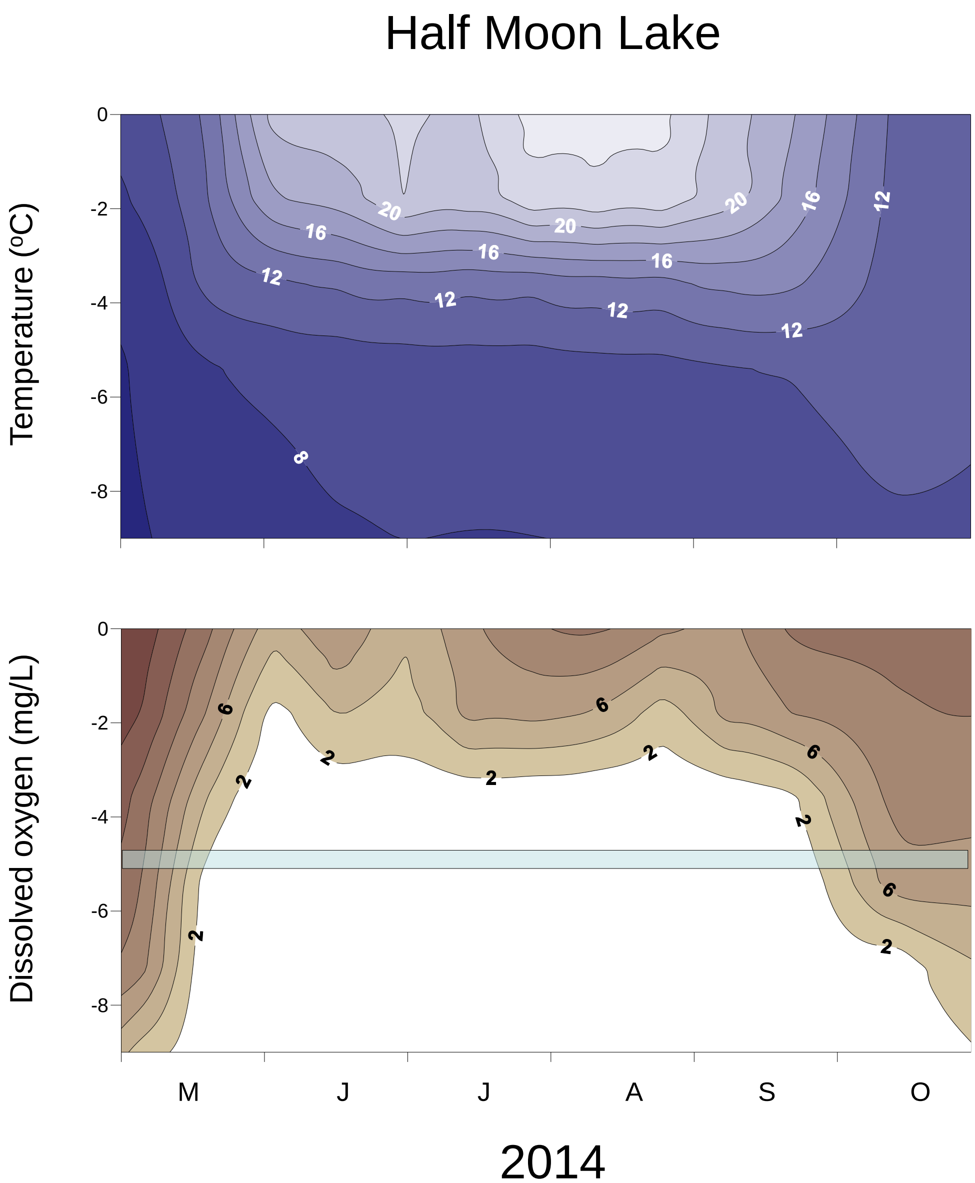

Figure 13. Seasonal and vertical variations in temperature (upper panel) and dissolved oxygen (lower panel) in Half Moon Lake during the summer of 2014. The white contour area in the lower panel denotes the extent of hypolimnetic anoxia (DO < 1 mg/L). The transparent blue horizontal bar represents the proposed depth contour for alum treatment.

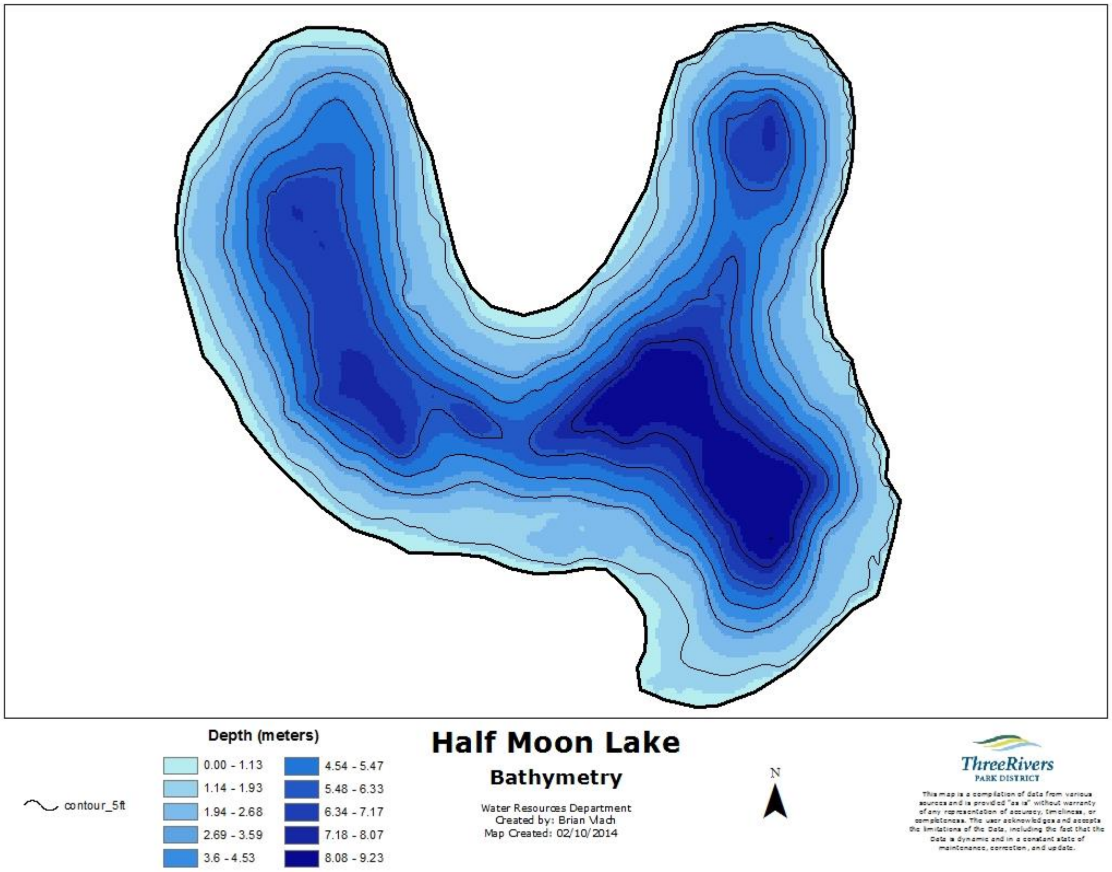

Figure 14. Bathymetry of Half Moon Lake.

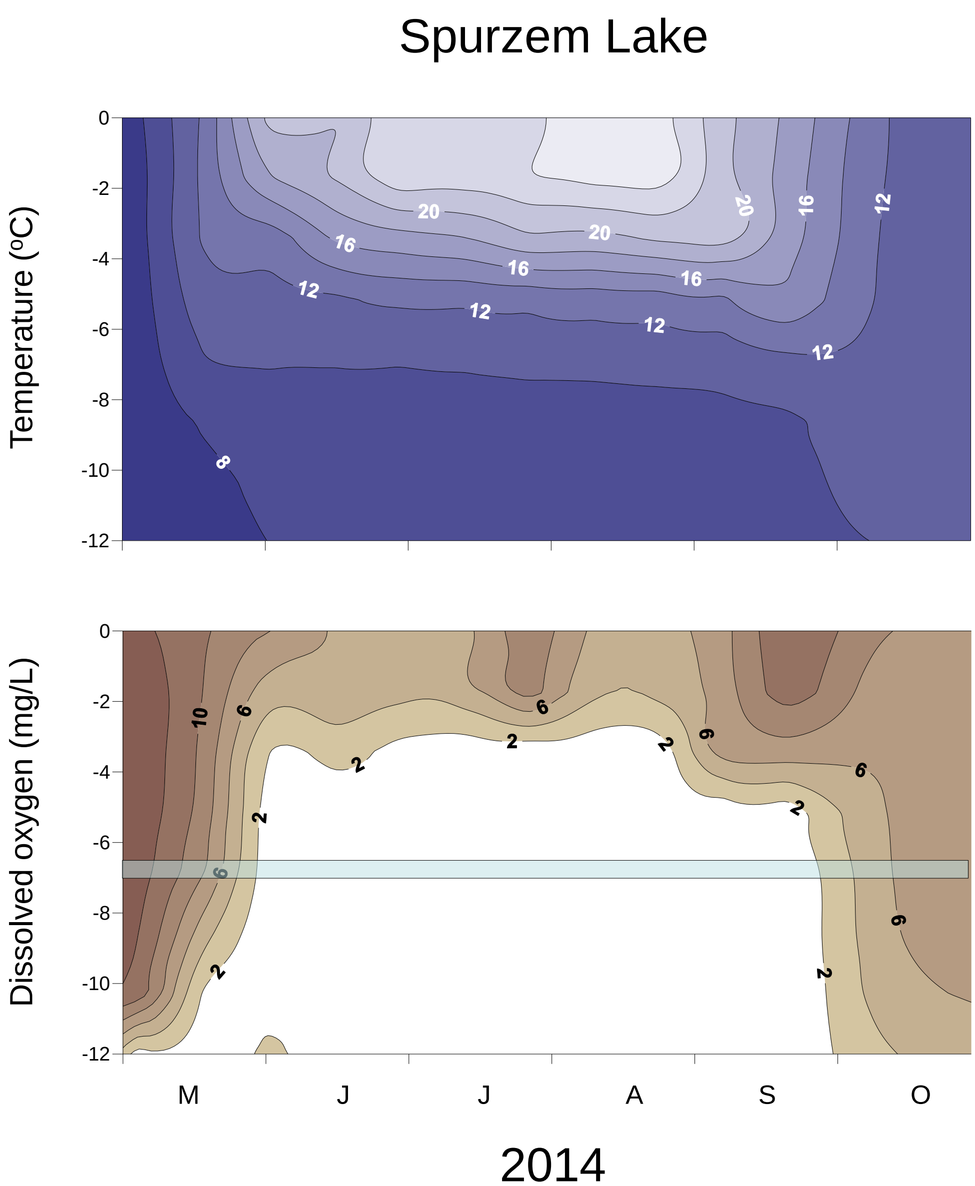

Figure 15. Seasonal and vertical variations in temperature (upper panel) and dissolved oxygen (lower panel) in Spurzem Lake during the summer of 2014. The white contour area in the lower panel denotes the extent of hypolimnetic anoxia (DO < 1 mg/L). The transparent blue horizontal bar represents the proposed depth contour for alum treatment.

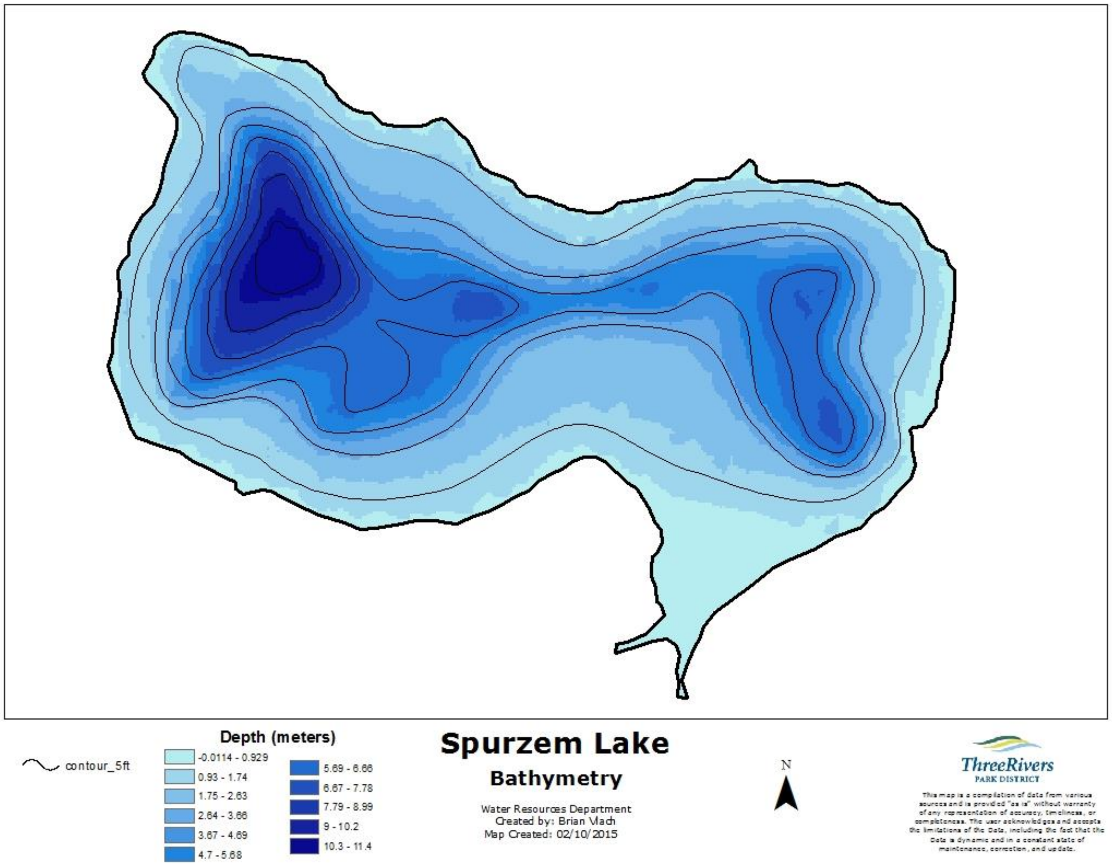

Figure 16. Bathymetry of Spurzem Lake.

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 (mg/g DW)	Redox P (mg/g DW)	Redox P (% total P)	Bio-labile P (mg/g DW)	Bio-labile P (% 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 (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/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

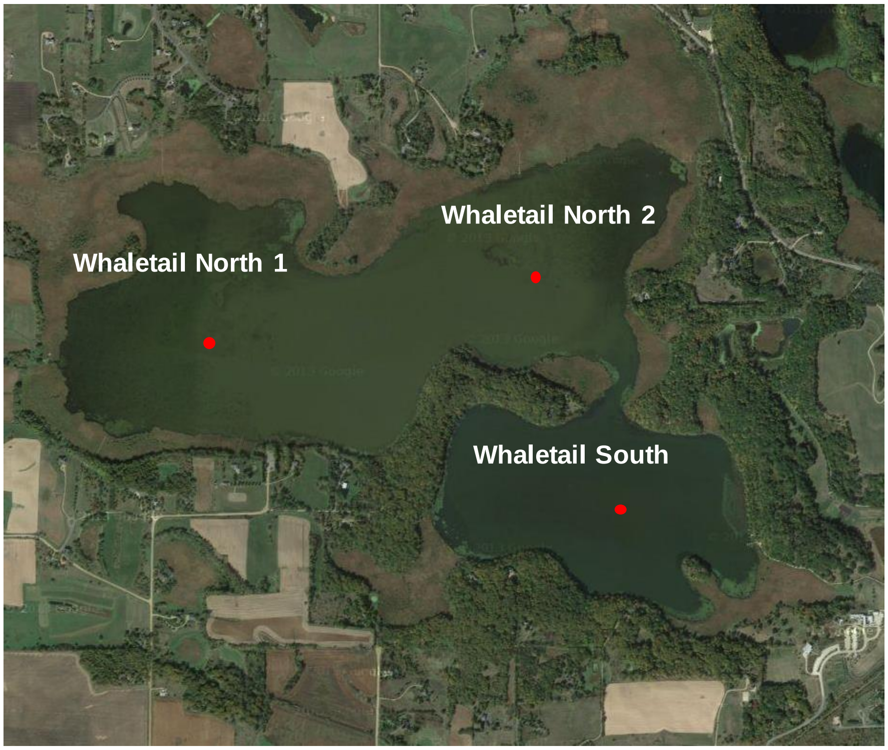

Figure 1. Sediment sampling station locations in Whaletail Lake.

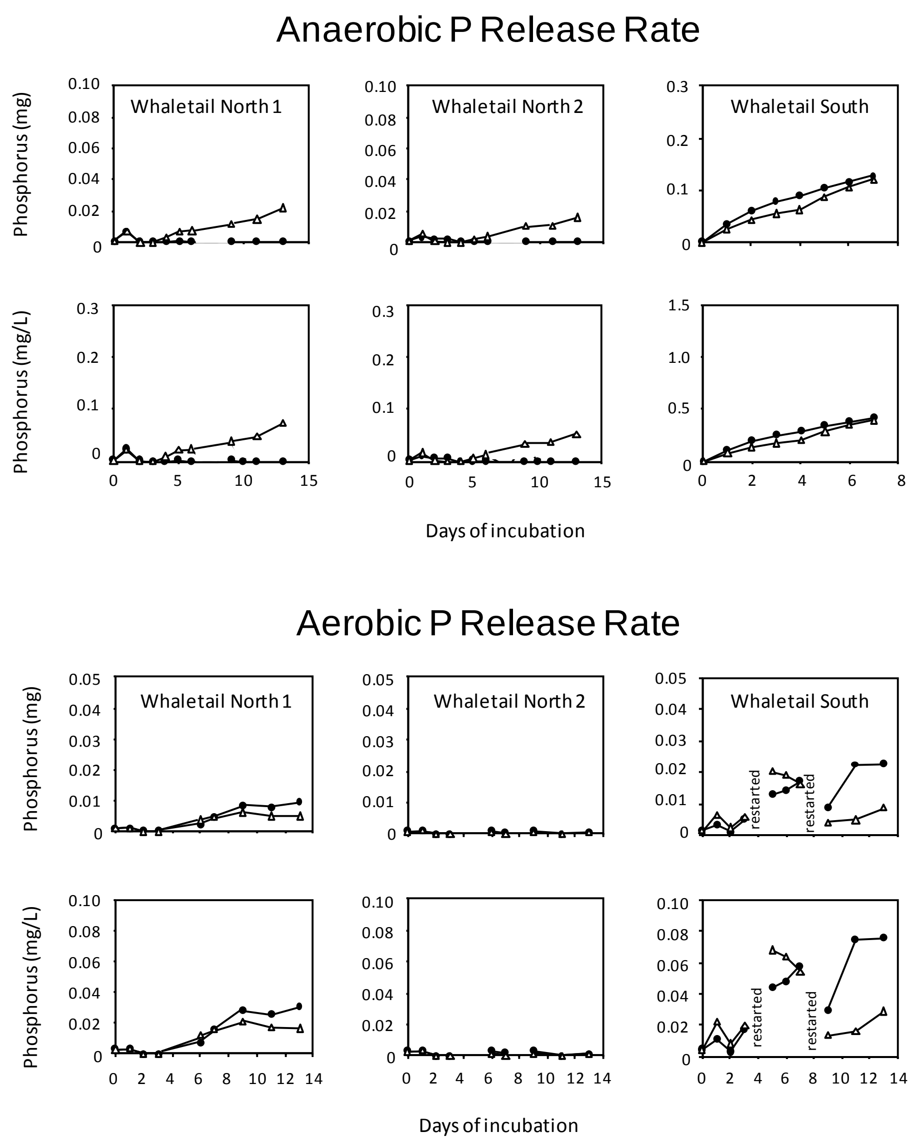

Figure 2. Changes in soluble reactive phosphorus mass and concentration in the overlying water column under anaerobic (upper panels) and aerobic (lower panels) conditions versus time for sediment cores collected from Whaletail Lake.

Appendix F: Pioneer-Sarah Creek Watershed TMDL Implementation Cost Estimate

Project Element Description	Average Unit Cost Range	Total Cost Range
10 small urban stormwater retro-fit projects[1]	$30,000 - $60,000/project	$300,000 - $600,000
10 wetland restoration projects[3]	$40,000 - $80,000/project	$400,000 - $800,000
6 livestock feedlot/pasture improvement projects[2]	$25,000-$50,000/project	$150,000 - $300,000
3,500 feet of row crop field buffers [2]	$10-$20/foot	$35,000 - $70,000
50 development reviews for compliance w/ PSCWMC standards[1]	$200-$400/review	$10,000 - $20,000
Curly-leaf pondweed control in lakes (3 lakes/160 ac. for 7 years)[2]	$200-$300/ac/yr	$224,000 - $336,000
Immobilization of phosphorus release from enriched lake sediments (5 lakes/270 ac.)[2]	$2,000-$3,000/ac	$540,000 - $810,000
3 Common carp assessment and removal projects	$50,000 - $100,000/ effort	$150,000 - $300,000
20 septic system upgrades[2]	$4,000 - $8,000/system	$80,000 - $160,000
Urban/rural-agricultural education efforts (20 years)[3]	$10,000-$20,000/year	$200,000 - $400,000
Sub-total		$2,089,000 - $3,796,000
20% contingency		$417,800 - $759,200
TOTAL		$2,506,800 - $4,555,200

1 Applies to permitted sources

2 Applies to non-permitted source

3 Applies to both permitted and non-permitted sources