Watershed

April 2021

Sauk River Chain of Lakes Total Maximum Daily Load Report

Identifying the amount of nutrients that the Sauk River Chain of Lakes and the Eden Valley Creek Subwatershed lakes can receive from point and nonpoint sources and still provide beneficial recreational uses.

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

Authors

Emmons & Olivier Resources, Inc.
Minnesota Pollution Control Agency

Editing

Administrative staff

Document Number: wq-iw8-38e

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Abbreviations

1W1P	One Watershed, One Plan
AFO	animal feeding operation
AU	animal unit
AUID	assessment unit identification
BMP	best management practice
BWSR	Board of Water and Soil Resources
CAFO	concentrated animal feeding operation
Chl-*a*	chlorophyll-*a*
CRP	Conservation Reserve Program
CREP	Conservation Reserve Enhancement Program
DEMs	digital elevation models
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
EMC	event mean concentration
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
EQuIS	Environmental Quality Information System
ERDC	Engineer Research and Development Center
EVC	Eden Valley Creek
FWMC	flow-weighted mean concentrations
GIS	geographic information systems
GSM	growing season mean
HSPF	Hydrologic Simulation Program–Fortran
HUC	Hydrologic Unit Code
ITPHS	imminent threat to public health and safety
IWM	intensive watershed monitoring
km^2	square kilometer
LA	load allocation
LC	loading capacity

LS	lakeshed runoff
lb	pound
lb/day	pounds per day
lb/yr	pounds per year
m	meter
MAWQCP	Minnesota Agricultural Water Quality Certification Program
mg/L	milligrams per liter
mg/m^2-day	milligrams per square meter per day
MIDS	Minimal Impact Design Standards
MOS	margin of safety
MPCA	Minnesota Pollution Control Agency
MS4	municipal separate storm sewer system
NCHF	North Central Hardwood Forests
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
ppb	parts per billion
P	phosphorus
PWP	Permanent Wetland Preserve
R	runoff from shoreline lots
RC	reserve capacity
RIM	Reinvest in Minnesota
RNR	River Nutrient Region
SDS	state disposal system
SRCL	Sauk River Chain of Lakes
SRP	soluble reactive phosphorus
SRWD	Sauk River Watershed District
SSTS	subsurface sewage treatment systems
ST	septic tanks
SWCD	soil and water conservation district
SWPPP	Stormwater Pollution Prevention Plan

TMDL	total maximum daily load
TP	total phosphorus
TSS	total suspended solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WLA	wasteload allocation
WMD	Water Management District
WRAPS	Watershed Restoration and Protection Strategy
WRP	Wetland Reserve Program
WQBEL	water quality-based effluent limit
WWTP	wastewater treatment plant

Executive summary

This total maximum daily load (TMDL) study addresses nutrient impairments in 14 lakes of the Sauk River Watershed, which is located within the Upper Mississippi River Basin west and northwest of St. Cloud, Minnesota. These lakes do not meet Minnesota's water quality standards due to excessive nutrient concentrations and nuisance algal blooms. The project area of 925 mi^2 (592,275 acres) is located in five counties of central Minnesota, with the majority in Stearns County. The impaired lakes are distributed along two converging flow paths: (1) the predominant Sauk River flowing from the north through the Sauk River Chain of Lakes (SRCL; 10 impaired lakes); and (2) the much smaller Eden Valley Creek (EVC) flowing from the south through four impaired lakes and then into Horseshoe Lake, the most upstream of the Sauk Chain of Lakes (Figure 1). The goal of this TMDL is to quantify the pollutant reductions needed to meet state lake water quality standards for nutrients in all of these lakes.

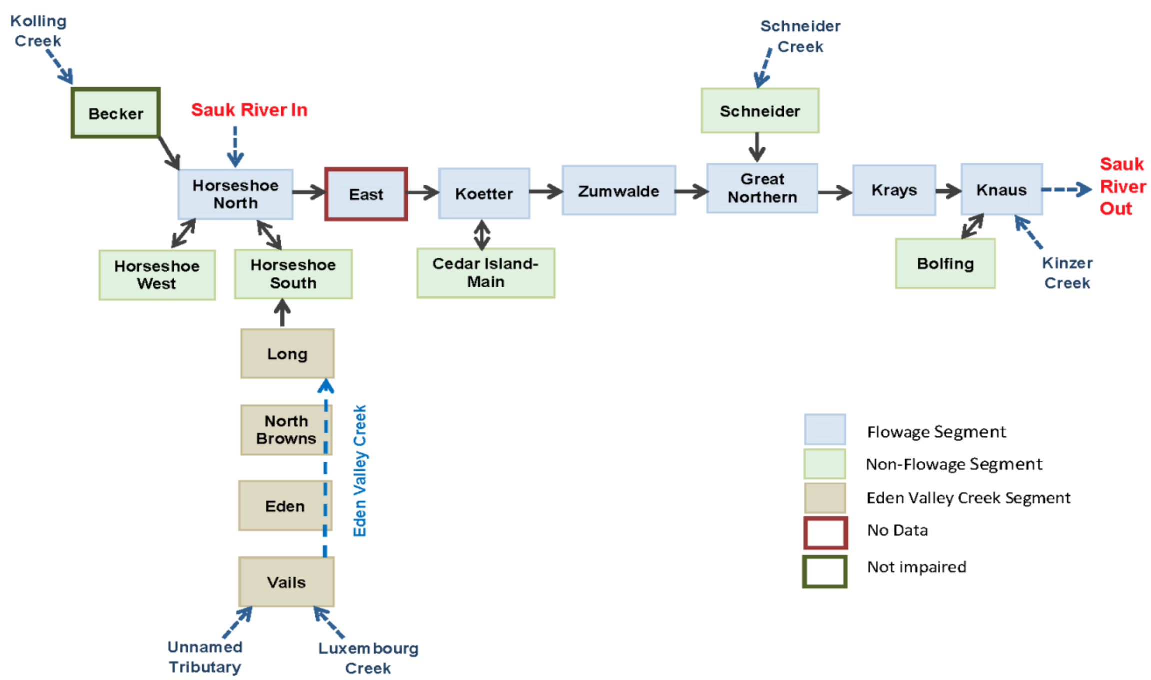

Figure 1. Sauk Chain of Lakes and Eden Valley Watershed Unit Flow Network (modified from Walker 2009)

Phosphorus is the primary focus of this TMDL, as this pollutant drives a wide array of river, stream and lake biological responses affecting beneficial uses. In this regard, the Sauk River's phosphorus loading dominates water quality in the SRCL (reservoir lakes), as does that of EVC to the southern natural basin lakes (Vails, Eden, North Browns, and Long Lake). Achieving the river phosphorus standard will have positive cascading/domino effects upon downstream lakes from the 'king-pin' lakes, Vails (EVC) and Horseshoe North (Sauk River and EVC).

While all of the project lakes have a long history of nutrient enrichment, the SRCL has also been a remarkable story of success, with measurable improvements (68% phosphorus reduction) resulting from over 25 years of collaboratively sponsored point and nonpoint source rehabilitations totaling over $26.7 million. As one of the Minnesota Pollution Control Agency's (MPCA's) first basin-wide assessments conducted in the mid-1980s, water quality goals/targets were ecoregion-based. Improving water quality monitored in the Sauk Chain of Lakes has tracked values predicted in 1985 quite well as projected point and nonpoint load reductions were achieved. However, additional reductions are required to achieve more recently developed river and lake site-specific standards. In that regard, this TMDL study is an example of adaptive management in that it builds upon the past efforts, is refocused by updated monitoring data, and guided by proven predictive tools. The net result is a midcourse correction and refinement of allowable loading rates to fully achieve river and lake water quality standards and beneficial uses.

Nutrient budgets and lake response models used to define the TMDL and its load allocations (LAs; for nonpoint sources) and wasteload allocations (WLAs; for point sources) were based on a TMDL development study prepared by William W. Walker in 2009. Walker's extensively calibrated and validated models were updated to reflect the new lake and river standards and recent monitoring data. As shown in Table 1 below, reductions required by this TMDL range from 7% to 51% for the Sauk Chain of Lakes and 63% to 83% for the Eden Creek lakes, which have not been as well studied until recent years. Corresponding phosphorus allocations were derived for each of the impaired waters and will serve to guide this next phase of rehabilitative actions. There are six National Pollutant Discharge Elimination System (NPDES) regulated wastewater treatment plants (WWTPs) with a WLA assigned in this TMDL report. For all WWTPs, except for the Freeport WWTP, the WLA is equal to the existing permit limit. The vast majority of the phosphorus reductions are nonpoint source related.

Table 1. TMDL summary

Lake	Loading Capacity (TMDL) (lb/yr)	Reduction Needed (lb/yr)	Reduction Needed (%)
Bolfing	414	145	26%
Cedar Island–East	76,669	40,425	35%
Cedar Island–Koetter	71,325	28,782	29%
Cedar Island–Main	1,744	883	34%
Eden	2,192	5,831	73%
Great Northern	68,311	34,987	34%
Horseshoe Lake			
Horseshoe North	68,787	56,083	45%
Horseshoe South	2,918	3,056	51%
Horseshoe West	733	54	7%
Knaus	69,693	51,095	42%
Krays	67,718	40,745	38%
Long	2,588	4,485	63%
North Browns	2,567	12,521	83%
Schneider	1,105	674	38%
Vails	2,567	6,768	73%
Zumwalde	65,984	36,925	36%

Implicit MOS only (see Section 4.1.4).

1. Project overview

1.1 Purpose

Section 303(d) of the federal Clean Water Act requires that TMDLs be developed for waters that do not support their designated uses. These waters are referred to as “impaired” and are listed in Minnesota’s list of impaired water bodies. The term “TMDL” refers to the maximum amount of a given pollutant a water body can receive on a daily basis and still achieve water quality standards. A TMDL study determines what is needed to attain and maintain water quality standards in waters that are not currently meeting them. A TMDL study identifies pollutant sources and allocates pollutant loads among those sources. The total of all allocations, including WLAs for permitted sources, LAs for nonpermitted sources (including natural background), and the margin of safety (MOS), which is implicitly or explicitly defined, cannot exceed the maximum allowable pollutant load.

This TMDL study addresses aquatic recreation use impairments due to excess nutrients (phosphorus) in 14 lakes in the SRCL Management Unit of the Sauk River Watershed (Hydrologic Unit Code [HUC] 07010202) in central Minnesota. The goal of this TMDL is to provide WLAs and LAs, and to quantify the pollutant reductions needed to meet the state water quality standards. These TMDLs are being established in accordance with Section 303(d) of the Clean Water Act, because the State of Minnesota has determined that these lakes exceed the state established standards for nutrients.

This study is an extension of an earlier TMDL development study prepared for the Sauk River Watershed District (SRWD) by William W. Walker (2009). Walker characterized flow and phosphorus loading patterns within the SRCL and developed a BATHTUB model (referred to in the report as the ‘Walker (2009) SRCL model’, see Section 4.1.1) that included 12 of the 14 impaired lakes addressed in this TMDL. Based on the unique flow and loading conditions in the SRCL identified by Walker, the MPCA has since developed site specific standards for many lakes located within the SRCL (Heiskary 2012). This TMDL incorporates those site specific standards into the Walker study modeling approach. It also incorporates more water quality data and addresses two impaired lakes, Eden and Vails, which were not included in the original study. Updates and modifications to Walker’s methods and models, which were required to complete this TMDL study, are discussed in Section 3.5 and Sections 4.1 through 4.1.1.5.

1.2 Identification of water bodies

This TMDL study includes 14 lakes (Table 2) within the SRCL Management Unit of the Sauk River Watershed (*HUC 07010202*) that are currently on Minnesota’s 2018 303(d) Impaired Waters List approved by the United States Environmental Protection Agency (EPA), or are expected to be on the 2022 Impaired Waters List. Ten of the impaired lakes are located within the Cedar Island Lake-Sauk River Subwatershed *(HUC 070102020604)* and are part of the SRCL, a system of interconnected, bay-like lakes located along or adjacent to the Sauk River flowage (flow path). The remaining lakes (Long, North Browns, Eden, and Vails Lakes) are located upstream and south of the chain along Eden Creek within the Long Lake Subwatershed (*HUC 070102020602*). In addition to lakes listed on the state’s 2018 303(d) list, Cedar Island–East Lake is assumed impaired and included in the TMDL. This lake is located between two impaired lake segments in the SRCL (Figure 2, Figure 3) and data from all of the flowage lakes will be pooled in future assessments. It is anticipated to be added to the State’s 2022 303(d) list. The MPCA further refined the loading capacity (LC) for Horseshoe Lake (Lake ID 73-0157-00, see Figure 2 and Figure 3) into allocations for the three distinct bays of the lake to account for the unique site specific standards (described in Section 2.4) developed for each bay. Together they are the TMDL for Horseshoe Lake.

The naming convention for Lake ID 73-0088-00 needs clarification. This water body is alternatively referred by at least three different names in existing literature and data sets. A sample of references is listed below:

Name	Documentation
Bolfing	Walker (2009); Minnesota Department of Natural Resources (DNR) surface water data; Environmental Quality Information System (EQuIS) database listing
Bolting	303d listing, Sauk River Monitoring and Assessment Report (MPCA 2011)
Bolfung	Walker (2009) SRCL model

In this TMDL report, this lake is referred to as "Bolfing," which is consistent the DNR surface water inventories and records for the lake in EQuIS data sets.

Table 2. Sauk River Watershed lake impairments addressed by this TMDL report

Lake Name (DNR LAKE ID)	Designated Use Class	Listing Year	Target TMDL Completion Year	Affected Use: Pollutant/Stressor
Bolfing 73-0088-00	2B, 3C	2004	2022	Aquatic Recreation: Nutrients/Eutrophication Biological Indicators
Cedar Island (East Lake)* 73-0133-04	2B, 3C	2022	2022	
Cedar Island (Koetter Lake) 73-0133-03	2B, 3C	2004	2022	
Cedar Island (Main Bay) 73-0133-01	2B, 3C	2004	2022	
Eden 73-0150-00	2B, 3C	2010	2022	
Great Northern 73-0083-00	2B, 3C	2004	2022	
Horseshoe 73-0157-00	2B, 3C	2004	2022	
Knaus 73-0086-00	2B, 3C	2004	2022	
Krays 73-0087-00	2B, 3C	2004	2022	
Long 73-0139-00	2B, 3C	2004	2022	
North Browns 73-0147-00	2B, 3C	2008	2022	

Lake Name (DNR LAKE ID)	Designated Use Class	Listing Year	Target TMDL Completion Year	Affected Use: Pollutant/Stressor
Schneider 73-0082-00	2B, 3C	2004	2022	
Vails 73-0151-00	2B, 3C	2010	2022	
Zumwalde 73-0089-00	2B, 3C	2004	2022	

* Proposed for inclusion on the State's 2022 303d Impaired Waters List.

A number of other TMDLs have been completed or are in the process of being completed in the Sauk River Watershed. Those which represent the closest upstream impairment along any flow path to the SRCL include Sauk (Southwest Bay), McCormic, Uhlenkohlts, Maria, Ellering, Sand, and Henry Lakes. All of these are located in the portion of the Sauk River Watershed upstream of the inflow to the SRCL at Richmond (Figure 4). To date, all but Maria and Ellering have approved TMDLs. Those incomplete TMDLs are targeted for completion in 2022.

1.3 Priority ranking

The MPCA's schedule for TMDL completions (Table 2), as indicated on Minnesota's Section 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned TMDL priorities with the watershed approach. 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 the EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration, and Protection under the CWA Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments that will be addressed by TMDLs by 2022. Impaired waters in the Sauk River Watershed addressed in this TMDL report are part of the MPCA prioritization plan to meet the EPA's national measure.

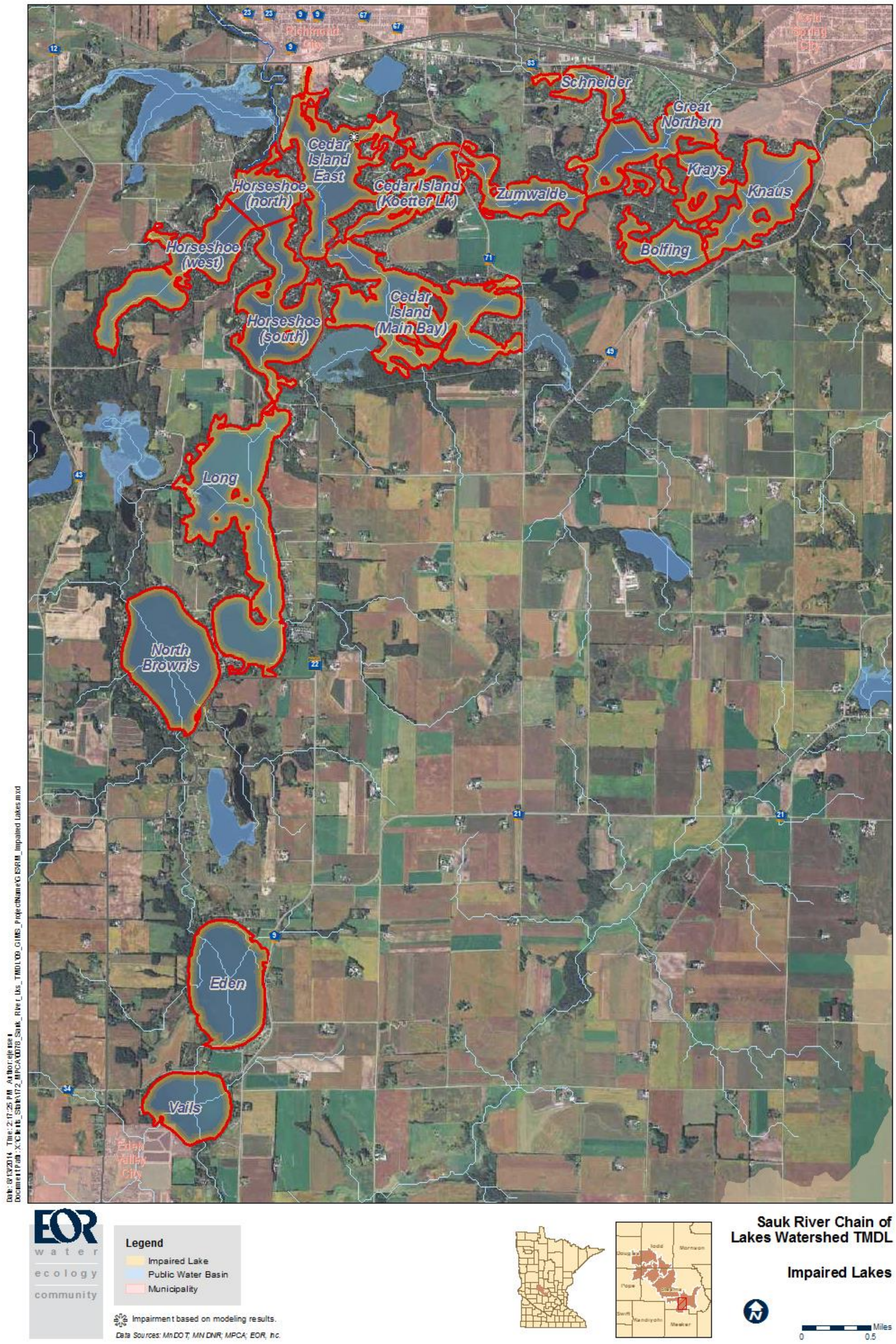

Figure 2. Impaired waters in the SRCL Management Unit addressed by this TMDL report are outlined in red.

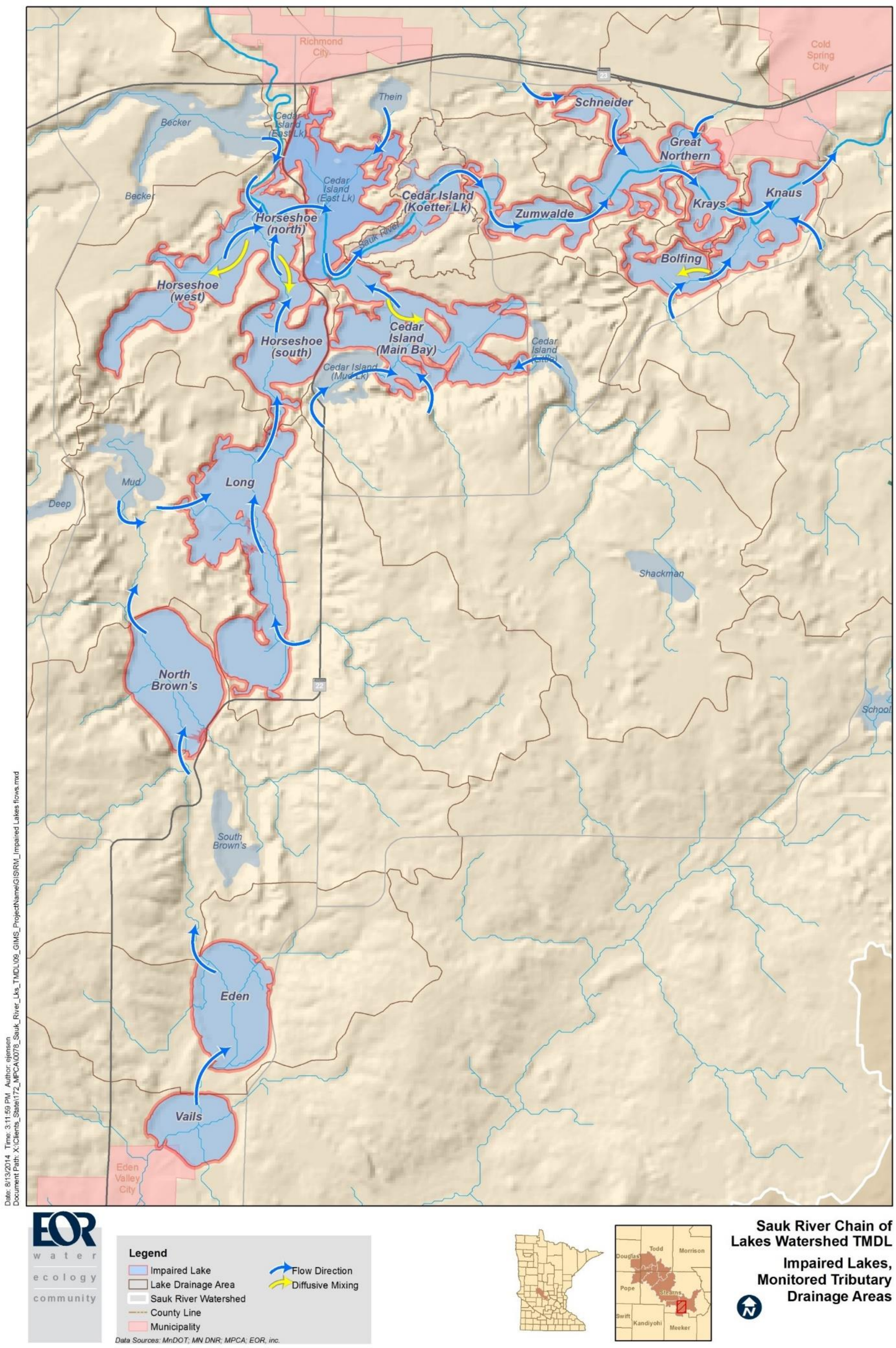

Figure 3. Flow paths, impaired waters in the SRCL Management Unit addressed by this TMDL report

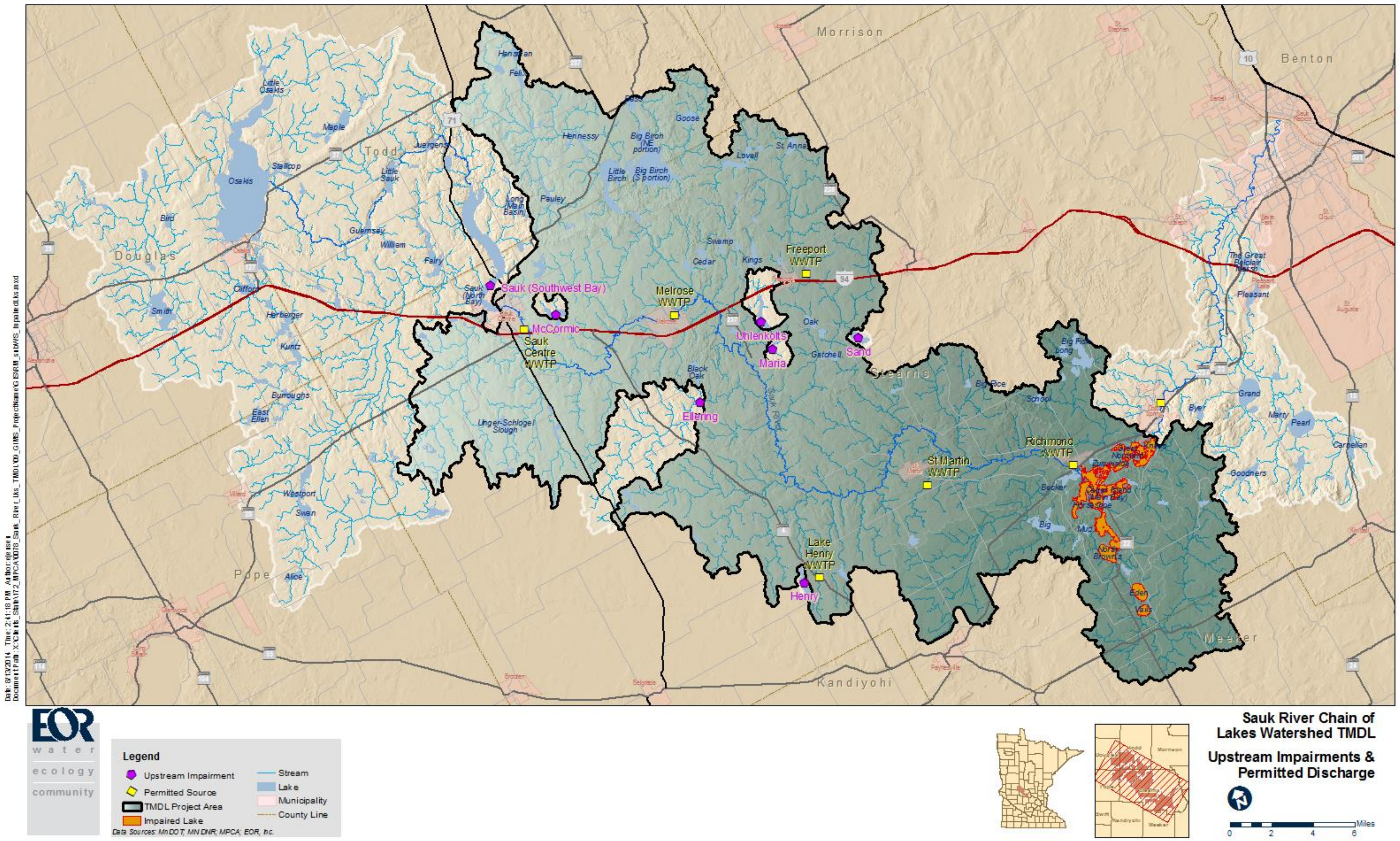

Figure 4. Sauk River Chain of Lakes TMDL project area showing upstream impaired waters and the location of NPDES/SDS permit holders.

Impaired lakes addressed in this TMDL are highlighted in orange.

2. Applicable water quality standards and numeric water quality targets

The federal Clean Water Act requires states to designate beneficial uses for all waters and develop water quality standards to protect each use. Water quality standards consist of several parts:

- Beneficial uses—Identify how people, aquatic communities, and wildlife use our waters
- Numeric criteria—Amounts of specific pollutants allowed in a body of water that still protect it for the beneficial uses
- Narrative criteria—Statements of unacceptable conditions in and on the water
- Antidegradation protections—Extra protection for high-quality or unique waters and existing uses

Together, the beneficial uses, numeric and narrative criteria, and antidegradation protections provide the framework for achieving Clean Water Act goals. Minnesota's water quality standards are in Minn. R. chs. 7050 and 7052.

2.1 Beneficial uses

The beneficial uses for waters in Minnesota are grouped into one or more classes as defined in Minn. R. 7050.0140. The classes and associated beneficial uses are:

- Class 1 – domestic consumption
- Class 2 – aquatic life and recreation
- Class 3 – industrial consumption
- Class 4 – agriculture and wildlife
- Class 5 – aesthetic enjoyment and navigation
- Class 6 – other uses and protection of border waters
- Class 7 – limited resource value waters

The Class 2 aquatic life beneficial use includes a tiered aquatic life uses framework for rivers and streams. The framework contains three tiers—exceptional, general, and modified uses.

All surface waters are protected for multiple beneficial uses, and numeric and narrative water quality criteria are adopted into rule to protect each beneficial use. TMDLs are developed to protect the most sensitive use of a water body.

2.2 Numeric criteria and state standards

Narrative and numeric water quality criteria for all uses are listed for four common categories of surface waters in Minn. R. 7050.0220. The four categories are:

- Cold water aquatic life and habitat, also protected for drinking water: Classes 1B; 2A, 2Ae, or 2Ag; 3A or 3B; 4A and 4B; and 5

- Cool and warm water aquatic life and habitat, also protected for drinking water: Classes 1B or 1C; 2Bd, 2Bde, 2Bdg, or 2Bdm; 3A or 3B; 4A and 4B; and 5
- Cool and warm water aquatic life and habitat and wetlands: Classes 2B, 2Be, 2Bg, 2Bm, or 2D; 3A, 3B, 3C, or 3D; 4A and 4B or 4C; and 5
- Limited resource value waters: Classes 3C; 4A and 4B; 5; and 7

The narrative and numeric water quality criteria for the individual use classes are listed in Minn. R. 7050.0221 through 7050.0227. The procedures for evaluating the narrative criteria are presented in Minn. R. 7050.0150.

The MPCA assesses individual water bodies for impairment for Class 2 uses—aquatic life and recreation. Class 2A waters are protected for the propagation and maintenance of a healthy community of cold water aquatic life and their habitats. Class 2B waters are protected for the propagation and maintenance of a healthy community of cool or warm water aquatic life and their habitats. Protection of aquatic life entails the maintenance of a healthy aquatic community as measured by fish and macroinvertebrate indices of biotic integrity (IBIs). Fish and invertebrate IBI scores are evaluated against criteria established for individual monitoring sites by water body type and use subclass (exceptional, general, and modified).

Both Class 2A and 2B waters are also protected for aquatic recreation activities including bathing and swimming, and the consumption of fish and other aquatic organisms. To determine if a lake supports aquatic recreational activities, its trophic status is evaluated using total phosphorus (TP), Secchi depth, and chlorophyll-*a* (Chl-*a*) as indicators. The ecoregion standards for aquatic recreation protect lake users from nuisance algal bloom conditions fueled by elevated phosphorus concentrations that degrade recreational use potential.

The impaired lakes in this TMDL are designated as Class 2B waters for aquatic recreation use (Minn. R. 7050.0140, subp. 3): "Aquatic life and recreation includes all waters of the state that support or may support fish, other aquatic life, bathing, boating, or other recreational purposes and for which quality control is or may be necessary to protect aquatic or terrestrial life or their habitats or the public health, safety, or welfare."

2.3 Antidegradation policies and procedures

The purpose of the antidegradation provisions in Minn. R. ch. 7050.0250 through 7050.0335 is to achieve and maintain the highest possible quality in surface waters of the state. To accomplish this purpose:

- Existing uses and the level of water quality necessary to protect existing uses are maintained and protected.
- Degradation of high water quality is minimized and allowed only to the extent necessary to accommodate important economic or social development.
- Water quality necessary to preserve the exceptional characteristics of outstanding resource value waters is maintained and protected.

- Proposed activities with the potential for water quality impairments associated with thermal discharges are consistent with Section 316 of the Clean Water Act, United States Code, title 33, Section 1326.

2.4 Sauk River Watershed lake water quality standards

TP is often the limiting factor controlling primary production in freshwater lakes. As lake TP concentrations increase, algal growth increases resulting in higher Chl-*a* concentrations and lower water transparency. In addition to meeting TP standards, Chl-*a* and Secchi transparency depth standards must also 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 (as summarized by Heiskary and Wilson 2005). Clear relationships were established between the causal factor TP and the response variables Chl-*a* and Secchi transparency. Based on these relationships, it is expected that by meeting the TP standard in each lake, the Chl-*a* and Secchi standards will likewise be met. The impaired lakes are located within the North Central Hardwood Forests (NCHF) Ecoregion. The applicable water quality standards are listed in Table 3.

In the NCHF Ecoregion, a separate water quality standard was developed for shallow lakes that tend to have poorer water quality than deeper lakes. According to the MPCA definition of shallow lakes, a lake is considered shallow if its maximum depth is less than 15 feet, or if the littoral zone (area where depth is less than 15 feet) covers at least 80% of the lake's surface area. Vails Lake is a shallow lake according to this definition. There are seven additional lakes within the SRCL with physical characteristics that fall within the scope of this definition and have been assigned site specific water quality standards as described below and as listed in Table 3.

Site specific standards for the SRCL (Heiskary 2012) were developed by MPCA under Minn. R. ch. 7050 (2008), subp. 2aD, which provides for the development of site specific eutrophication standards for reservoirs. The SRCL meets the definition of a reservoir under the following conditions:

- Several (shallow) lakes within the SRCL are located along the flowage of the Sauk River.
- Damming of the Sauk River near Cold Spring, Minnesota (the outlet to the SRCL) has created or enlarged basins located along the river and increased connectivity to basins off of the main flowage.

Unique characteristics of SRCL basins, which were taken into account in the development of site specific standards include:

- Short hydraulic residence time in basins located along the main Sauk River Flowage.
- Water quality in basins located along the main flowage that is heavily influenced by the Sauk River inflows.
- Advective and diffusive exchange of pollutant loads between basins located on the main flowage and deeper basins located off the main Sauk River Flowage.

To be listed as impaired (Minn. R. 7050.0150, subp. 5), the summer growing season (June through September) monitoring data must show that the standards for both TP (the causal factor) and either Chl-*a* or Secchi transparency (the response variables) were violated. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if it will be listed as impaired. For more details regarding the listing process, see the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* (MPCA 2012a).

Table 3. Lake eutrophication standards for NCHF Ecoregion and site specific standards for the Sauk River Chain of Lakes.

Lake Type	TP (ppb*)	Chl-*a* (ppb)	Secchi (m)
NCHF General: Eden, Schneider, Long, North Browns	< 40	< 14	> 1.4
NCHF Shallow Lakes: Vails	< 60	< 20	> 1.0
SITE SPECIFIC STANDARDS (Heiskary 2012)			
Flowage (Shallow): Horseshoe North, Cedar Island–East, Cedar Island–Koetter, Zumwalde, Great Northern, Krays, Knaus	< 90	< 45	> 0.8
Nonflowage: Horseshoe West, Horseshoe South, Bolfing, Cedar Island–Main	< 55	< 32	> 1.4

*ppb = parts per billion

3. Watershed and water body characterization

No part of the Sauk River Watershed is located within the boundary of a federally recognized Indian reservation.

The watershed area for the SRCL is approximately 592,275 acres and covers parts of five counties (Stearns, Meeker, Todd, Douglas, and Pope) with the largest portion in Stearns County. The Sauk River inflow at Richmond accounts for 82% of the total watershed area above the SRCL outlet, and a majority of the flow and phosphorus loading to the SRCL. Impaired lakes located directly along the Sauk River flowage include Horseshoe North, Cedar Island–East, Cedar Island–Koetter, Zumwalde, Great Northern, Krays, and Knaus Lakes. Nonflowage lakes include Horseshoe West, Horseshoe South, Cedar Island–Main Lake, Schneider Lake, and Bolfing Lake. Long Lake and North Browns Lake are sometimes listed as part of the SRCL, but the hydrology and water quality of these lakes are not significantly influenced by Sauk River flows. The remaining two impaired lakes addressed in the TMDL, Eden and Vails lakes, are located in the EVC Subwatershed. EVC contributes approximately 5% of the flow volume and 3% of TP loading to the SRCL. Other tributaries that contribute seasonal flows include Kolling Creek (from West), Kinzer Creek (from East), and Schneider Creek (from West). Several smaller lakes and tributaries are part of the flow network of the SRCL (Figure 2, Figure 3). The flow network for lakes and tributaries modeled explicitly in the TMDL study are shown in Figure 5.

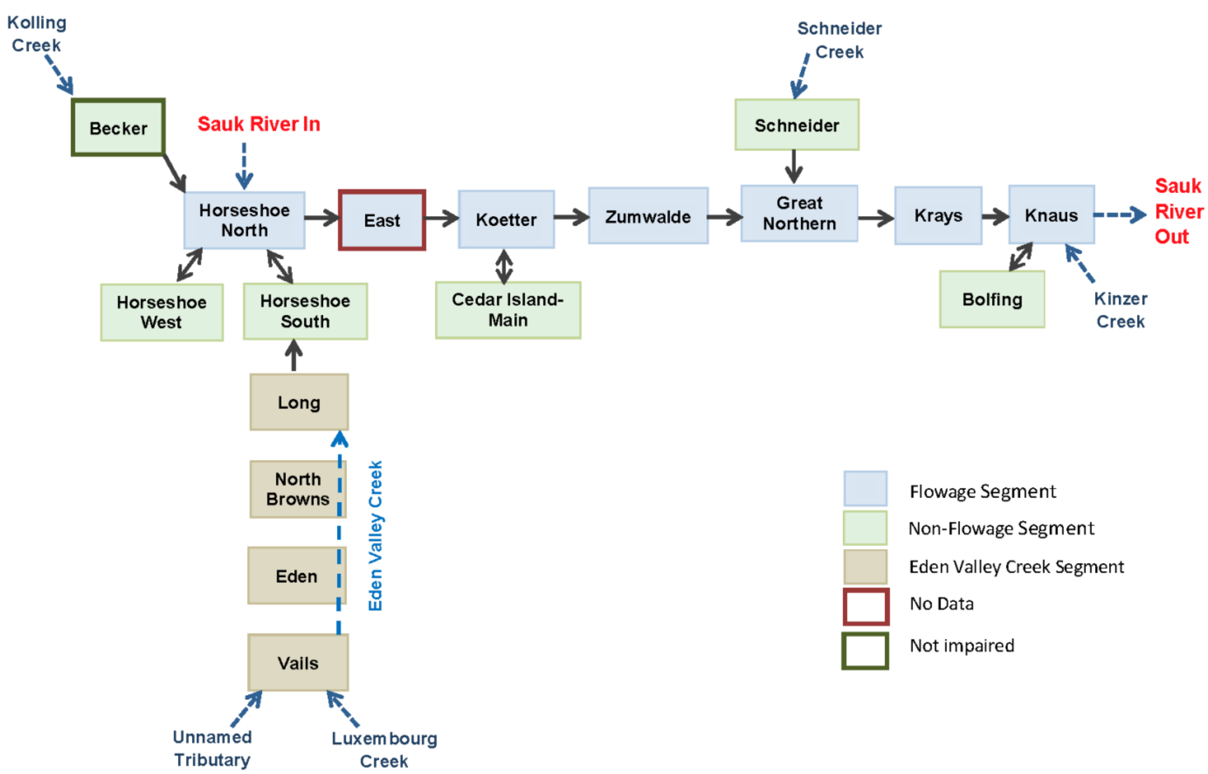

Figure 5. Sauk River Chain of Lakes and Eden Valley Watershed Unit Flow Network (modified from Walker 2009).

3.1 Lakes

As reported by Heiskary (2012), SRCL meets the reservoir definition based on the series of lakes located along the Sauk River and the presence of the outlet dam near the city of Cold Spring. Based on notes from a 1901 court case, the damming that served to form the basins directly on the flowage dates back to 1856 when a milldam was constructed at a constriction in the river at Cold Spring. The effect of the dam was to raise the water levels of the river by 7.5 feet, overflow large tracts of adjacent land up to 16 miles up the river, and the formation of several lakes and ponds along its course.

The morphometric characteristics of the impaired lakes included in this report are listed in Table 4. With the exception of Eden and Vails Lakes, values for lake surface area, % littoral, volume, mean depth, and maximum depth were obtained from Walker (2009). For Eden and Vails Lakes, surface areas, lake volumes, mean and maximum depths, and littoral areas (< 15 feet) were calculated using digitized bathymetric contours (DNR). Watershed areas for all lakes were calculated using digital maps of HUC-12 boundaries (DNR). Reported watershed areas represent the entire drainage areas for any given lake (watershed areas for lakes segments located upstream in the chain are included) and include lake surface areas.

Table 4. Impaired lake morphometric characteristics

Lake	Lake Segment Type	Surface area (ac)	Littoral area (% total area)	Volume (ac-ft)	Mean depth (ft)	Maximum depth (ft)	Watershed area (ac)	Watershed area§: surface area	Lakeshed area§: surface area
Horseshoe North	SRCL Flowage	62	64	324	5.2	14	571,282	9214:1	2:1
Cedar Island–East	SRCL Flowage	269	99	649	2.6	48	572,060	2,175:1	3:1
Cedar Island–Koetter	SRCL Flowage	129	94	486	3.6	30	577,401	4,476:1	3:1
Zumwalde	SRCL Flowage	121	98	729	6.2	21	577,659	4,774:1	4:1
Great Northern	SRCL Flowage	189	99	1,134	6.2	16	590,591	3,125:1	5:1
Krays	SRCL Flowage	91	96	648	6.9	40	590,749	6,492:1	2:1
Knaus	SRCL Flowage	210	99	1,377	6.6	16	592,275	2,820:1	3:1
Horseshoe South	SRCL Nonflowage	252	15	4,860	19.4	50	34,090	109:1	2:1
Horseshoe West	SRCL Nonflowage	314	64	3,645	11.5	30	950	3:1	4:1
Cedar Island–Main	SRCL Nonflowage	504	56	7,209	14.1	70	4,718	9:1	9:1
Bolfing	SRCL Nonflowage	106	63	1,377	13.1	35	981	9:1	9:1
Schneider	SRCL deep lake	54	46	1,053	20.0	55	11,933	221:1	3:1
Vails	*(EVC/Long Lake*)*	150	97	1,354	9.0	21	23,275	155:1	11:1
Eden	*(EVC/Long Lake)*	260	54	5,088	19.6	77	25,217	97:1	7:1
North Browns	*(EVC/Long Lake)*	311	40	5,751	18.4	35	29,577	95:1	7:1
Long	*(EVC/Long Lake)*	487	68	4,860	9.8	34	33,570	69:1	8:1

§Watershed = entire drainage area; Lakeshed = direct drainage only (as modeled), monitored tributaries and upstream lakesheds are not included.

*Eden Valley Creek/Long Lake Subwatershed.

3.2 Subwatersheds

The impaired lakes are distributed along two converging flow paths: (1) the predominant Sauk River flowing from the north through the SRCL (10 impaired lakes); and (2) the much smaller EVC flowing from the south through four impaired lakes and then into Horseshoe Lake, the most upstream of the SRCL (Figure 1). Improving the water quality of headwater or 'king-pin' lakes, Vails (EVC) and Horseshoe North (SRCL and EVC), will have a domino/cascading positive effect upon their downstream lakes' water quality. Lake segments located along the SRCL flowage have large watershed-to-lake surface area ratios (e.g. 555:1) and relatively small direct drainage areas (lakeshore and immediate runoff areas). Hence, the first lake of the SRCL, Horseshoe North, receives the brunt of the large Sauk River's and the EVC's loading, and is thus the 'king-pin' for determining downstream SRCL segments' water quality. This also highlights limitations in meeting downstream segment load capacities (TMDLs) by adjusting LAs for lakeshed sources which are small relative to the entire Sauk River. Lake segments located off of the main flowage tend to have larger direct drainage areas, and most have small monitored tributaries that were included in the lake models. Figure 6 identifies the SRCL and EVC lakeshed and tributary drainage areas. [Note: Monitored tributary drainage areas are not included in lakeshed direct drainage areas.] Lakeshed and tributary drainage areas used in lake water quality models are listed in Table 5 and Table 6.

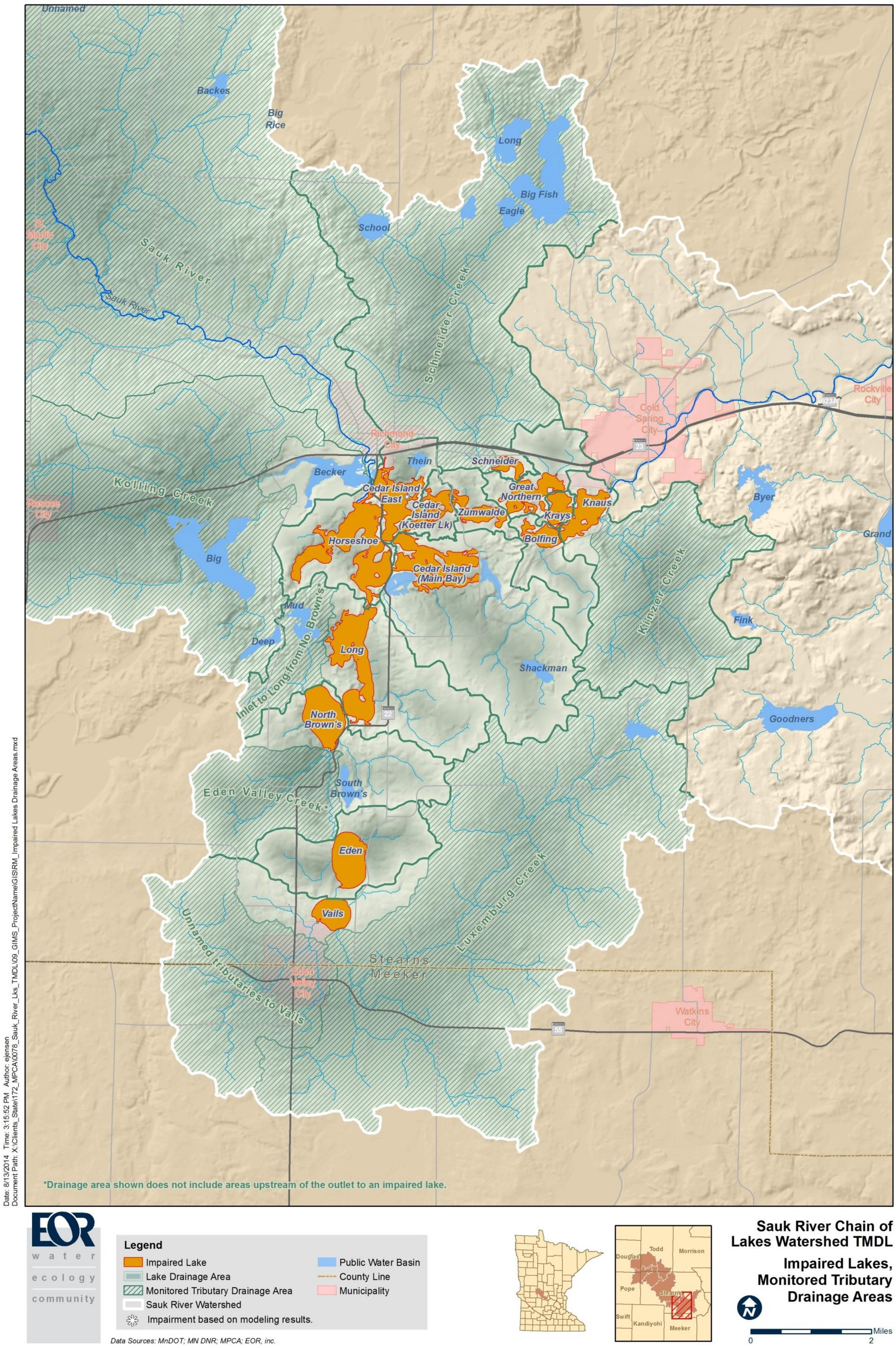

Figure 6. Direct drainage areas to lakes and monitored tributaries in the SRCL and EVC. Impaired lakes addressed in the TMDL have been highlighted (see also Figure 4).

3.3 Land cover

Land cover data for the entire Sauk River Watershed were summarized from the 2006 National Land Cover Dataset (NLCD) downloaded from the United States Geological Survey (USGS). This information was used to define potential pollutant sources and BMPs that may be applicable within each subwatershed. Land covers are shown in Figure 7 and summarized in Table 5 and Table 6 for each impaired lake lakeshed and tributary. Tributary drainage areas do not include lakeshed direct drainage. Due to the number of categories, land cover classes were simplified as follows:

- Undeveloped includes evergreen forests, deciduous forests, mixed forests and scrub/shrub.
- Developed includes developed open space, and low, medium and high density developed areas.
- Grassland includes native grass stands, alfalfa, clover, long term hay, and pasture.
- Cropland includes all annually planted row crops (corn, soybeans, wheat, oats, barley, etc.), and fallow crop fields.
- Wetland includes wetlands and marshes.
- Open water includes: all lakes and rivers.

Table 5. Land cover distribution within direct drainage area for SRCL and EVC impaired lakes

Waterbody Name	Open Water	Wetland	Cropland	Pasture Land	Undeveloped	Urban (all)	Total	Lakeshed Area
(LAKE ID)	(% Total Area)							(ac)
Bolfing **73-0088-00**	11%	0%	46%	27%	11%	5%	100%	980
Cedar Island–East **73-0133-04**	39%	3%	13%	12%	8%	25%	100%	778
Cedar Island–Koetter **73-0133-03**	35%	3%	18%	29%	10%	5%	100%	373
Cedar Island–Main **73-0133-01**	13%	1%	38%	26%	15%	6%	100%	4,718
Great Northern **73-0083-00**	19%	5%	15%	30%	16%	16%	100%	999
Horseshoe **73-0157-00** Horseshoe N Horseshoe S Horseshoe W	40%	1%	25%	15%	12%	8%	100%	1,620

Waterbody Name	Open Water	Wetland	Cropland	Pasture Land	Undeveloped	Urban (all)	Total	Lakeshed Area
Knaus **73-0086-00**	39%	0%	28%	13%	10%	9%	100%	546
Krays **73-0087-00**	59%	0%	0%	8%	30%	3%	100%	159
Long **73-0139-00**	14%	3%	44%	24%	11%	5%	100%	2,764
North Browns **73-0147-00**	10%	1%	59%	20%	6%	4%	100%	2,054
Schneider **73-0082-00**	21%	4%	28%	23%	16%	9%	100%	173
Zumwalde **73-0089-00**	35%	4%	11%	24%	10%	8%	100%	508
Eden **73-0150-00**	14%	2%	48%	25%	6%	6%	100%	1,943
Vails **73-0151-00**	6%	0%	2%	14%	72%	6%	100%	1,146

Table 6. Land cover distribution within drainage areas for modeled tributaries located within the SRCL and EVC.

Waterbody Name (AUID or Lake ID)	Open Water	Wetland	Cropland	Pasture Land	Undeveloped	Urban (all)	Total	Total Area
	(% Total Area)							(ac)
Sauk River (at Richmond) **07010202-557**	4%	4%	51%	28%	7%	5%	100%	486,824
Kolling Creek 07010202-608	3%	4%	65%	18%	5%	4%	100%	22,106
Luxembourg Creek 07010202-550	7%	3%	54%	22%	8%	6%	100%	16,187
Unnamed Tributary to Vails 07010202-651	1%	1%	66%	18%	5%	9%	100%	4,465
Schneider Creek 07010202-616	8%	4%	34%	32%	18%	5%	100%	9,742
Kinzer Creek 07010202-565	<1%	2%	54%	25%	14%	5%	100%	4,314
Eden Valley Creek§ 07010202-545	<1%	1%	71%	18%	6%	5%	100%	2,306 (27,523)
Inlet to Long from North Browns§§ 07010202-610	6%	7%	36%	30%	17%	4%	100%	1,228 (30,763)

§Land use and area are shown only for the drainage area located upstream of Eden Lake. The total drainage area is shown in parenthesis.

§§Land use and area are shown only for the drainage area located upstream of North Browns Lake. The total drainage area is shown in parenthesis.

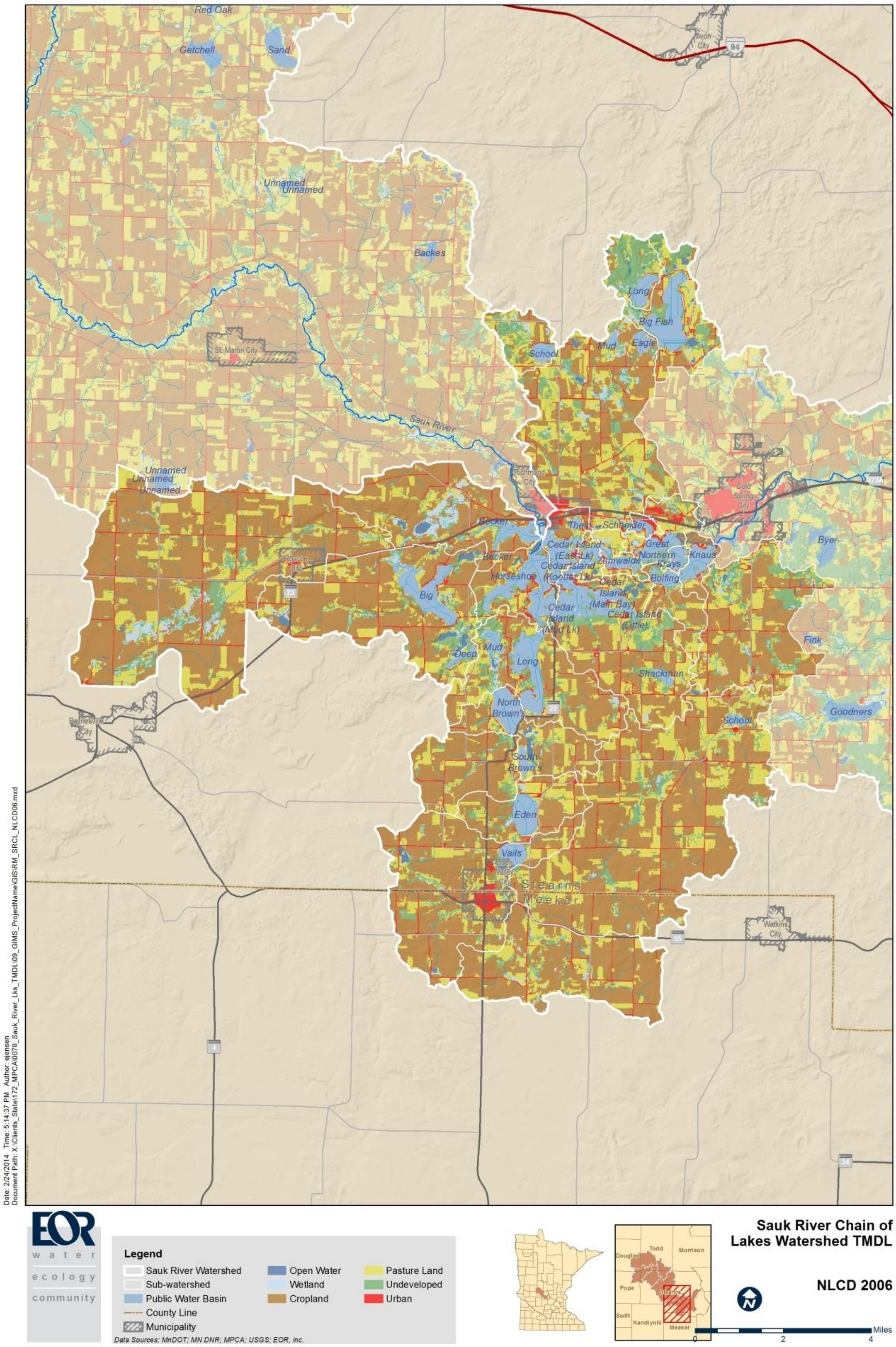

Figure 7. Land cover within the SRCL and EVC subwatersheds

3.4 Water quality

Lake water quality was summarized for each lake based on available data. The existing in-lake water quality conditions were quantified using data obtained from the MPCA EQuIS database (downloaded September 2013). Growing season (June through September) means were calculated for TP, Chl-*a*, and Secchi depth (Secchi) for the 10-year time period 2002 through 2011. This time period was chosen because it offered the best overall consistency in data records for the 14 impairments addressed in the TMDL. It also incorporates the time period used to calibrate the BATHTUB model developed by Walker (2002 through 2006) and the time period that the MPCA used to assess these lakes for nutrient impairments in the 2010 assessment cycle (MPCA 2011). The 10-year growing season mean (GSM) TP, Chl-*a*, and Secchi for each impaired lake is listed in Table 7. A summary of water quality data used to estimate long-term average conditions for impaired lakes can be found in Appendix A.

Because of the extended time line of this TMDL report's development and review, water quality data were collected on some of the impaired lakes after the TMDLs were developed and the report was originally written. However, changes are not substantial enough to necessitate revising the TMDL calculations. Appendix H presents data for lakes with a substantial amount of recent water quality data. For the most part, TP levels have decreased since 2011.

Table 7. 10-year growing season mean, Jun–Sept, 2002–2011 TP, Chl-*a*, and Secchi

Lake Name	10-year Growing Season Mean (June – September)					
	TP		Chl-*a*		Secchi	
	(ppb)	CV	(ppb)	CV	(m)	CV
Site Specific Standard - Flowage	**<90**	**--**	**<45**	**--**	**>0.8**	**--**
Horseshoe – Horseshoe N	n/a	n/a	n/a	n/a	n/a	n/a
Cedar Island–East	n/a	n/a	n/a	n/a	n/a	n/a
Cedar Island–Koetter	126.4	0.4	78.9	0.3	0.6	0.4
Zumwalde	139.8	0.4	65.2	0.5	0.6	0.4
Great Northern	136.0	0.4	76.8	0.3	0.6	0.2
Krays	144.0	0.5	75.6	0.5	0.6	0.4
Knaus	155.8	1.2	76.3	0.4	0.7	0.4
Site Specific Standard-Nonflowage	**<55**	**--**	**<32**	**--**	**>1.4**	**--**
Horseshoe South	112.6	1.2	60.7	0.6	1.1	0.5
Horseshoe West	59.0	1.2	33.3	0.3	1.2	0.8
Cedar Island–Main	82.8	0.8	46.4	0.4	1.2	0.7
Bolfing	74.1	0.4	55.9	0.5	1.2	0.9
NCHF Lakes	**<40**	**--**	**<14**	**--**	**>1.4**	**--**
Schneider	60.5	0.9	34.7	0.6	1.7	0.7
Eden	109.5	0.5	36.4	0.9	1.8	0.7

Lake Name	10-year Growing Season Mean (June – September)					
	TP		Chl-*a*		Secchi	
	(ppb)	CV	(ppb)	CV	(m)	CV
North Browns	155.8	1.2	41.1	0.7	1.8	0.7
Long	89.9	0.5	62.2	0.5	1.4	0.3
NCHF Shallow Lakes	**<60**	--	**<20**	--	**>1.0**	--
Vails	177.8	0.5	63.3	0.8	1.6	0.5

n/a = Not available

CV = coefficient of variation, defined as the standard error divided by the mean.

NCHF = Northern Central Hardwood Forest

3.5 Pollutant source summary

Sources of pollutants in the Sauk River Watershed include permitted and nonpermitted sources. The permitted sources discussed here are pollutant sources that require a NPDES permit. Nonpermitted sources are pollutant sources that do not require an NPDES permit. All Minnesota NPDES permits are also state disposal system (SDS) permits, but some pollutant sources require SDS permit coverage alone without NPDES permit coverage (e.g., spray irrigation, large septic systems, land application of biosolids, and small feedlots).

The phrase “nonpermitted” does not indicate that the pollutants are illegal, but rather that they do not require an NPDES permit. Some nonpermitted sources are unregulated, and some nonpermitted sources are regulated through non-NPDES programs and permits such as state and local regulations.

3.5.1 Phosphorus

Section 3.5 discusses the major phosphorus sources that have been quantified, using collected monitoring data and water quality modeling, to both assess the existing contributions of pollutant sources and determine pollutant load reductions required to meet individual TMDLs. To the extent practical, this study uses pollutant source estimates completed by Walker in 2009. Water quality models (BATHTUB) for the 14 impaired lakes consist of both a modified version of the Walker (2009) SRCL model (referred to as the ‘Chain of Lakes model’ in this report) and others that were created as independent lake models. For lakes that were modeled as part of the modified version of the Walker (2009) SRCL model, the only changes made to pollutant source inventories were updates to estimated loading from septic systems (Section 3.5.1.2; see also Appendix B). For lakes modeled using independent BATHTUB models, the general approach taken by Walker was adopted, but based on data availability components of lakeshed drainage (described in Section 3.5.1.2) were lumped into a single source estimates. Methods used for estimating existing pollutant loads are discussed in sections 3.5.1.1 and 3.5.1.2. BATHTUB models are described in sections 4.1.1.1 through 4.1.1.5.

3.5.1.1 Permitted sources of phosphorus

Regulated surface water dischargers of phosphorus are permitted through the NPDES/SDS permits. Regulated sources of phosphorus addressed in this TMDL study include the six municipal WWTPs listed in Table 8. All WWTPs in the project area are located upstream of the Sauk River inlet to the SRCL and discharge either directly to the Sauk River or to waters that drain to the Sauk River. Phosphorus loads from permitted sources were accounted for in the LC for Horseshoe Lake North, the lake in the furthest upstream segment of the SRCL. WLAs for WWTPs are discussed in Section 4.1.3.

Table 8. WWTPs in the SRCL project area.

Facility Name	NPDES Permit	Design Flow (MGD)	WLA Concentration Assumptions (mg/L)	Permit Limit (kg/yr)	WLA lbs/yr
Freeport WWTP	MNG580019	0.13	*1.0*	180#	*397*
Lake Henry WWTP	MN0020885	0.04	*3.1*	174§	*384*
Melrose WWTP	MN0020290	3.0	*0.8*	3,325§	*7,730*
Richmond WWTP	MN0024597	0.31	*0.4*	168§	*370*
Saint Martin WWTP	MN0024783	0.042	*0.8*	46.5§	*103*
Sauk Centre WWTP	MN0024821	0.888	*0.8*	982.5§	*2,166*

#Freeport WWTP does not currently include a total phosphorus effluent limit.

§Existing total phosphorus effluent limit.

Other wastewater sources that are upstream of this chain of lakes include GEM Sanitary district WWTP (MNG580205), which is upstream of Ellering Lake; a WLA will be assigned in a future TMDL for that water body.

NuStar Sauk Center Terminal (MN0057771) is upstream of Sauk Lake and was addressed in the Sauk Lake TMDL. (MPCA 2016). Osakis WWTP is upstream of Faille Lake and Lake Osakis and is being addressed in the Osakis Lakes Area TMDL.

There are neither permitted Municipal Separate Storm Sewer (MS4) communities nor industrial NPDES/SDS wastewater permits with phosphorus benchmark reporting requirements in the TMDL project area. Phosphorus loads from other regulated sources (construction and industrial stormwater runoff) were accounted for indirectly in the LC for each lake as described in Section 4.1.3. A small percent of the project area is permitted through construction and industrial stormwater permits, and they are not considered a significant source.

NPDES/SDS permitted animal feeding operations

Concentrated animal feeding operations (CAFOs) are defined by the EPA based on the number and type of animals. The MPCA currently uses the federal definition of a CAFO in its permit requirements of animal feedlots along with the definition of an animal unit (AU). In Minnesota, the following types of livestock facilities are required to operate under an NPDES permit or a state issued SDS permit: a) all federally defined CAFOs that have had a discharge, some of which are under 1,000 AUs in size; and b) all CAFOs and non-CAFOs that have 1,000 or more AUs.

CAFOs and AFOs with 1,000 or more AUs must be designed to contain all manure and manure contaminated runoff from precipitation events of less than a 25-year, 24-hour storm event. Having and complying with an NPDES permit allows some enforcement protection if a facility discharges due to a 25-year, 24-hour precipitation event and the discharge does not contribute to a water quality impairment. Large CAFOs permitted with an SDS permit or those not covered by a permit must contain all runoff, regardless of the precipitation event. Therefore, many large CAFOs in Minnesota have chosen to have an NPDES permit, even if discharges have not occurred in the past at the facility. A current manure management plan that complies with Minn. R. 7020.2225 and the respective permit is required for all CAFOs and AFOs with 1,000 or more AUs.

All CAFOs are inspected by the MPCA in accordance with the MPCA NPDES Compliance Monitoring Strategy approved by the EPA. All CAFOs (NPDES permitted, SDS permitted, and not required to be permitted) are inspected by the MPCA on a routine basis with an appropriate mix of field inspections, offsite monitoring, and compliance assistance.

For the SRCL Watershed TMDL, all NPDES and SDS permitted feedlots are designed to have zero discharge, and as such they are not considered a significant source of phosphorus. All other feedlots are accounted for as nonpermitted sources. The land application of all manure, regardless of whether the source of the manure originated from permitted (e.g., CAFOs) or nonpermitted AFOs, is also accounted for as a nonpermitted source.

3.5.1.2 Nonpermitted sources of phosphorus

The following are the sources of phosphorus not requiring NPDES/SDS permit coverage that were evaluated in the TMDL study:

- Tributary loads
- Upstream lakes
- Lakeshed drainage
  - Runoff from shoreline lots (developed parcels)
  - Lakeshed runoff
  - Subsurface sewage treatment systems (SSTS)
- Atmospheric deposition
- Internal loads

Tributary Loads

Tributary loads were estimated using monitoring data for stream water quality and flow. Monitored tributary watersheds collectively drain approximately 554,003 acres, or about 94% of the SRCL Watershed. A variety of sources contribute to pollutant loads transported by monitored tributaries including, but not limited to: agricultural drainage; runoff from animal feedlots not requiring a NPDES/SDS permit; runoff from construction and industrial sites or other disturbed areas; developments; seepage from subsurface septic systems; and enriched runoff from fertilized (manure, commercial fertilizer) fields. Of particular note is the presence of numerous animal feedlots (nonNPDES/SDS) in the watershed (Appendix G.2). Nonpermitted sources of phosphorus within tributary watersheds were not evaluated categorically in the Walker (2009) study and a full-scale assessment was outside the scope of this TMDL. For the TMDL, tributary loads were assigned a single LA, which represents all sources of phosphorus within the tributary watershed. A more fine-scaled assessment of phosphorus sources would be beneficial for targeting BMPs during implementation of the TMDL (Section 8).

Existing phosphorus loads for monitored tributaries within the SRCL were estimated with FLUX32 software using the flow-weighted average method. The flow-weighted average method provides a loading estimate based on the flow-weighted average pollutant concentration multiplied by the mean flow over the averaging period. A May through September averaging period was chosen for modeling tributary loads. May was included in tributary modeling because phosphorus loading to lakes during this part of the year largely determines the amount of phosphorus available at the beginning of the growing season. Water quality data from the most recent 10-year time period for which paired flow and TP data were available were used in tributary load calculations. For tributaries modeled as part of the Chain of Lakes model (modified version of the Walker (2009) SRCL model), this time period was 2001 through 2010. For tributaries modeled in separate individual BATHTUB models (Vails, Eden, North Browns, Long, and Schneider Lakes), this time period was 2000 through 2009. See Appendix A for a summary of flow and water quality data used to estimate tributary loads.

Flow data used to estimate tributary loads was gathered from a variety of sources. For tributaries modeled as part of the Chain of Lakes model, a combination of monitored flows and estimated flows was used. Monitored flow records were provided by the SRWD for the Sauk River at Richmond (2001 through 2010), the Sauk River at Cold Springs (2005 through 2010), and other monitored tributaries (data was available for 2006). Missing flow records were estimated using regressions that were developed by Walker (2009). A Hydrologic Simulation Program - FORTRAN (HSPF) model framework for the Sauk River and South Fork Crow was developed by RESPEC Consulting and Services for the MPCA as part of 2011 Clean Water Land and Legacy grant programs. Modeling was completed in 2012, and HSPF data for the Sauk River Watershed were obtained from the MPCA in September 2013. HSPF simulated flows were used for all tributaries modeled in independent BATHTUB models (North Browns, Schneider, Eden, and Vails Lakes). Flow and water quality data used to model each tributary are summarized in Appendix A, and estimated tributary loads for each impaired lake are shown in Table 9 and Table 10.

Upstream Lakes

The BATHTUB model developed by Walker (2009) simulates hydraulic exchanges, both advective and diffusive, between lake segments in the SRCL. Advective transport is the movement of phosphorus that is transported by flowing water. Diffusive transport is the movement of phosphorus across a concentration gradient, from a segment with a higher concentration to a segment with a lower concentration. Typically most phosphorus is transported between lake segments in the direction of flow (i.e., advective transport); however, some phosphorus may also move in the opposite direction based on diffusive transport. Advective exchanges are simulated by linking segment outflows to downstream segments in the model. Diffusive exchanges can be modeled by calibrating dispersion coefficients to simulate the spatial distribution of a pollutant across the modeled system. In the Walker study, dispersion rates were calibrated to observed in-lake TP concentrations for the period 2002 through 2006 and confirmed using observed chloride concentrations for the same time period. The chloride mass balance developed for the SRCL informed the understanding of flow exchanges between lakes. Dispersion rate coefficients calibrated by Walker were used in the updated Chain of Lakes BATHTUB model. Upstream lake loads (both advective and diffusive) were assigned LAs distinct from monitored tributaries and other sources of phosphorus.

Table 9. Average phosphorus loads to impaired waters from the total watershed area for lake segments included in the Chain of Lakes model (modified version of Walker (2009) SRCL model, see Section 4.1.1.1).

Lake	Model Segment Type	Modeled Tributaries	Upstream Lakes		Lakeshed Drainage			Atmospheric Deposition	Additional Internal Loading[§]
			Advective Load Components	Diffusive Load Components	Runoff from Shoreline lots	Lakeshed Runoff	Septic Tanks		
		(lb/yr)	(lb/yr)	(lb/yr)	(lb/yr)	(lb/yr)	(lb/yr)	(lb/yr)	(lb/yr)
Horseshoe North	flowage	105,847*	7,292	n/a	17	34	27	19	0
Cedar Island–East	flowage	n/a	116,904	n/a	38	5	66	81	0
Cedar Island -Koetter	flowage	n/a	99,949	n/a	30	22	67	39	0
Zumwalde	flowage	n/a	92,408	n/a	25	17	67	36	10,356
Great Northern	flowage	n/a	101,853	n/a	24	50	74	56	0
Krays	flowage	n/a	101,887	n/a	16	15	45	27	6,473
Knaus	flowage	968	108,035	n/a	116	36	81	63	11,488
Horseshoe S	nonflowage	n/a	3,647	1,061	35	2	133	94	1,002
Horseshoe W	nonflowage	n/a	n/a	438	73	94	106	75	0
Cedar Island -Main	nonflowage	n/a	n/a	919	69	633	179	152	675
Bolfing	nonflowage	n/a	n/a	345	25	110	46	32	0

*Sauk River inflow at Richmond excluding permitted source loads.

[§] See Section 4.1.1.4

Table 10. Average phosphorus loads to impaired waters for lake segments modeled using independent BATHTUB models (see Section 4.1.1.1).

Lake	Lake System or Subwatershed	Modeled Tributaries (lb/yr)	Lakeshed Drainage: Lakeshed Runoff (lb/yr)	Lakeshed Drainage: Septic Tanks (lb/yr)	Atmospheric Deposition (lb/yr)	Additional Internal Loading (lb/yr)
Schneider	SRCL	1,615	22	114	16	12
Vails	EVC/Long Lake	1,469§ 4,387§§	340	10	45	3,084
Eden	EVC/Long Lake	5,448*	391	39	78	2,067
North Browns	EVC/Long Lake	4,519	348	122	94	10,005
Long	EVC/Long Lake	6,127†	596	77	146	127

*Outflow from Vails Lake

†Outflow from North Browns Lake plus watershed runoff for that portion of the watershed located upstream of the inlet to Long Lake and downstream of the outlet to North Browns Lake.

§Unnamed Tributary to Vails Lake

§§Luxembourg Creek

Lakeshed Drainage

Runoff from areas draining directly to impaired lakes, including unmonitored tributary watersheds, is referred to as 'lakeshed drainage' in the TMDLs. In the Walker (2009) SRCL model, three sources of phosphorus pollution were estimated which fall into this category—lakeshed runoff, runoff from shoreline lots (phosphorus loading from developed parcels above and beyond background lakeshed runoff), and background phosphorus loading from shoreline septic systems. The Walker SRCL model estimates of phosphorus loading from lakeshed runoff and shoreline lots were adopted for use in the Chain of Lakes model; however, estimates of background phosphorus loading from SSTSs (septic systems) were updated to reflect septic system surveys conducted by Stearns County between 2008 through 2011 (Stearns County 2011). For lakes modeled using independent BATHTUB models, runoff from shoreline lots (developed parcels) was not distinguished from lakeshed runoff. Instead, lakeshed runoff was estimated using the Simple Method, which accounts for differences in land use within the lakeshed area including developed land around shorelines. Background phosphorus loading from septic systems were also estimated for these lakes. To avoid confusing terminology, components of lakeshed drainage were combined under one LA for 'lakeshed drainage' in the TMDL. Methods for estimating components of lakeshed drainage are described below.

Lakeshed Runoff for the Chain of Lakes Model

In the Walker (2009) SRCL BATHTUB model, lakeshed runoff was estimated by prorating nearby gauged tributary flows by lakeshed drainage area. Lakeshed loads were calculated from derived runoff volumes and a TP concentration of 54.3 ppb (Walker 2009), the average value from tributary monitoring of all three of the smaller gauged tributaries (Kolling, Kinzer, and Schneider Creeks). On an areal basis, this value translates into an export rate of 14.2 kg P/km^2. These values were retained in the Chain of Lakes model. Load estimates for lakeshed runoff for lakes included in the Chain of Lake model are listed in Table 9.

Lakeshed Runoff for the Independent BATHTUB Models

Due to different runoff characteristics, the Simple Method (Schueler 1987) was used to provide lakeshed runoff volumes and phosphorus loads used in the independent lake models for Schneider, Vails, Eden, North Browns and Long Lakes. The Simple Method uses an equation that relates watershed pollutant load to watershed drainage area, rainfall depth, percent impervious cover, and event mean runoff pollutant concentration (EMC) based on land cover and soil type. Land cover data were obtained from the 2006 NLCD (https://www.mrlc.gov/data/legends/national-land-cover-database-2006-nlcd2006-legend) and soils data were obtained from the Natural Resources Conservation Service (NRCS) soil survey (http://soils.usda.gov/survey/). Unique combinations of land cover and soil types were generated in ArcGIS and assigned an EMC according to Table 12. Each land cover/soil combination was also assigned an estimated impervious percentage based on the NRCS curve number methodology and the Simple Method one-year, 24-hour rainfall event runoff calculation. The sum of all runoff generated by each land cover/soil combination was then calibrated to the estimated annual runoff volume and multiplied by a corresponding EMC to estimate the annual watershed TP load. Annual runoff volumes for lakeshed drainage areas were estimated using an average runoff depth for basins modeled in the HSPF framework (2000 through 2009). The average annual runoff for basins located in the Long Lake Subwatershed (*HUC 070102020602*) ranged from 4.6 to 6.5 inches per year, the high end representing the one urbanized area in the subwatershed (Eden Valley, Minnesota). A value of 5 in/yr, the average runoff depth for nonurbanized basins, was used to estimate runoff volumes for lakeshed drainage areas. Load estimates for lakeshed runoff used in independent BATHTUB models are listed in Table 10.

Table 11. Lakeshed annual flow volumes based on five inches annual runoff and Simple Method TP loads for direct drainages

Impaired lake	Direct drainage area (ac)	Flow (ac-ft/yr)	TP Load (lb/yr)	TP Conc. (ppb)
Eden	1,942	717	391.1	185.8
Long	2,780	512	270.4	189.1
North Brown	2,054	679	348.3	188.5
Schneider	173	47	21.9	168.6
Vails	1,146	569	340.4	220.0

Table 12. TP event mean concentration (EMC) values by land cover and soil type

NLCD 2006 Description	Generalized Land Cover	TP EMC (ppb)
Cultivated Crops	Agriculture	250
Developed, High Intensity	Urban	200
Developed, Medium Intensity	Urban	200
Developed, Low Intensity	Urban	200
Developed, Open Space	Urban	200
Pasture Hay	Pasture	100
Grassland/Herbaceous	Grassland	50
Shrub/Scrub	Forest	50
Deciduous Forest	Forest	50
Evergreen Forest	Forest	50
Mixed Forest	Forest	50
Open Water	Water	50
Emergent Herbaceous Wetland	Water	50
Woody Wetlands	Water	50
Barren Land	Barren	50

Runoff from Shoreline Lots (Chain of Lakes Model)

Excess runoff from shoreline lots was estimated in the Walker (2009) SRCL model using an export rate of 0.27 lb/ac/yr (0.30 kg/ha/yr) and inventories of lakeshore lots provided by the SRWD. This export value falls within the range of estimated phosphorus export rates in the Upper Mississippi River Basin for the most common land use types in the SRCL: 0.155 kg/ha/yr (deciduous forest)–0.66 kg/ha/yr (agriculture) (Barr 2004). The value adopted for use in the Walker (2009) SRCL model reflects an increased percent impervious surface and higher intensity land use compared to undeveloped land in the ecoregion. This source was incorporated into lakeshed drainage in the TMDL, but was modeled as a separate (tributary) source in BATHTUB using a nominal discharge volume of 0.001 hm^3/yr and a concentration equivalent to the estimated annual load divided by this nominal volume. The nominal flow volume was used because runoff volumes were already accounted for in the lakeshed runoff load component of lakeshed drainage. Estimated excess phosphorus loads for runoff from shoreline lots are listed in Table 9. This source was estimated only for lakes included in the Chain of Lakes model and values were taken from the Walker (2009) SRCL model.

Subsurface Sewage Treatment Systems (Septic Systems)

Estimates for background SSTS loads were based on assumptions described in the Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (MPCA 2004) listed in Appendix A and septic system inspection record summaries provided by Stearns County. Inspection summaries for 2008 through 2010 were available for all lakes except North Browns, Eden, and Vails. County level information on SSTS units was available through the MPCA SSTS Annual Report (2012), but information provided by Stearns County offered better lake-specific data. Inspections summaries for each lake included the number of SSTS units inspected, the percent conforming, and the year of inspection. An additional 523 conforming units were inspected previously in 2003 through 2007. These additional conforming units were assumed to be distributed among the lakes in the same proportion as recently inspected systems. The total number of septic units was estimated as the number inspected (2008 through 2011) plus the appropriate proportion of additional conforming units. Failure rates for each lake take into account the additional conforming units. Subsurface sewage treatment system loads were incorporated into lakeshed drainage in the TMDL, but were modeled as a separate (tributary) source in BATHTUB using a nominal discharge volume of 0.001 hm^3/yr and a concentration equivalent to the estimated annual load divided by this nominal volume. The nominal flow volume was used since runoff volumes were already accounted for in lakeshed runoff load component of lakeshed drainage.

For North Browns Lake, the total number of SSTS units was derived from septic load estimates developed by Walker (2009) and confirmed through inspection of recent aerial photographs of housing units. For Eden and Vails Lakes, the number of SSTS units was based on inspection of aerial photographs. The failure rate applied to SSTS units for these lakes was taken as the average failure rate for all other lakes as reported in inspection summaries. Observed or estimated failure rates were used to estimate current phosphorus loading conditions for impaired lakes and septic loads were included in existing lakeshed drainage loads. When lakeshed load reductions were needed to meet TMDL goals, these reductions include the phosphorus loads from failing SSTS units which are required to be brought into compliance as a result of recent inspections. In many cases, a lakeshed load reduction was not required to meet TMDL goals, and the expected reductions in phosphorus loading associated with upgrades to failing septic systems (required to pass inspection) will offer an additional MOS for individual TMDLs.

Atmospheric Deposition

Atmospheric deposition represents the phosphorus from rainfall and bound to particulates in the atmosphere that is deposited directly onto surface waters as the particulates settle out of the atmosphere. The atmospheric deposition loading rates used in the Walker BATHTUB model was 33.66 mg/m^2/yr, or 0.30 lb/ac of TP per year. This rate agrees with estimates based on the Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (Barr 2007). The two major land use types in the project area are agriculture (cropland and pastureland, 78%) and undeveloped (8%). For the Upper Mississippi River Basin, dry deposition rates for phosphorus in an average year are estimated at 0.270 kg/ha/yr for agriculture and 0.114 kg/ha/yr for forest, and the wet deposition rate is estimated at 0.098 kg/ha/yr. Using a weighted average for the dry deposition, the estimated atmospheric deposition rate (wet + dry deposition) in the SRCL Watershed is 0.35 kg/ha/yr, or 0.31 lb/ac/yr. The Walker rate was applied to each impaired lake surface area to determine the total pounds per year of atmospheric phosphorus deposition (Table 9, Table 10).

Internal Loads

For the purposes of this TMDL study, lake internal loading refers to the phosphorus quantities that originate from lake sediments or macrophytes and is released back into the water column. Internal loading can occur via:

1. Chemical release from the sediments is caused by anoxic (lack of oxygen) conditions in the overlying waters or high pH (> 9) resulting from intense algal/macrophyte productivity. If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus can be released,

particularly from low iron content sediments, and mixed throughout the water column from storm events and seasonal whole-lake mixing (spring and fall). In shallow lakes, the periods of profundal sediment anoxia may occur frequently over short periods of time causing sediment phosphorus release. Oxic sediments can also release lower quantities of phosphorus due to chemical gradients, low sediment binding capacity (low iron/aluminum/calcium absorption), high pH (> 9) and diurnal circulations along the littoral and pelagic boundaries (James and Barko 1991).

2. Physical disturbance of the sediments caused by bottom-feeding fish (such as carp and bullhead), motorized boat activity, and wind mixing. This is more common in shallow lakes and areas than in deeper lake zones.
3. Macrophyte scenescence and decay, particularly relating to Eurasian water milfoil and curly-leaf pondweed (*Potamogeton crispus*) that are aggressive invasives capable of rapid colonization and domination of littoral areas. Curly-leaf pondweed typically dies back in early to mid-summer and is subject to rapid decay in warm-water, thereby contributing to peak growing season phosphorus concentrations. In other instances, macrophytes are apparently effective at stabilizing sediment and retard internal loading. They can also alter pH and DO as the sediment-water interface in the littoral zone, causing P release from sediments with subsequent transport of enriched water into open-water areas via temperature change and wind mixing.

Sediment Studies and Historical Perspectives:

Internal loading through chemical release from sediments (number 1 above) can be estimated by comparing the release rate of soluble reactive phosphorus (SRP) from lake sediment cores incubated with lake water under oxic and anoxic conditions. An independent assessment of SRP release rates for impaired lakes included in the TMDL was beyond the scope of current study, but internal loads have been quantified in previous studies. Among these the U.S. Army Corps of Engineers Engineer Research and Development Center's (ERDC's) Eau Galle Aquatic Ecology Laboratory (James 2006) measured multiple sediment core SRP release rates for five SRCL lakes (Schneider, Cedar Island-East, Cedar Island-Main, Horseshoe East, and Horseshoe West Lakes). Relatively high SRP release rates of > 10 mg/m^2/day were measured for anoxic conditions in 7 of 10 assays and > 1 mg/m^2/day under oxic conditions in 5 of 5 assays. James (2006) stated that SRP release from lake sediments in the SRCL was indicative of eutrophic conditions, and that internal loading from anoxic and oxic sediment conditions may be an important part of phosphorus budgets in these lakes.

Ramstack and Edlund (2008) used paleolimnological techniques to reconstruct the trophic and sediment history of the Horseshoe Chain of Lakes (now called the SRCL). They found that the SRCL has undergone significant shifts in productivity and increases in sedimentation rates beginning in the late 1800s and early 1900s, with the most distinct changes occurring in Cedar Island and Bolfing Lake segments. Reconstruction based on diatom species indicated that Horseshoe Lake's historical TP concentrations fluctuated from 50 ppb prior to European settlement, to modern era values of 62 to 93 ppb. In a similar fashion, Cedar Island and Bolfing Lakes' historical levels of 18-30 ppb shifted to modern era values in the 65 to 100 ppb range. Horseshoe Lake was also found to have very high and erratic sedimentation rates that pushed the limits of the lead-210 dating technology.

Sauk River phosphorus loading to the SRCL has declined significantly as a result of substantial point and nonpoint source reductions. Peak phosphorus loadings from the Sauk River were estimated in the 1980s to range from 213,000 to 347,000 lb-P/yr (97 to 157 metric tons, MPCA (1985)) compared to about 117,500 lb-P/yr (including WLAs) based on load estimates completed for the TMDL. Correspondingly noted over this time have been significant reductions in Horseshoe North TP concentrations, the headwaters of the SRCL (Figure 8). The decline of Horseshoe Lake TP concentrations has also been accompanied by much smaller oscillation of year-to-year average summer concentrations between wet and dry years since the late 1990s.

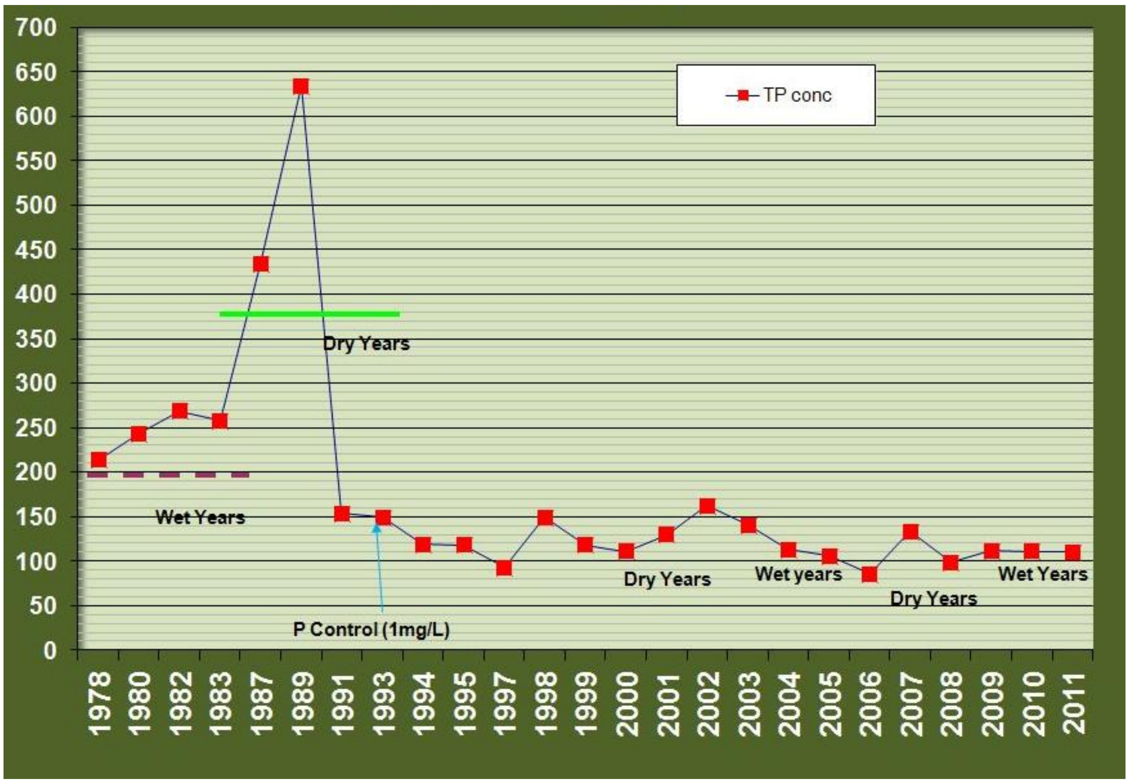

Figure 8. Historic June–September mean TP in Horseshoe Lake North, Richmond, Minnesota.
Figure courtesy of Steve Heiskary, MPCA (2012).

Lake internal loading rates are a function of watershed phosphorus loading rates, sediment chemistry, climate patterns and flushing rates. The SRCL sediments have been enriched from decades of high historical phosphorus loading as confirmed by the Science Museum of Minnesota and ERDC sediment core studies, and have relatively high potential for anoxic and oxic phosphorus release rates. It is likely that the SRCL, as well as the less studied Eden Creek related lakes, experience substantial and periodic internal loading rates that may pulse phosphorus into their water columns, particularly during hot calm summer periods. Spiraling of these internal generated phosphorus pulses via advective flows from the upper chain lakes to downstream segments can be expected, generating periods of otherwise unexplained and substantial mass-balance residuals. In general, internal loads can be expected to decline and eventually stabilize over time as water quality improves and sediment phosphorus residuals are flushed from the system.

NonNPDES/SDS permitted animal feeding operations

AFOs under 1,000 AUs and those that are not federally defined as CAFOs do not operate with permits. In Minnesota, feedlots with greater than 50 AUs, or greater than 10 AUs in shoreland areas, are required to register with the state or delegated county. Manure management plans help ensure that its potential impacts on water quality are mitigated. Facilities with fewer AUs are not required to register.

The animals raised in AFOs produce manure that is stored in pits, lagoons, tanks, and other storage devices. The manure is then applied or injected to area fields as fertilizer. When stored and applied properly, this beneficial re-use of manure provides a natural source for crop nutrition. It also lessens the need for fuel and other natural resources that are used in the production of fertilizer. AFOs, however, can pose environmental concerns. Inadequately managed manure runoff from open lot feedlot facilities and improper application of manure can contaminate surface or groundwater. Registered feedlots in the Sauk River Watershed are mapped in Appendix G.2. The map in Appendix G.3 note feedlots that are in close proximity to surface waters or sensitive soils. Livestock are potential sources of fecal bacteria and nutrients to streams in the Sauk River Watershed, particularly when direct access is not restricted and/or where feeding structures are located adjacent to riparian areas.

Animal waste from nonpermitted AFOs can be delivered to surface waters from failure of manure containment, runoff from the AFO itself, or runoff from nearby fields where the manure is applied. While a full accounting of the fate and transport of manure was not conducted for this project, a large portion of it is ultimately applied to the land surface and, therefore, this source is of possible concern. While not explicitly modeled as part of this project, loads from feedlots are implicitly accounted for in the source load estimates for each lake.

Natural background sources

"Natural background" is defined in both Minnesota statute and rule. The Clean Water Legacy Act (Minn. Stat. § 114D.15, subd. 10) defines natural background as "characteristics of the water body resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics, that affect the physical, chemical, or biological conditions in a water body, but does not include measurable and distinguishable pollution that is attributable to human activity or influence." Minn. R. 7050.0150, subp. 4 states, "'Natural causes' means the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in a water body in the absence of measurable impacts from human activity or influence."

Natural background sources are inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes such as soil loss from upland erosion and stream development, atmospheric deposition, and loading from natural land covers, etc. However, for each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment, and therefore natural background is accounted for and addressed through the MPCA's water body assessment process. Natural background conditions were evaluated within the source assessment portion of this study. These source assessment exercises indicate that natural background inputs are generally low compared to livestock, cropland, streambank, wastewater treatment facilities, failing SSTSs, and other anthropogenic sources.

Based on the MPCA's water body assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of any of the impairments and/or affect the water bodies' ability to meet state water quality standards.

4. TMDL development

A waterbody's TMDL represents the LC, or the amount of pollutant that a water body can assimilate while still meeting water quality standards. The LC is allocated to the waterbody's pollutant sources. The allocations include WLAs for NPDES-permitted sources, LAs for nonpermitted sources (including natural background), and an MOS, which is implicitly or explicitly defined. The sum of the allocations and MOS cannot exceed the LC, or TMDL.

This section presents the overall approach to estimating the components of the TMDL. The pollutant sources were first identified and estimated in the phosphorus source assessment. The LC of each lake was then estimated using an in-lake phosphorus response model that was sequenced among WLAs and LAs. A TMDL for a waterbody that is impaired as the result of excessive loading of a particular pollutant can be described by the following equation:

$$\boxed{\mathbf{TMDL = LC = \sum WLA + \sum LA + MOS + RC}}$$

Where:

- **Loading capacity (LC):** the greatest pollutant load a waterbody can receive without violating water quality standards
- **Wasteload allocation (WLA):** the pollutant load that is allocated to point sources, including wastewater treatment facilities, regulated construction stormwater, and regulated industrial stormwater required by NPDES/SDS permits for a current or future permitted pollutant source
- **Load allocation (LA):** the pollutant load that is allocated to sources not requiring NPDES/SDS permit coverage, including nonregulated urban and agricultural stormwater runoff, atmospheric deposition, and internal loading
- **Margin of Safety (MOS):** an accounting of uncertainty about the relationship between pollutant loads and receiving water quality
- **Reserve Capacity (RC):** the portion of the LC attributed to the growth of existing and future load sources

4.1 Phosphorus

4.1.1 Loading capacity methodology

The modeling software BATHTUB (Version 6.1) was selected to evaluate phosphorus loads and reservoir/lake water quality responses. BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999) and is publicly available. It has been widely used and peer-reviewed in Minnesota and throughout the United States. BATHTUB is a steady-state annual or seasonal model that predicts summer (June through September) mean lake surface water quality based on phosphorus loading characteristics, hydrology and lake morphometry. Walker (2009) determined that the seasonal time-scale (May through September) was an appropriate period for accurately portraying growing season eutrophication responses specified by Minnesota's lake eutrophication standards for the SRCL reservoir segments and lakes in the EVC/Long Lake Subwatershed. BATHTUB incorporates statistical calculations that account for data variability and provide a standard assessment method for estimating confidence in model predictions. The heart of BATHTUB is a mass-balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

Twelve impaired lakes (14 lake segments, see Section 1.2) addressed in this study were modeled in the Walker (2009) SRCL model (all but Eden and Vails Lake). The Walker model was calibrated to water quality and flow conditions for the period 2002 through 2006. Since that time, additional water quality and flow data have become available and there is some indication that water quality within the SRCL has improved (see Appendix A). Therefore, all lakes were re-modeled for this TMDL project using updated inputs, model segmentation, and calibration procedures as described below.

4.1.1.1 System Representation in Models

In typical applications of BATHTUB, lake and reservoir systems are represented by a flow network of segments and tributaries. Segments are the basins (lakes or reservoirs) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined by mass balances of flow and pollutant loading to a particular segment. For this study, the system was represented using six BATHTUB models. The Chain of Lakes model, which includes 10 interconnected impaired lake segments (three segments representing Horseshoe Lake), is a modified version of the Walker (2009) SRCL model. The remaining impaired lakes were modeled as single segments using individual BATHTUB models. The model types are described in more detail below.

Chain of Lakes Model (modified version of Walker (2009) SRCL model)

Impaired lakes included in this model are Bolfing, Cedar Island–East, Cedar Island–Koetter, Cedar Island–Main, Horseshoe North, Horseshoe South, Horseshoe West, Great Northern, Knaus, Krays, and Zumwalde Lakes. The model also contains one lake that is not impaired (and therefore not included in the TMDL)—Becker. Grouping these lakes in one model allows for better representation of hydrologic exchanges between lakes or bays and better describes the influence of the Sauk River on water quality of the system. Appropriate model selection (Section 4.1.1.3) and calibration (Section 4.1.1.4) allows for representation of flowage and nonflowage characteristics of different lakes in the system. The Walker (2009) SRCL model included Long, North Browns, and Schneider Lakes, which were removed from the larger model because of distinctly different basin morphometry and/or flows characteristics, and therefore different phosphorus sedimentation characteristics. Phosphorus sedimentation characteristics are further described in Section 4.1.1.3.

Independent BATHTUB Models

Lakes with individual BATHTUB models include Schneider, Long, North Browns, Eden, and Vails Lake that are physically distinct from each other and the SRCL. These lakes are located upstream of the SRCL along either the Schneider Creek or the EVC drainage flow networks. Since these lakes have neither the flowage characteristics of lakes located along the Sauk River nor large interconnected surface areas, separate modeling approaches offer better representations of lake dynamics.

4.1.1.2 BATHTUB Model Inputs

BATHTUB model required inputs include lake morphometry (Table 4), observed lake water quality (Table 7), atmospheric deposition rates (Section 3.5.1.2), precipitation, evaporation, and tributary flow and phosphorus concentrations (Table 13). Use of the most recent long-term water quality averages to calibrate the model (outlined below) adheres to MPCA and EPA approved methodologies. BATHTUB model inputs are described below and listed in Table 13, Table 14, and Table 15.

Precipitation and Evaporation

Estimates of precipitation rates (0.47 m) and evaporation rates (0.61 m) for the averaging period, May through September, were taken from Walker (2009). The Walker estimates are based on analysis of long-term flow and precipitation records (1978 through 2006) for the SRCL region. Precipitation and evaporation rates apply only to the lake surface areas.

Atmospheric Deposition

An average phosphorus atmospheric deposition loading rate of 0.31 lb/ac-yr was incorporated into modeling and consistent with Walker (2009). See discussion titled *Atmospheric Deposition* in Section 3.5.1.2 for more details.

Segment Data: Lake Morphometry and Observed (Existing) Water Quality

Lake morphometric data for Eden and Vails Lakes were derived from digital bathymetric contour data obtained from DNR. Volumes were calculated using the equation for the volume of a frustrum cone: $V = 1/3H(A1 + A2 + SQRT(A1*A2))$. For all other lake segments, morphometric data were as reported by Walker (2009).

Existing water quality was modeled using long-term averages for water quality parameters. Ten-year growing season (June through September) mean values were calculated from the most recent 10-year (2002 through 2011) time period for TP, Chl-*a*, and Secchi transparency. The GSM was used to model existing lake concentrations because it is the period during which algal growth is greatest, and therefore represents critical conditions in the lakes. It is also the period used to assess water quality for eutrophication standards (Table 3). Data were obtained from the MPCA Environmental Data Access database accessed in September of 2013. Water quality data for lake segments are summarized in Appendix A.

Tributary Data: Flow Rate, Phosphorus Concentrations, and Drainage Area

Loading period (May through September) mean flow and TP flow-weighted mean concentrations (FWMCs) for the monitored tributaries were calculated using FLUX32 software (Walker 1996) based on the most recent 10-year period of record. Primary FLUX32 outputs include pollutant loads, defined as the amount (mass) of a pollutant passing a stream location over a defined period of time, FWMC, and CV(Mean). The CV(Mean) is the standard error/mean and is a measure of precision of the FWMC. Flow weighted means concentrations are computed by dividing the pollutant load by the total flow volume. FLUX32 calculation methods are described more fully in Section 3.5.1.2 and supporting data are summarized in Appendix C. Flow and water quality data used to estimate loads from monitored tributaries are summarized in Appendix A.

Methods used to determine lakeshed loads, runoff from shoreline lots, and background SSTS loads are described in Section 3.5.1.2. Monitored tributary and lakesheds drainage areas were obtained from the Walker (2009) SRCL model or derived from digital elevation models (DEMs) available through the DNR (North Browns, Schneider, Eden, Vails).

4.1.1.3 BATHTUB Phosphorus Sedimentation Model

BATHTUB allows a choice among several different phosphorus sedimentation models. In the original SRCL BATHTUB model developed by Walker (1996), phosphorus sedimentation was modeled using a first-order settling velocity. This mode assumes that sedimentation per unit area is proportional to the average concentration of phosphorus in the water column. This selection facilitates the modeling of hydraulic exchanges between lakes and bays. The model is calibrated to the existing spatial distribution of phosphorus in the system by adjusting the phosphorus settling coefficients for each segment. For lakes modeled using independent BATHTUB models, the Canfield-Bachmann Lakes phosphorus sedimentation model best predicted in-lake phosphorus concentrations.

Table 13. BATHTUB segment input data (SRCL nonflowage lake segment shaded blue).

Input Parameter	Surface area (km^2)	Lake fetch (km)	Mean depth (m)	Growing Season Mean TP (ppb)	Precipitation[§] (m)	Evaporation[§] (m)
Chain of Lakes BATHTUB Model (modified Walker (2009) SRCL model)						
Horseshoe North	0.25	1.0	1.5	n/a	0.47	0.61
Cedar Island–East	1.09	1.8	1.5	n/a		
Cedar Island–Koetter	0.52	3.0	1.5	126.4		
Zumwalde	0.49	2.0	1.5	139.8		
Great Northern	0.76	1.0	1.5	136.0		
Krays	0.37	1.0	1.5	144.0		
Knaus	0.85	1.0	1.5	155.8		
Becker[§§]	*0.97*	*2.0*	*2.4*	*60.2*		
Horseshoe South	1.27	1.5	3.5	112.6		
Horseshoe West	1.01	1.0	3	59.0		

Input Parameter	Surface area (km^2)	Lake fetch (km)	Mean depth (m)	Growing Season Mean TP (ppb)	Precipitation[§] (m)	Evaporation[§] (m)
Cedar Island–Main	2.04	2.0	4.3	82.8		
Bolfing	0.43	1.0	4.02	74.1		
Independent BATHTUB Models						
Schneider	0.22	1.0	6.1	60.5	0.47	0.61
Vails	0.61	1.0	2.8	177.8		
Eden	1.05	1.5	6.0	109.5		
North Browns	1.26	1.8	5.6	155.8		
Long	1.97	3.0	3.0	89.9		

[§]Depth for the model averaging period, May–Sept, which corresponds to the loading period for the lakes.
[§§]Lake modeled, but not included in the TMDL (Becker Lake is not impaired).
n/a = not available

Table 14. Chain of Lakes BATHTUB model (modified Walker (2009) SRCL model), tributary input data (SRCL nonflowage lake segment shaded grey).

Input Parameter	Monitored Tributaries				Lakeshed Runoff			Shoreline Runoff		Background Septic	
	Tributary Name	Drainage Area (km^2)	Flow (hm^3/yr)	TP (ppb)	Drainage Area (km^2)	Flow (hm^3/yr)	TP (ppb)	Flow[§§] (hm^3/yr)	TP (ppb)	Flow[§§] (hm^3/yr)	TP (ppb)
Horseshoe North	Sauk River	2087.8	286.5	186	1.04	0.28	54.3	0.001	7,746.2	0.001	12,080
Cedar Island–East	N/A				0.15	0.04	54.3	0.001	17,443.6	0.001	30,034
Cedar Island–Koetter	N/A				0.72	0.19	54.3	0.001	13,518.8	0.001	30,195
Zumwalde	N/A				0.56	0.14	54.3	0.001	11,193.0	0.001	30,602
Great Northern	Inflow from Schneider	42.4	9.3	60.5	1.62	0.42	54.3	0.001	10,902.2	0.001	33,527
Krays	N/A				0.49	0.13	54.3	0.001	7,122.8	0.001	20,455
Knaus	Kinzer Creek	18.5	5.8	76.4	1.14	0.30	54.3	0.001	52,621.5	0.001	36,689
Becker[§]	*Kolling Creek*	*97.4*	*20.9*	*45.9*	*1.00*	*0.26*	*54.3*	*0.001*	*15,263.1*	*0.001*	*37,579*
Horseshoe South	N/A				0.07	0.02	54.3	0.001	15,939.5	0.001	60,401
Horseshoe West	N/A				2.99	0.78	54.3	0.001	33,296.7	0.001	48,321
Cedar Island–Main	N/A				20.25	5.29	54.3	0.001	31,253.1	0.001	81,252
Bolfing	N/A				3.53	0.92	54.3	0.001	11,483.7	0.001	20,862

[§]Lake modeled, but not included in the TMDL (not impaired).

[§§]Nominal value used because flow is already accounted for in lakeshed runoff component, concentrations are equivalent to the total estimated source load divided by the lakeshed runoff volume (see Section 3.5.1.2).

Table 15. Independent BATHTUB models, tributary input data

Input Parameter	Monitored Tributaries				Lakeshed Runoff			Background Septic	
	Tributary Name	Drainage Area (km^2)	Flow (hm^3/yr)	TP (ppb)	Drainage Area (km^2)	Flow (hm^3/yr)	TP (ppb)	Flow (hm^3/yr)	TP (ppb)
Schneider	Schneider Creek	41.7	9.2	79.6	0.47	0.06	168.6	0.001	51,540
Vails	Luxembourg Creek	69.8	10.0	200.0	4.69	0.70	220.0	0.001	4,433
	Unnamed Tributary	19.1	3.5	192.0					
Eden	Outflow from Vails	101.5	13.9	177.8	6.80	0.96	185.8	0.001	17,733
North Browns	Eden Valley Creek	118.0	16.8	122.0	6.60	0.84	188.5	0.001	55,414
Long	Inflow to Long from North Browns	124.6*	17.7	157.2	4.90	1.43	189.1	0.001	34,908

*Total drainage area of North Browns Lake (119.7 km^2) plus areas in the Long Lake Watershed draining to this tributary (4.9 km^2).

4.1.1.4 Model Calibration

The models were calibrated to existing water quality data according to Table 16, and then were used to determine the phosphorus LC (TMDL) of each lake.

The BATHTUB model implicitly assumes an average rate of internal loading. When the predicted in-lake TP concentration was *lower* than the average observed (monitored) concentration, an explicit additional residual load was added to calibrate the model; this internal/residual load represents loading that is in addition to the average rate assumed in the model. It has been documented that many Minnesota lakes in agricultural and urban regions can have histories of high phosphorus loading and poor water quality (Heiskary and Wilson 2005). For this reason, it is reasonable that internal loading may be higher than that of the lakes in the data set used to derive the Canfield-Bachmann lakes sedimentation model. The percent reduction for internal loading in the TMDL tables refers to the additional internal load. That is, a 100% reduction in internal load indicates that the additional internal load needs to be reduced until the total internal load equals the average rate of internal loading that is implicit in BATHTUB. It is also possible that the watershed model loading estimates did not fully account for shock loading from increasingly common intense storms or unidentified hot spots (areas of high soil P from fertilizer or manure application). When the predicted in-lake TP concentration was *higher* than the average monitored concentration, the phosphorus sedimentation rate (mg/m^3) was increased by increasing the TP calibration factor to calibrate the model.

Table 16. Model calibration summary for the impaired lakes (SRCL nonflowage lake segment shaded blue).

Impaired Lake	BATHTUB P Sedimentation Model	Calibration Mode	Calibration Factor	Dispersion Rate§§
Chain of Lakes BATHTUB Model				
Horseshoe N	Settling Velocity	TP Calibration Factor	12.0	0
Cedar–East		TP Calibration Factor	11.4	0
Cedar–Koetter		TP Calibration Factor	10.2	0
Zumwalde		Added Internal Load	26.35 mg/m^2-day	0
Great Northern		TP Calibration Factor	1.3	0
Krays		Added Internal Load	22.00 mg/m^2-day	0
Knaus		Added Internal Load	16.70 mg/m^2-day	0
Becker§		*TP Calibration Factor*	*1.05*	*4.79*
Horseshoe S		Added Internal Load	1.05 mg/m^2-day	9.57
Horseshoe W		TP Calibration Factor	1.15	1.91
Cedar–Main		Added Internal Load	0.41 mg/m^2-day	9.57
Bolfing		TP Calibration Factor	1.28	1.91
Independent BATHTUB Models				
Schneider	Canfield and Bachmann Lakes	Added Internal Load	0.07mg/m^2-day	n/a
Vails		Added Internal Load	6.31 mg/m^2-day	n/a
Eden		Added Internal Load	2.44 mg/m^2-day	n/a
North Browns		Added Internal Load	9.83 mg/m^2-day	n/a
Long		Added Internal Load	0.08 mg/m^2-day	n/a

§Lakes modeled, but not included in the TMDL (not impaired/not assessed).
§§Calibration of dispersion rates completed by Walker (2009).

Extensive model calibration and validation assessments were completed as part of this TMDL by Walker (2009) to assure that the models appropriately and fairly represent these lakes' dynamics.

> The models simulate cause-effect pathways linking phosphorus loads to eutrophication-related water quality conditions. While considerable complexity is introduced in this case because of the number and inter-connected features of the lakes, the underlying model equations and calibrations are relatively simple and have been tested against data from large populations of lakes in Minnesota and other regions (Walker 2006). TMDLs for these lakes have been formulated on long-term-average time scales (five years), which tend to govern lake water quality response to nutrient loads and are consistent with expressions of eutrophication criteria as long-term summer means (Walker 2003). The effects of seasonal and year-to-year variations in TP loads and other factors are buffered to an extent by storage and recycling of historical loads in the lake water column, biota, and sediments. Spatial and temporal variations are also reflected in correlations between average phosphorus concentrations and frequencies of nuisance algal blooms, which have been linked with user perceptions of beneficial uses related to aesthetic qualities, swimmable conditions as well as fisheries. Such relationships were used as a partial basis for developing Minnesota's eutrophication criteria (Heiskary & Wilson 2005; Heiskary & Wilson 2008).

Lastly, similar models and methodologies were used by the MPCA (1985) to predict Sauk River inflow and resulting lake phosphorus concentrations resulting from reductions in wastewater (50%) and nonpoint source (10%) loadings. At that time, it was projected that the average Sauk River inflow to the SRCL would be reduced to a flow-weighted mean value of about 174 ppb, which tracks the observed 1995 through 2006 value of 171 ppb. Corresponding predicted average SRCL lake TP values ranged from ~85 to 161 ppb, versus the observed 60 to 165 ppb (2002 through 2006). Hence, the modeling methodology reasonably portrays lake responses to various reduction scenarios used in this TMDL.

4.1.1.5 Determination of lake loading capacity (TMDL) and reductions needed to meet standards

Sauk River Chain of Lakes Model

Water quality in the SRCL is primarily driven by the Sauk River's phosphorus loading, and to a much smaller extent, local runoff as modified by individual basin flow patterns and lake phosphorus sedimentation characteristics. Given the influence of the Sauk River on water quality in the SRCL, Horseshoe Lake North is the 'king-pin' or primary focus of the TMDL development because, as the first lake in the chain, it receives the vast majority of the loading and changes in this lake will be propagated to downstream lakes (see Figure 5 for flow network). The Walker (2009) SRCL model (and the Chain of Lakes model used for this TMDL study) were constructed to appropriately represent the dominant influence of the Sauk River on the SCRL system. In a similar fashion, achieving water quality standards in Vails Lake, the headwater or 'king-pin' lake of the EVC lakes, will sequentially affect downstream lakes Eden, North Browns and Long Lakes.

Three different scenarios were used to determine the LC, appropriate LAs, and potential water quality outcomes for lakes included in the SRCL BATHTUB model. These models examine:

1. The scale of individual lake phosphorus loads necessary to achieve lake standards (Individual Lake Load Capacity Scenario)
2. Lake-by-lake sequential effects of phosphorus loading along the chain (Individual TMDL Scenario)
3. Cumulative domino effect of improved water quality to downstream lakes (Comprehensive TMDL Scenario for the SRCL).

Modeling scenarios are described in more detail in the sections that follow. All scenarios are based on the calibrated model (phosphorus settling and dispersion coefficients were retained), but different load reduction strategies were used to attain the required model output. Supporting data and modeling output for all scenarios is included Appendix D.

Individual Lake Loading Capacity Scenario

This scenario was used to determine the LC for each lake in the SRCL. In this model each lake achieves the phosphorus water quality standard by variation of loading rates. Lake by lake, loads were adjusted downward until the water quality standard was attained in each lake. The total inflow load in each individual lake LC scenario represents the LC for that lake. For some downstream lakes, the load reduction needed to attain the water quality standard was less than the load reduction associated with the upstream lake attaining the water quality standard. In this way, the model does not take into account cumulative effects of water quality in the SRCL.

Individual TMDL Scenario

This scenario was used to determine the wasteload and LAs for each lake in the SRCL. Sequential effects of achieving standards are taken into account in each individual TMDL scenario model, but only on a lake-by-lake basis. For each lake, the model assumes that water quality standards are achieved in the lake segment(s) immediately upstream of the given lake. With this approach, allocations do not assume that upstream lake water quality is better than water quality standards. For Cedar Island–Main, Horseshoe South, Knaus, Krays, and Zumwalde Lakes, there is no difference between the LC and individual TMDL scenarios. Load reductions were derived from the mass balances calculated for each lake in this model. The strategy used to model individual TMDL scenarios is described below:

- Outflows concentrations from the lake segment(s) *immediately* upstream of the given segment were set to the water quality standard of the upstream lake segment (even when the TMDL model for the upstream segment predicted water quality better than standard).
- Monitored tributary concentrations were reduced to account for upstream TMDLs and/or stream water quality standards. For the Horseshoe Lake North TMDL, the Sauk River inflow was set to 100 ppb.
- When the reductions described above resulted in modeled water quality that exceeded (i.e., better than) the water quality standard for a given segment, the amount by which the water quality standard was exceeded was taken an as an explicit MOS (Section 4.1.4) in the TMDL.

- If the reductions described above were not sufficient to meet the water quality standard in a lake segment, reductions were made to LAs (lakeshed drainage) and/or internal/residual loads until the water quality standard was achieved.

Comprehensive TMDL Scenario for the Sauk River Chain of Lakes

This scenario was used to evaluate the cumulative effects along the SRCL resulting from a Sauk River inflow concentration of 100 ppb, along with achieving water quality standards at points furthest upstream along flow paths into the SRCL. The comprehensive scenario also **provides input into the MOS calculations**. Lake segments representing these points are Becker (not impaired, receives flow from Kolling Creek), Horseshoe South Lake (receives inflows from Long Lake), Cedar Island–Main (receives a majority of flow from upstream lakeshed), and Great Northern Lake (receives inflow from Schneider Lake). The strategy used to model the comprehensive TMDL scenario is described below:

- The Sauk River inflow concentration was set to 100 ppb as described above. The resulting load includes both WLAs and LAs for the Sauk River at Horseshoe Lake North.
- The concentrations of other monitored tributaries were reduced to reflect TMDL goals for upstream impaired lakes (where applicable).

Independent BATHTUB Models (Schneider, Vails, Eden, North Browns and Long Lakes)

For these lakes, the TMDL model scenario was used to determine both the LC and the allocations. Using the calibrated model for each lake as a starting point, the tributary phosphorus concentrations were reduced until the model indicated that the TP standard was met to the nearest one-tenth ppb. First, upstream impaired lake phosphorus concentrations were assumed to meet lake water quality standards. Next, the flow weighted mean TP concentrations of monitored tributaries were reduced until the lake phosphorus concentration met the lake water quality standard. Tributary concentrations were not reduced below 60 ppb at this point. If further reductions were needed, internal loads were reduced until the lake phosphorus concentration met the lake water quality standard. If the lake water quality standard was still not achieved when the internal load was reduced to zero, additional reductions were made to monitored tributaries and the lakeshed drainage. Supporting data (model output) for independent BATHTUB models is included in Appendix E.

4.1.2 Load Allocation Methodology

The LA is allocated to existing or future nonpermitted pollutant sources.

One LA was defined for each impaired lake. The LA includes all sources of phosphorus that do not require NPDES permit coverage: watershed runoff, internal/residual loading, atmospheric deposition, and any other identified loads described in Section 3.5.1. The remainder of the LC (TMDL) after subtraction of the MOS and WLA was used to determine the LA for each impaired lake, on an areal basis.

Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion of this study (Section 3.5.1.2). For all impairments addressed in this TMDL report, natural background sources are implicitly included in the LA portion of the TMDL tables, and reductions should focus on the major human attributed sources identified in the source assessment.

4.1.3 Wasteload allocation methodology

The WLA is allocated to existing or future NPDES-permitted pollutant sources.

4.1.3.1 Construction stormwater

Construction stormwater is regulated by NPDES/SDS permits for any construction activity disturbing a) one acre or more of soil, b) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre, or c) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The WLA for stormwater discharges from sites where there is construction activities reflects the number of construction sites $\geq$ 1 acre expected to be active in the impaired lake subwatershed at any one time.

A categorical WLA was assigned to all construction activity in each impaired lake subwatershed. First, the average annual fraction of the impaired lake subwatershed area under construction activity over the past five years was calculated based on MPCA Construction Stormwater Permit data from January 1, 2007 to October 6, 2012 (Table 17), area weighted based on the fraction of the subwatershed located in each county. This percentage was multiplied by the portion of the TMDL LA associated with direct drainage (both lakeshed drainage and monitored tributary loads) to determine the construction stormwater WLA. Tributary and lakeshed LA were reduced by an amount equivalent to the construction stormwater WLA.

Table 17. Average annual percent area regulated under the NPDES/SDS Construction Stormwater Permit (2007–2012).

County	Average Annual Percent Area Under Construction (%)
Meeker	0.1%
Stearns	0.1%

4.1.3.2 Industrial Stormwater

Industrial stormwater is regulated through an NPDES/SDS permit (MNR050000 and MNG490000) when stormwater discharges have the potential to come into contact with materials and activities associated with the industrial activity. The WLA for industrial stormwater was calculated as equal to the construction stormwater WLA because industrial activities make up a very small fraction of the watershed area.

4.1.3.3 NPDES/SDS permitted animal feeding operations

NPDES permitted, SDS permitted, and CAFOs not requiring permits are required to be designed and operated in a manner such that they have zero discharge. WLAs are not assigned to these AFOs; this is equivalent to a WLA of zero. All other nonCAFO feedlots and the land application of all manure are accounted for in the LA for nonpermitted sources.

4.1.3.4 Individual NPDES/SDS permitted facilities

An individual WLA was provided for all NPDES/SDS permitted WWTPs discharging to surface waters within an impaired lake's drainage area. The WLAs are a function of facility design flow and the effluent concentration assumptions listed in Table 8. For all WWTPs, except for the Freeport WWTP, the WLA is equal to the existing permit limit. The Freeport WWTP WLA was calculated based on the facility's 0.13 mgd average wet weather design flow and 1.0 mg/L TP. Freeport will not have to upgrade their existing facility to meet their WLA. Continuously discharging municipal WWTP WLAs were calculated based on the average wet weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year.

If a permittee that is assigned a WLA in this report has previously been assigned one or more WLAs for the same pollutant for another TMDL, the applicable permit(s) and/or associated planning documents will need to address the most restrictive WLA.

4.1.4 Margin of Safety

MOS is a portion of the TMDL that is set aside to account for the uncertainties associated with achieving water quality standards. MOS is usually expressed in terms of percentage of the LC that is set aside as an uncertainty/insurance measure. MOS can be explicitly defined as a set-aside amount. In other instances, the MOS can be estimated implicitly due to conservative modeling and assessment methods used in the TMDL characterization. This TMDL uses both implicit and explicit MOSs on a lake-by-lake basis.

This TMDL study is based on over three decades of quality assured monitoring efforts of numerous project area streams and lakes beginning with the MPCA's 'Limnological Investigation of the Sauk River and the Horseshoe-Chain-of-Lakes' (MPCA 1985), which characterized the SRCL water flows and phosphorus loading rates. Since that time, additional monitoring has been conducted by the SRWD and MPCA and summarized by Walker (2009), who also developed unbiased statistically-based approaches to fill gaps in the flow and data record. Complete details are provided in Walker (2009). Lake monitoring data from the SRCL and EVCL have been used in the development of statewide lake and river standards, and as such are implicitly addressed by those efforts. Uncertainty in lake BATHTUB model estimates were reduced by corroborating results with these monitoring data, other basin modeling results (RESPEC 2011) and long-term USGS monitoring station for the Sauk River at St. Cloud (USGS Station 05270500). This system has been well-characterized including the use of well-calibrated and validated models that fairly represent the TMDL study area.

An explicit 5% MOS was included in TMDLs for lake segments modeled using independent BATHTUB models (Long, North Browns, Schneider, Eden, and Vails Lakes). In general, these lakes are located upstream of flowage segments and have larger areas of direct drainage than most lakes in the SRCL model. Water quality in the EVC lakes is not significantly influenced by water quality in the Sauk River, and a 5% MOS provides a reasonable cushion against uncertainties.

For SRCL flowage lakes (Figure 5), the Sauk River dominates water quality. Attainment of standards for the chain's headwater lakes will strongly determine downstream segments' quality. In the Chain of Lakes model, the goal was to achieve a 5% explicit MOS in all segments through a combination of reductions in upstream lake loads (water quality standards) and reductions to individual lakeshed LAs. For some downstream segments, modeled water quality was significantly better than lake standards when an upstream segment(s) achieved its specified water quality standard(s). In these cases, the explicit MOS is equal to the amount by which the downstream lake segment was predicted to exceed its specified water quality standard. In some downstream lake segments prone to large internal loads, improvements in upstream water quality were not sufficient to produce an explicit MOS of 5%. In these cases, reductions were made to LAs to the extent reasonable to produce the maximum explicit MOS possible (see note† Table 18).

The effects of reducing the Sauk River inlet's phosphorus concentration to the Central River Nutrient Region (RNR) river eutrophication standard of 100 ppb begin with the first lake of the SRCL, Horseshoe North, and are propagated down through the remaining lakes of the chain. This positive domino effect was estimated by the *comprehensive TMDL scenario for the SRCL* model. In cases where the cascading/domino effect was predicted to result in water quality better than that lake's standard, the predicted improved water quality (additional reduction compared to individual lake TMDL models) was used as an 'implicit' MOS (summary Table 18). The predictive models used for this TMDL have been extensively calibrated and validated and fairly represent system dynamics. Therefore, the MOSs used in this TMDL are sufficient for the purposes of characterizing reasonable TMDL allocations.

Table 18. Summary of margins of safety by impaired lake.

SRCL flowage segment shown in white background, SRCL nonflow segment shown in grey, and EVC/Long Lake Subwatershed shown in blue.

Lake Segment	Load Capacity (lb/yr)	Explicit MOS (TMDLs)		Additional Expected Reductions Based on Chain of Lakes Comprehensive TMDL model	
		(lb/yr)	%	Source of Additional Reduction	(lb/yr)§
Horseshoe North†	68,787	3,439	**5%**	*Modeled water quality in Becker Lake <60 ppb TP*	147
Cedar Island–East†	76,669	11,814	**15%**	*Modeled water quality in Horseshoe North <90 ppb TP*	598
Cedar Island–Koetter†	71,325	5,865	**8.2%**	*Modeled water quality in Cedar Island-East <90 ppb TP*	10,370
Zumwalde†	65,984	*(Implicit)*		*Modeled water quality in Cedar Island-Koetter <90 ppb TP*	4,535§§
Great Northern†	68,311	1,814	**2.7%**	*Modeled water quality in Zumwalde <90 ppb TP*	4,476
Krays†	67,718	*(Implicit)*		*Krays Lake meets the water quality standard without reductions of internal/residual loads in comprehensive scenario*	N/A§§
Knaus†	69,693	*(Implicit)*		*Modeled water quality in Krays exceeds the TMDL model*	N/A§§
Horseshoe South	2,918	146	**5.0%**	N/A	N/A§§
Horseshoe West	733	181	**24.7%**	*Modeled water quality in Horseshoe North and Becker Lakes < 90 ppb and <60 ppb, respectively*	N/A
Cedar Island–Main	1,744	87	**5.0%**	*Modeled water quality in Horseshoe North <90 ppb TP*	N/A§§
Bolfing	415	34	**8.3%**	N/A	N/A
Schneider	1,105	55	**5.0%**	N/A	N/A

Lake Segment	Load Capacity (lb/yr)	Explicit MOS (TMDLs)		Additional Expected Reductions Based on Chain of Lakes Comprehensive TMDL model	
		(lb/yr)	%	Source of Additional Reduction	(lb/yr)§
Vails	2,567	128	**5.0%**	N/A	N/A
Eden	2,192	110	**5.0%**	N/A	N/A
North Browns	2,567	128	**5.0%**	N/A	N/A
Long	2,588	130	**5.0%**	N/A	N/A

†Water quality in flowage lakes is highly dependent on water quality of the Sauk River and upstream lakes. SRCL Lakeshed loads are very small compared to upstream lake loads limiting the allocation of explicit MOSs.
§Includes only reductions above and beyond those written in the TMDL.
§§Internal/Residual load was not reduced in the scenario but may decrease as water quality in the chain improves.

4.1.5 Seasonal Variation and Critical Conditions

In-lake and in-stream water quality vary seasonally. In Minnesota lakes and streams, the majority of the watershed phosphorus load often occurs during the spring. During the growing season months (June through September), phosphorus concentrations may not change substantially if major runoff events do not occur. However, Chl-*a* concentration may still increase throughout the growing season due to warmer temperatures fostering higher algal growth rates. In lakes, phosphorus concentrations can increase throughout the growing season from internal sources, leading to increased algal-related Chl-*a* concentrations. This seasonal variation has been factored into the development of Minnesota's lake standards for maintaining beneficial uses based on swimmable and fishable conditions (Heiskary and Wilson 2005) during critical summer periods. This TMDL's targeted allocations are based on Minnesota's lake standards and summer critical conditions.

4.1.6 Percent reduction

The estimated percent reductions provide a rough approximation of the overall reduction needed for the waterbody to meet the TMDL. The percent reduction is a means to capture the level of effort needed to reduce phosphorus concentrations in the watershed. The percent reductions should not be construed to mean that each of the separate sources listed in the TMDL table needs to be reduced by that amount. The reductions needed to meet each individual allocation and the LC are calculated as the existing load minus the TMDL load.

4.1.7 Future Growth

Potential changes in population and land use over time in the Sauk River Watershed could result in changing sources of pollutants and runoff characteristics. Possible changes and how they may or may not impact TMDL allocations are discussed below, particularly relating to urban growth and potential future MS4 communities.

4.1.7.1 Load Transfer

There are currently no regulated MS4s in the project area; however this may not be the case in the future. Because MS4-permitted land areas can be subject to change, the MPCA's Stormwater Program includes general guidelines for TMDLs that outline the potential circumstances under which transfer of watershed runoff allocations may need to occur and how load transfers between and/or within the WLA and LA categories should be assigned. This information is provided in the event that a future regulated MS4 designation(s) is made within the project area.

1. One or more nonregulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
2. A new MS4 or other stormwater-related point source is identified. 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 (Section 4.1.2). One transfer rate was defined for each impaired lake as the total WLA divided by the watershed area downstream of any upstream impaired waterbody (acres). In the case of a load transfer, the amount transferred from LA to WLA will be based on the area (acres) of land coming under permit coverage multiplied by the transfer rate (lb/ac-yr). The MPCA will make these allocation shifts. 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. Individual transfer rates for each lake TMDL are listed in Table 19.

Table 19. Transfer rates for future regulated MS4 dischargers in the impaired lake watersheds

	WLA transfer rates	
Lake name	(lb/ac-yr)	(lb/ac-day)
Bolfing	0.19	0.00051
Cedar Island–East	0.19	0.00052
Cedar Island–Koetter	0.19	0.00052
Cedar Island–Main	0.15	0.00041
Eden	0.09	0.00023
Great Northern	0.15	0.00041
Horseshoe North	0.11	0.00030
Horseshoe South	0.33	0.00090
Horseshoe West	0.08	0.00022
Knaus	0.25	0.00068
Krays	0.48	0.00131
Long	0.31	0.00086
North Browns	0.20	0.00055
Schneider	0.64	0.00175
Vails	2.09	0.00572
Zumwalde	0.18	0.00048

4.1.8 TMDL Summary

The following rounding conventions were used in the TMDL summary tables:

- Values ≥10 reported in mass/day have been rounded to the nearest pound.
- Values <10 and ≥1 reported in mass/day have been rounded to the nearest tenth of a pound.
- Values <1.0 reported in mass/day have been rounded to the nearest hundredth of a pound, or to enough significant digits so that the value is greater than zero and a number is displayed in the table.
- While some of the numbers in the table shows multiple digits, they are not intended to imply great precision; this is done primarily to make the arithmetic accurate.
- Some small arithmetic errors may exist; this is due to rounding.

4.1.8.1 Horseshoe Lake North Phosphorus TMDL

- Horseshoe Lake North is a flowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 90 ppb.
- A majority of the existing phosphorus load (94% including wasteloads) to Horseshoe Lake North (the northern bay of Horseshoe Lake) is associated with the Sauk River inflow to the SRCL. Horseshoe Lake North is the first of seven flowage segments in the chain. It is therefore the 'king-pin' of the flowage in so far as improvements in this lake will sequentially benefit downstream lakes. Downstream lakes are of two types: (1) flowage segments (Cedar Island–East, Cedar Island–Koetter, Zumwalde, Krays, and Knaus Lakes), which each receive a majority of their phosphorus loads as inflow from other upstream flowage segment(s); and (2) nonflowage segments (Horseshoe West, Horseshoe South, Cedar Island–Main, Schneider, and Bolfing Lakes) which contribute flow to the chain and may exchange phosphorus through diffusion with flowage segments.
- The Sauk River Watershed area draining to Horseshoe Lake North is quite large at 486,824 (acres), in contrast to its small lakeshed of about 92 acres. As a consequence, lakeshed loads are very small compared to the Sauk River inflow load.
- The lake model was calibrated without the addition of any internal/residual loads, indicating that internal loading in Horseshoe Lake North is similar in magnitude to natural background rates implicit in the lake model.

To meet the TMDL, the TP load to Horseshoe Lake needs to be reduced by 56,083 lb/yr (45%). This reduction will have cumulative beneficial effects upon the remaining downstream flowage segments and can be achieved through:

- A reduction in the Sauk River inflow of 56%. This reduction corresponds with a Sauk River concentration of 95 ppb at the lake inlet when the reduced WLA is taken into account. This target of 95 ppb is derived from the Minnesota Central RNR TP criteria of 100 ppb and was reduced for the Horseshoe Lake North TMDL to accommodate the 5% explicit MOS. The Sauk River inflow target can be achieved through a combination of improved water quality in upstream impaired lakes and reductions in watershed runoff concentration through typical agricultural and urban BMPs. Improved water quality in upstream impaired lakes is expected to reduce phosphorus loads to the Sauk River by approximately 13,914 lb/yr (Appendix F).

- Reductions to inflows associated with Horseshoe Lakes South and West meeting the phosphorus standard (55 ppb).
- A lakeshed load reduction of 27% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming under recent inspections.

In addition to the explicit MOS described above, additional MOS is implicitly provided through the *comprehensive TMDL scenario for the SRCL.* The TMDL scenario for Horseshoe Lake North assumes that inflows from Becker Lake reflect the phosphorus standard for that lake (60 ppb); however, water quality in Horseshoe Lake North improves in response to both improvement in Sauk River water quality and water quality in lakes located along the EVC flow network to the SRCL. In the *comprehensive TMDL scenario,* modeled phosphorus concentrations in Becker Lake are lower than the phosphorus standard (50 ppb vs. 60 ppb). If realized, the comprehensive scenario results in an additional, small reduction of 147 lb/yr TP to Horseshoe Lake North.

Table 20. Horseshoe Lake North phosphorus TMDL and allocations

Horseshoe Lake North Load Component		Existing~	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Lake Henry WWTP	172	384	1.1	*n/a*	*n/a*
	Melrose WWTP	3,853	7,330	20.0	*n/a*	*n/a*
	Richmond WWTP	168	370	1.0	*n/a*	*n/a*
	Saint Martin WWTP	25	103	0.3	*n/a*	*n/a*
	Sauk Center WWTP	540	2,166	5.9	*n/a*	*n/a*
	Freeport WWTP	232	397	1.1	*n/a*	*n/a*
	Construction Stormwater (MNR100001)	53	53	0.15	0.0	0%
	Industrial Stormwater (MNR050000)	53	53	0.15	0.0	0%
	Total WLA	**5,096**	**10,856**	**30**	*n/a*	**n/a**
Load Allocations*	*Sauk River Inflow***	*112,386*	*49,441*	*135*	*62,945*	*56%*
	Advective Inflows	*7,292*	*4,976*	*14*	*2,316*	*32%*
	Lakeshed Drainage	*77*	*56*	*0.15*	*21*	*27%*
	Atmospheric	19	19	0.052	0.0	0%
Total LA		**119,774**	**54,492**	**149**	**65,282**	**55%**
5% MOS			**3,439**	**9.4**		
TOTAL		**124,870**	**68,787**	**188**	**56,083**	**45%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

**Sauk River Load Allocation = Total Sauk inflow load – WLAs

~Existing loads = 2000–2011 average discharged WWTP loads

4.1.8.2 Cedar Island-East Lake TMDL

- East Lake is a flowage segment in the SRCL.
- Modeled GSM phosphorus concentrations in East Lake (138.2 ppb) are above the site specific phosphorus standard of 90 ppb.
- A majority of the existing phosphorus load (99.6%) is transferred to the lake through inflows from Horseshoe Lake North, the next upstream lake segment along the Sauk River flowage.
- Potential sources of phosphorus from the lakeshed are cropland and developed land covers (23% of the total watershed area).

- The lake model was calibrated without the addition of internal/residual loads, indicating that East Lake's internal loading is similar in magnitude to natural background rates implicit in the lake model.

To meet the TMDL, the TP load to East Lake needs to be reduced by 40,425 lb/yr (35%). Reductions to inflows associated with Horseshoe Lake North meeting the phosphorus standard (90 ppb) are more than sufficient to meet the TMDL goal in East Lake, including an explicit MOS of 15%. Additional factors which provide an implicit MOS include the following:

- Based on the *Comprehensive TMDL scenario for the SRCL*, modeled water quality in Horseshoe Lake North exceeds the water quality standard (89.2 vs. 90 ppb TP). If realized, this would result in an additional reduction of 597.7 lb/yr TP to East Lake.

Table 21. Cedar Island–East Lake phosphorus TMDL and allocations

Cedar Island -East Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.1	0.1	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.1	0.1	(<0.01)	0.0	0%
	Total WLA	**0.2**	**0.2**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Inflow from Horseshoe Lake North*	*116,904*	*64,665*	*177*	*52,239*	*45%*
	Direct Drainage	*109*	*109*	*0.30*	*0.0*	*0%*
	Total Watershed/In-lake	117,013	64,774	177	52,239	45%
	Atmospheric	81	81	0.22	0	0%
	Total LA	**117,094**	**64,855**	**177**	**52,239**	**45%**
15% MOS			**11,814**	**32**		
TOTAL		**117,239.7**	**76,669.0**	**210**	**40,425**	**35%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

4.1.8.3 Cedar Island–Koetter Lake Phosphorus TMDL

- Koetter Lake is a flowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 90 ppb.
- A majority of the existing phosphorus load (99%) is transferred to the lake through inflows from East Lake, the next upstream lake segment along the Sauk River flowage. The existing condition for inflow from East Lake was taken from the calibrated BATHTUB model, which predicts a GSM phosphorus concentration of 138.2 ppb for East Lake, well above the site specific standard of 90 ppb.

- Potential sources of phosphorus from the lakeshed are cropland and developed land covers (23% of the total watershed area).
- The lake model was calibrated without the addition of internal/residual loads, indicating that Koetter Lake's internal loading is similar in magnitude to natural background rates implicit in the lake model.

To meet the TMDL, the TP load to Koetter Lake needs to be reduced by 28,782 lb/yr (29%). Reductions to inflows associated with East Lake meeting the phosphorus standard (90 ppb) are more than sufficient to meet the TMDL goal in Koetter Lake including an explicit MOS of 8%. Additional factors which provide an implicit MOS include the following:

- Modeled water quality in East Lake exceeds the water quality standard (75.1 vs. 90 ppb TP) based on the *Comprehensive TMDL scenario for the SRCL*. If realized, this would result in an additional reduction of 10,370.4 lb/yr TP to Koetter Lake.

Table 22. Cedar Island–Koetter Lake phosphorus TMDL and allocations

Koetter Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.1	0.1	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.1	0.1	(<0.01)	0.0	0%
	Total WLA	**0.2**	**0.2**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Inflow from East Lake*	*99,949***	*65,302*	*179*	*34,647*	*35%*
	Lakeshed Drainage	*119*	*119*	*0.3*	*0.0*	*0%*
	Total Watershed/In-lake	100,068	65460	179	34,647	35%
	Atmospheric	39	39	0.11	0	0%
	Total LA	**100,107**	**65,460**	**179**	**34,647**	**35%**
8% MOS			**5,865**	**16**		
TOTAL		**100,107**	**71,325**	**195**	**28,782**	**29%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

**The calibrated model (existing condition) predicts concentrations in East Lake that violate the water quality standard. The TMDL goal adopts the site specific standard of 90 ppb for East Lake.

4.1.8.4 Zumwalde Lake Phosphorus TMDL

- Zumwalde Lake is a flowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 90 ppb.
- Zumwalde Lake is the located mid-way along the Sauk River flowage. A majority of the existing phosphorus load (90%) is from up-gradient Koetter Lake's discharge.

- A majority of the existing phosphorus load (90%) is transferred to the lake through inflows from Koetter Lake, the lake segment immediate upstream of Zumwalde along the Sauk River flowage.
- Lakeshed drainage contributes <1% of the existing phosphorus load. Potential sources of phosphorus from the lakeshed are cropland and developed land covers (19% of the total watershed area).
- The lake model indicated that there is a large phosphorus load (10,356 lb/yr) that is unaccounted for in watershed modeling. This unexplained residual is likely dominated by cumulative up-gradient lake segment internal loads, with lesser amounts from developed areas and failing septic systems. Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Zumwalde Lake needs to be reduced by 36,925 lb/yr (36%). This can be achieved through:

- Reductions in advective loading (29%) associated with Koetter Lake meeting the phosphorus standard (90 ppb).
- Reduction in the lakeshed load of 17% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming under 2008 through 2011 inspections.
- Reduction of the additional Internal/Residual Load by 97% to 360 lb/yr.

No explicit MOS was written in the TMDL for Zumwalde Lake. Zumwalde is a flowage lake and water quality for this lake is highly dependent on water quality in upstream segments. Additional factors which provide an implicit MOS include the following:

- Modeled water quality in Koetter Lake exceeds the water quality standard (70 vs. 90 ppb) based on the *comprehensive TMDL scenario for the SRCL*. If realized, this would result in an additional reduction 4,533.6 lb P/yr to Zumwalde Lake (Table 18).

Improvements beyond those modeled in the *comprehensive TMDL scenario for the SRCL* are possible, as internal loading is reduced in Zumwalde and upstream lake segments via flushing along the flowage segments.

Table 23. Zumwalde Lake phosphorus TMDL and allocations

Zumwalde Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.1	0.1	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.1	0.1	(<0.01)	0.0	0%
	Total WLA	**0.2**	**0.2**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Inflow from Koetter Lake*	*92,408*	*65,497*	*179*	*26,911*	*29%*
	Lakeshed Drainage	*109*	*91.0*	*0.25*	*18*	*17%*
	Internal/Residual#	*10,356*	*360*	*.99*	*9,996*	*97%*
	Total Watershed/In-lake	102,873	65,948	180	36,925	36%
	Atmospheric	36	36	0.10	0.0	0%
	Total LA	**102,909**	**65,984**	**180**	**36,925**	**36%**
MOS§			**Implicit**	**Implicit**		
TOTAL		**102,909**	**65,984**	**180**	**36,925**	**36%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

§See text above for explanation.

4.1.8.5 Great Northern Lake Phosphorus TMDL

- Great Northern Lake is a flowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 90 ppb.
- A majority of the existing phosphorus load (99.8%) is transferred to the lake through advective flow components. These include inflows from Zumwalde Lake (98.6% existing of the TP load), located upstream of Great Northern Lake along the Sauk River flowage, and Schneider Lake, located to the north off of the main flowage.
- Lakeshed drainage contributes <1% of the existing phosphorus load. Potential sources of phosphorus from the lakeshed are cropland and developed land covers (33% of the total watershed area).
- The lake model was calibrated without the addition of any internal/residual loads, indicating that internal loading in Great Northern Lake is similar in magnitude to natural background rates implicit in the lake model.

To meet the TMDL, the TP load to Great Northern Lake needs to be reduced by 34,987 lb/yr (34%). Reductions in advective load components associate with Zumwalde Lake and Schneider Lake meeting specified phosphorus standards (90 ppb, 40 ppb) along with required upgrades to nonconforming SSTS units (23.5 lb/yr, Appendix B) are sufficient to meet the TMDL in Great Northern Lake with a 2.7% explicit MOS.

Great Northern Lake is a flowage lake in the SRCL and water quality in this lake is highly dependent on water quality in upstream lakes. The 2.7% explicit MOS was considered sufficient because modeling results indicate that the lake response to improved water quality upstream is significant. In the *Comprehensive TMDL scenario for the SRCL* (see Section 4.1.1.5), the phosphorus concentrations in Great Northern Lake is 81.1 ppb, well below the phosphorus standard (90 ppb).

Table 24. Great Northern Lake phosphorus TMDL and allocations

Great Northern Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload	Construction stormwater (MNR100001)	1.0	1.0	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	1.0	1.0	(<0.01)	0.0	0%
Allocations	**Total WLA**	**2.0**	**2.0**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Inflow from Zumwalde Lake*	*101,853*	*65,496*	*179*	*36,357*	*36%*
	Inflow from Schneider Lake	*1,241*	*820*	*2.2*	*421*	*34%*
	Lakeshed Drainage	*146*	*123*	*0.34*	*23*	*16%*
	Total Watershed/In-lake	103,240	66,439	182	36,801	36%
	Atmospheric	56	56	0.15	0	0%
	Total LA	**103,296**	**66,495**	**182**	**36,801**	**36%**
2.7% MOS§			**1,814**	**5.0**		
TOTAL		**103,298**	**68,311**	**187**	**34,987**	**34%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

§ 2.7% Explicit MOS = TMDL - LA - WLA.

4.1.8.6 Krays Lake Phosphorus TMDL

- Krays Lake is a flowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 90 ppb.
- Krays Lake is second from the last (flowage segment-wise) in the Sauk River flowage. A majority of the existing phosphorus load (94%) is transferred to the lake as inflows from Great Northern Lake.
- The lakeshed for Krays Lakes includes only 67.5 acres of land and lakeshed drainage contributes <1% of the existing phosphorus load.

- The lake model indicated that there is a large residual phosphorus load (6,473 lb/yr) that is unaccounted for in watershed modeling. Most of this unexplained residual is likely cumulative up-gradient internal loading as well as lesser amounts from urban runoff, legacy sources, and other external loads not captured by the methodology. Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Krays Lake needs to be reduced by 40,475 lb/yr (38%). This can be achieved through:

- Reduction in phosphorus loading associated with Great Northern Lake meeting the phosphorus standard (90 ppb).
- A lakeshed load reduction of 16% achieved through typical urban source, rate and volume control BMPs and required upgrades to SSTS units, which were nonconforming during 2008 through 2011 inspections.
- Reduction of the additional Internal/Residual Load by 96% to 248 lb/yr.

The MOS for Krays Lake is implicit only. Krays Lake is a flowage lake located on the downstream end of the SRCL and as such water quality in this lake is highly dependent on the water quality of the upstream lake segments. Factors which provide an implicit MOS include the following:

- Modeled water quality in Great Northern Lake exceeds the water quality standard (81.7 vs. 90 ppb) based on the *comprehensive TMDL scenario for the SRCL*. If realized, Krays lake will meet the water quality goal of 90 ppb without any additional reduction (no reduction to lakeshed or internal/residual loads would be required).
- Explicit MOSs included in the TMDLs for upstream lake segments provide some implicit MOS for Krays Lake (see Table 18).

Improvements beyond those modeled in the *comprehensive TMDL scenario for the SRCL* are possible as internal loading is reduced in Krays Lake and upstream lake segments by flushing though the system.

Table 25. Krays Lake phosphorus TMDL and allocations

Krays Lake Load Component		Existing (lb/yr)	TMDL Load (lb/yr)	TMDL Load (lb/day)	Reduction (lb/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.1	0.1	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.1	0.1	(<0.01)	0.0	0%
	Total WLA	**0.2**	**0.2**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Inflow from Gt. Northern*	*101,887*	*67,379*	*184*	*34,508*	*34%*
	Lakeshed Drainage	*76*	*64*	*0.18*	*12*	*16%*
	Internal/Residual#	*6,473*	*248*	*0.68*	*6,225*	*96%*
	Total Watershed/In-lake	108,436	67,691	185	40,745	38%
	Atmospheric	27	27	0.074	0	0%
	Total LA	**108,463**	**67,718**	**185**	**40,745**	**38%**
MOS§			**Implicit**	**Implicit**		
TOTAL		**108,463**	**67,718**	**185**	**40,475**	**38%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

§See text above for explanation.

4.1.8.7 Knaus Lake Phosphorus TMDL

- Knaus Lake is a flowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 90 ppb.
- Knaus Lake is the last of the flowage segments and discharges at the Cold Spring dam. A majority of the existing phosphorus load (90%) is transferred to the lake from Krays Lake.
- The modeled tributary, Kinzer Creek, contributes 1% of the existing phosphorus load.
- Lakeshed drainage contributes <1% of the existing phosphorus load. Potential sources of phosphorus from the lakeshed are cropland and developed land covers (37% of the total watershed area) and on-site septic systems along the shoreline (approximately 90 units) which had an estimated failure rate of 13% based on 2010 inspection records.
- The lake model indicated that there is a large phosphorus load (11,488 lb/yr) that is unaccounted for in watershed modeling. Most of this unexplained residual is likely due to cumulative up-gradient internal loading as well as lesser amounts from urban runoff, legacy sources, and other external loads not captured by the methodology. Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Knaus Lake needs to be reduced by 51,095 lb/yr (42%). This can be achieved through:

- Reductions in upstream phosphorus loading associated with Krays Lake and Bolfing Lake meeting the phosphorus standard (90 ppb and 55 ppb, respectively).
- Reduction in the lakeshed load of 9% achieved through typical urban source, rate and volume control BMPs and required upgrades to SSTS units, which were nonconforming under recent inspections.
- Reduction of the additional Internal/Residual Load by 91%.

The MOS for Knaus Lake is implicit only. Knaus Lake is the segment furthest downstream in the SRCL and water quality for this lake is highly dependent on water quality of upstream lake segments. Phosphorus loading to Knaus Lake is not significantly reduced in the *comprehensive TMDL scenario for the SRCL* compared to the TMDL, but improvements beyond those modeled in the *comprehensive TMDL scenario* are possible, as internal loading in Knaus and upstream lake segments is reduced by flushing from the system. Some implicit MOS is provided through the explicit margins of safety included in the TMDLs of upstream lake segments (see Table 18).

Table 26. Knaus Lake phosphorus TMDL and allocations

Knaus/Park Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	1	1	(<0.01)	0	0%
	Industrial Stormwater (MNR050000)	1	1	(<0.01)	0	0%
	Total WLA	**2**	**2**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Inflow from Krays Lake and Bolfing Lake*	*108,035*	*67,465*	*185*	*40,570*	*38%*
	Inflow from Kinzer Creek	*967*	*967*	*2.6*	*0.0*	*0%*
	Lakeshed Drainage	*232*	*212*	*0.58*	*20*	*9%*
	Internal/Residual #	*11,488*	*983*	*2.7*	*10,505*	*91%*
	Total Watershed/In-lake	120,722	69,627	191	51,095	42%
	Atmospheric	64	64	0.18	0	0%
	Total LA	**120,786**	**69,691**	**191**	**51,095**	**42%**
MOS§			**Implicit**	**Implicit**		
TOTAL		**120,788**	**69,693**	**191**	**51,095**	**42%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

§See text above for explanation.

4.1.8.8 Horseshoe Lake South Phosphorus TMDL

- Horseshoe Lake South is a nonflowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 55 ppb.
- The majority of the existing phosphorus load (61%) is from Long Lake inflows.
- Horseshoe Lake South is the southeastern bay of Horseshoe Lake and is considered a nonflowage lake segment in the SRCL; however, a significant portion (17%) of the existing phosphorus load comes indirectly from the Sauk River through diffusive mixing with Horseshoe Lake North.
- Lakeshed loads make up only 1% of the existing phosphorus load. Potential sources of phosphorus from the lakeshed are cropland and developed land covers (33% of the total lakeshed area for Horseshoe Lake).
- The lake model indicated that there is a large phosphorus load (1,002 lb/yr) that is unaccounted for in watershed modeling. This unexplained residual is likely a mix of internal loads and external loads not captured in the methodology (methods adopted from Walker 2009, see Section 3.5.1.2). Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Horseshoe Lake South needs to be reduced by 3,056 lb/yr (51%). This can be achieved through:

- Reduction in loading from up-gradient Long Lake associated with meeting the phosphorus standard (40 ppb).
- Reduction in the diffusive load component associated with Horseshoe Lake North meeting the phosphorus standard (90 ppb).
- Reduction in the lakeshed load of 48% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming during 2008 through 2011 inspections.
- Reduction of the additional Internal/Residual Load by 76%.

Table 27. Horseshoe Lake South phosphorus TMDL and allocations

Horseshoe Lake South Load Component		Existing (lb/yr)	TMDL Load (lb/yr)	TMDL Load (lb/day)	Reduction (lb/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.2	0.2	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.2	0.2	(<0.01)	0.0	0%
	Total WLA	**0.4**	**0.4**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Advective Inflows***	*3,647*	*1,623*	*4.4*	*2,024*	*56%*
	*Diffusive Loads****	*1,061*	*730*	*2.0*	*331*	*31%*
	Lakeshed Drainage	*170*	*88*	*0.24*	*82*	*48%*
	Internal/Residual #	*1,002*	*237*	*0.65*	*765*	*76%*
	Total Watershed/In-lake	5,880	2,678	7.3	3,202	54%
	Atmospheric	94	94	0.3	0.0	0%
	Total LA	**5,974**	**2,772**	**7.6**	**3,202**	**54%**
5% MOS			**146**	**0.4**		
TOTAL		**5,974**	**2,918**	**8.0**	**3,056**	**51%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.
**TMDL goal based on target water quality for Long Lake (40 ppb).
***TMDL goal based on diffusive load to Horseshoe South when Horseshoe North, Becker and Horseshoe West Lakes meet target water quality (90 ppb, 60 ppb, 55 ppb).
Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

4.1.8.9 Horseshoe Lake West Phosphorus TMDL

- The lake's water quality violates the site specific phosphorus standard of 55 ppb.
- Horseshoe Lake West is the southwestern bay of Horseshoe Lake and is considered a nonflowage lake segment in the SRCL. A majority (62%) of the existing phosphorus load comes indirectly from the Sauk River through diffusive mixing with Horseshoe Lake North.
- There are no significant tributary inflows to Horseshoe Lake West and the remainder of the load is from lakeshed drainage. Potential important sources of phosphorus from the lakeshed are cropland and developed land covers (33% of the total lakeshed area for Horseshoe Lake).
- The lake model was calibrated without the addition of any internal/residual loads, indicating that internal loading in Great Northern Lake is similar in magnitude to natural background rates implicit in the lake model.

To meet the TMDL, the TP load to Horseshoe Lake West needs to be reduced by 54 lb/yr (7%). Reductions in diffusive loading associated with Horseshoe Lake North meeting the phosphorus standard

(90 ppb) are sufficient to meet the TMDL goal in Horseshoe Lake West, including an explicit MOS of >10%.

Table 28. Horseshoe Lake West phosphorus TMDL and allocations

Horseshoe Lake West Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload	Construction stormwater (MNR100001)	0.3	0.3	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.3	0.3	(<0.01)	0.0	0%
Allocations	**Total WLA**	**0.6**	**0.6**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Diffusive Load from Horseshoe North*	*438*	*203*	*0.56*	*235*	*54%*
	Lakeshed Drainage	*273*	*273*	*0.75*	*0.0*	*0%*
	Total Watershed/In-lake	711	476	1.3	235	33%
	Atmospheric	75	75	0.21	0	0%
	Total LA	**786**	**551**	**1.5**	**235**	**30%**
24.7% MOS			**181**	**0.50**		
TOTAL		**787**	**733**	**2.0**	**54**	**7%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

4.1.8.10 Cedar Island-Main Lake Phosphorus TMDL

- Cedar Island–Main Lake is a nonflowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 55 ppb.
- A significant portion of the existing phosphorus load (47%) comes from diffusive mixing with East Lake. Based on BATHTUB modeling, the existing GSM phosphorus concentration in East Lake is approximately 138.2 ppb. The phosphorus concentration gradient between East and Cedar Island–Main Lakes is reduced in the goal scenario, in turn reducing diffusive loads to Cedar Island-Main Lake (existing range: 138.2 ppb – 82.8 ppb, goal range: 90 ppb – 55 ppb).
- Lakeshed drainage makes up approximately 33% of the existing total load. Potential important sources of phosphorus from the watershed are cropland and developed land covers (42% of the total watershed area).
- The lake model indicated that there is a relatively large residual phosphorus load (675 lb/yr) unaccounted for in watershed modeling. This load is likely a mix of internal load, and external loads not captured by the methodology (methods adopted from Walker 2009, see Section 3.5.1.2). Data were not available for an independent assessment of internal loading, but

additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Cedar Island Lake needs to be reduced by 883 lb/yr (34%). This can be achieved through:

- Reductions in diffusive phosphorus loads associated with East Lake meeting the phosphorus standard (90 ppb).
- Lakeshed load reduction of 23% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming during 2008 through 2011 inspections.
- Reduction of the additional Internal /Residual load by 87%.

Table 29. Cedar Island–Main Lake phosphorus TMDL and allocations

Cedar Island-Main Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload	Construction stormwater (MNR100001)	0.8	0.8	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.8	0.8	(<0.01)	0.0	0%
Allocations	**Total WLA**	**1.6**	**1.6**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Diffusive Load from East Lake*	*919*	*738*	*2.0*	*181*	*20%*
	Lakeshed Drainage	*879*	*680*	*1.9*	*199*	*23%*
	Internal/Residual #	*675*	*85*	*.23*	*590*	*87%*
	Total Watershed/In-lake	2,473	1503	4.1	970	39%
	Atmospheric	152	152	0.42	0	0%
	Total LA	**2,625**	**1655**	**4.6**	**970**	**37%**
5% MOS			**87**	**0.2**		
TOTAL		**2,627**	**1,744**	**4.8**	**883**	**34%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

4.1.8.11 Bolfing Lake Phosphorus TMDL

- Bolfing Lake is a nonflowage segment in the SRCL.
- The lake's water quality violates the site specific phosphorus standard of 55 ppb.
- A majority of the existing phosphorus load (62%) is transferred to the lake from Knaus Lake through mixing and diffusion.

- Potential important sources of phosphorus from the watershed are cropland and developed land covers (51% of the total watershed area).
- The lake model was calibrated without the addition of internal/residual loads, indicating that internal loading in Bolfing Lake is similar in magnitude to natural background rates implicit in the lake model.

To meet the TMDL, the TP load to Bolfing Lake needs to be reduced by 145lb/yr (26%). Reductions in diffusive phosphorus loading from Knaus Lake meeting the phosphorus standard (90 ppb TP) are more than sufficient to meet the TMDL goal in Bolfing including an explicit MOS of 8%.

Table 30. Bolfing Lake phosphorus TMDL and allocations

Bolfing Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.2	0.2	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.2	0.2	(<0.01)	0.0	0%
	Total WLA	**0.4**	**0.4**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Diffusive Load from Knaus Lake*	*345*	*167*	*0.46*	*178*	*52%*
	Lakeshed Drainage	*182*	*181*	*0.50*	*1*	*0%*
	Total Watershed/In-lake	527	348	0.96	179	34%
	Atmospheric	32	32	0.088	0	0%
	Total LA	**559**	**380**	**1.0**	**179**	**32%**
8% MOS§			**34**	**0.093**		
TOTAL		**559**	**414**	**1.1**	**145**	**26%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

4.1.8.12 Schneider Lake Phosphorus TMDL

- Schneider Lake is a deep lake located just upstream of Great Northern Lake (a flowage lake in the SRCL).
- The lake's water quality violates the phosphorus standard of 40 ppb.
- A majority of the existing phosphorus load (91%) is from Schneider Creek.
- Potential sources of phosphorus from the lakeshed are cropland and developed land covers (42% of the total watershed area).
- The lake model indicated that there is a small phosphorus load (12 lb/yr) that is unaccounted for in watershed modeling. This load is likely a combination of external as well as internal loads not

captured by the methodology (phosphorus concentrations from smaller watershed areas may exceed the values used in the Simple method calculations). Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Schneider Lake needs to be reduced by 674 lb/yr (38%). This can be achieved through:

- Reduction of 43% to the Schneider Creek inflow load.
- A lakeshed load reduction of 18% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming under recent inspections.
- Reduction of the additional Internal/Residual Load by 100%.

Table 31. Schneider Lake phosphorus TMDL and allocations

Schneider Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload	Construction stormwater (MNR100001)	1	1	(<0.01)	0	0%
	Industrial Stormwater (MNR050000)	1	1	(<0.01)	0	0%
Allocations	**Total WLA**	**2**	**2**	**(<0.01)**	**0**	**0%**
Load Allocations*	*Inflow from Schneider Creek*	*1,615*	*922*	*2.5*	*693*	*43%*
	Lakeshed Drainage	*134*	*110*	*0.3*	*24*	*18%*
	Internal/Residual #	*12*	*0*	*0*	*12*	*100%*
	Total Watershed/In-lake	1,761	1,032	2.8	729	41%
	Atmospheric	16	16	0.044	0	0%
	Total LA	**1,777**	**1,048**	**2.8**	**729**	**41%**
5% MOS			**55**	**0.15**		
TOTAL		**1,779**	**1,105**	**3.0**	**674**	**38%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

4.1.8.13 Vails Lake Phosphorus TMDL

- Vails Lake is a shallow lake in the EVC /Long Lake Subwatershed.
- The lake's water quality violates the phosphorus standard of 60 ppb.

- A majority of the existing phosphorus load (70%) was estimated to be from Luxembourg Creek. Potential important sources of phosphorus from the Luxembourg Creek Watershed are cropland and developed land covers (60% of the total watershed area).
- Lakeshed loads make up 6% of the existing phosphorus load. Potential sources of phosphorus from the lakeshed are cropland and developed land covers (52% of the total watershed area).
- The lake model indicated that there is a large phosphorus load (3,084lb/yr) that is unaccounted for in watershed modeling. The exceptionally high unexplained P load residual is likely a combination of internal loading as well as external loads not captured by the methodology (phosphorus concentrations from smaller watershed areas may exceed the values used in the Simple method calculations). Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Vails Lake needs to be reduced by 6,768 lb/yr (73%). This can be achieved through:

- Tributary load reductions of 62% (Unnamed Tributary) and 63% (Luxembourg Creek), which can be accomplished by reducing average watershed TP concentrations to 74 ppb in these watersheds through a combination of source, rate and volume control practices.
- A lakeshed load reduction of 41% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming during 2008 through 2011 inspections.
- Reduction of the additional Internal/Residual Load by 100%

Table 32. Vails Lake phosphorus TMDL and allocations

Vails Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload	Construction stormwater (MNR100001)	2	2	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	2	2	(<0.01)	0	0
Allocations	**Total WLA**	**4**	**4**	**0.01**	**0.0**	**0%**
Load Allocations*	*Unnamed Tributary*	*1,467*	*551*	*1.5*	*916*	*62%*
	Luxembourg Creek	*4,385*	*1,632*	*4.5*	*2,753*	*63%*
	Lakeshed Drainage	*350*	*207*	*0.57*	*143*	*41%*
	Internal/Residual #	*3,084*	*0*	*0*	*3,084*	*100%*
	Total Watershed/In-lake	9,286	2,390	6.6	6,896	74%
	Atmospheric	45	45	0.12	0	0%
	Total LA	**9,331**	**2,435**	**6.7**	**6,896**	**74%**
5% MOS			**128**	**0.35**		
TOTAL		**9,335**	**2,567**	**7.1**	**6,768**	**73%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

4.1.8.14 Eden Lake Phosphorus TMDL

- Eden Lake is a deep lake in the EVC/Long Lake Subwatershed.
- The lake's water quality violates the phosphorus standard of 40 ppb.
- A majority of the existing phosphorus load (68%) is transferred to the lake from Vails Lake inflows.
- Potential important sources of phosphorus from the watershed are cropland and developed land covers (52% of the total watershed area).
- The lake model indicated that there is a large phosphorus load (2067 lb/yr) that is unaccounted for in watershed modeling. The exceptionally high unexplained P load residual is likely a combination of internal loading as well as external loads not captured by the methodology (phosphorus concentrations from smaller watershed areas may exceed the values used in the Simple method calculations). Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Eden Lake needs to be reduced by 5,831 lb/yr (73%). This can be achieved through:

- Reductions to inflows associated with Vails Lake meeting the phosphorus standard (60 ppb).
- A lakeshed load reduction of 61% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming during 2008 through 2011 inspections.
- Reduction of the additional Internal/Residual load by 100%.

Table 33. Eden Lake phosphorus TMDL and allocations

Eden Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload	Construction stormwater (MNR100001)	0.2	0.2	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.2	0.2	(<0.01)	0.0	0%
Allocations	**Total WLA**	**0.4**	**0.4**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Inflow from Vails Lake*	*5,448*	*1,838*	*5.0*	*3,610*	*66%*
	Lakeshed Drainage	*430*	*166*	*0.45*	*264*	*61%*
	Internal/Residual #	*2,067*	*0*	*0*	*2,067*	*100%*
	Total Watershed/In-lake	7,945	2,004	5.5	5,941	75%
	Atmospheric	78	78	0.21	0	0%
	Total LA	**8,023**	**2,082**	**5.7**	**5,941**	**74%**
5% MOS			**110**	**0.30**		
TOTAL		**8,023**	**2,192**	**6.0**	**5,831**	**73%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

4.1.8.15 North Browns Lake Phosphorus TMDL

- North Browns Lake is a deep lake in the EVC/Long Lake Subwatershed.
- The lake's water quality violates the phosphorus standard of 40 ppb.
- Potential important sources of phosphorus from the watershed are cropland (59%) and developed (4%) land covers.
- The lake model indicated that there is a large unexplained residual phosphorus load (10,005 lb/yr). The exceptionally high unexplained P load residual is likely a combination of internal loading as well as external loads not captured by the methodology (phosphorus concentrations from smaller watershed areas may exceed the values used in the Simple method calculations). Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to North Browns Lake needs to be reduced by 12,521 lb/yr (83%). This can be achieved through:

- A reduction in Eden Creek loads by 57%. The majority of this reduction is associated with Eden Lake (upstream) meeting the phosphorus standard (40 ppb TP).
- Lakeshed load reduction of 13% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming during 2008 through 2011 inspections.
- Reduction of the additional Internal/Residual Load by 100%.

Table 34. North Browns Lake phosphorus TMDL and allocations

North Browns Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload	Construction stormwater (MNR100001)	0.6	0.6	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.6	0.6	(<0.01)	0.0	0%
Allocations	**Total WLA**	**1.2**	**1.2**	**(<0.01)**	**0.0**	**0%**
Load Allocations*	*Eden Valley Creek*	*4,519*	*1,935*	*5.3*	*2,584*	*57%*
	Lakeshed Drainage	*469*	*409*	*1.1*	*60*	*13%*
	Internal/Residual #	*10,005*	*0*	*0*	*10,005*	*100%*
	Total Watershed/In-lake	14,993	2,344	6.4	12,649	84%
	Atmospheric	94	94	0.26	0.0	0%
	Total LA	**15,087**	**2,438**	**6.7**	**12,649**	**84%**
5% MOS			**128**	**0.35**		
TOTAL		**15,088**	**2,567**	**7.0**	**12,521**	**83%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

4.1.8.16 Long Lake Phosphorus TMDL

- Long Lake is a deep lake in the EVC/Long Lake Subwatershed.
- The lake's water quality violates the phosphorus standard of 40 ppb.
- The majority of the existing phosphorus load (88%) is transferred to the lake from up-gradient North Browns Lake via Eden Creek.
- Potentially important sources of phosphorus from the watershed are cropland (44%) and developed land covers (5%) of the total watershed area

- The lake model indicated that there is a small phosphorus load (127 lb/yr) that is unaccounted for in watershed modeling. This load is likely a mix of internal load, and external loads not captured by the methodology (phosphorus concentrations from smaller watershed areas may exceed the values used in the Simple method calculations). Data were not available for an independent assessment of internal loading, but additional resolution of internal and unknown residual load components may be obtained through targeted monitoring and adaptive management practices.

To meet the TMDL, the TP load to Long Lake needs to be reduced by 4,485 lb/yr (63%). This can be achieved through:

- A reduction in loading from North Browns Lake by 72%. This is achieved when the water quality standard (40 ppb) is met in North Browns Lake (located upstream of Long Lake). The inflow to Long from North Browns also includes runoff from the drainage area located between North Browns Lake and the inlet to Long Lake (see Figure 6, Table 6) Runoff concentrations for this drainage area were not reduced in the goal scenario.
- Lakeshed load reduction of 15% achieved through typical urban source, rate and volume control BMPs, and required upgrades to SSTS units which were nonconforming during 2008 through 2011 inspections.
- Reduction of the additional Internal/Residual Load by 83%.

Table 35. Long Lake phosphorus TMDL and allocations

Long Lake Load Component		Existing	TMDL Load		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.5	0.5	(<0.01)	0.0	0%
	Industrial Stormwater (MNR050000)	0.5	0.5	(<0.01)	0.0	0%
	Total WLA	1	1	**(<0.01)**	0.0	0%
Load Allocations*	*Inflow from North Browns Lake**	*6,127*	*1,719*	*4.7*	*4,408*	*72%*
	Lakeshed Drainage	*672*	*571*	*1.6*	*101*	*15%*
	Internal/Residual #	*127*	*21*	*0.057*	*106*	*83%*
	Total Watershed/In-lake	6,926	2,311	6.4	4,615	67%
	Atmospheric	146	146	0.40	0	0%
	Total LA	**7,072**	**2,457**	**6.8**	**4,615**	**65%**
5% MOS			**130**	**0.36**		
TOTAL		**7,073**	**2,588**	**7.1**	**4,485**	**63%**

*Outflow load from North Browns when mean in-lake TP is 40 ppb plus contribution from direct drainage.

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Reduction of internal load refers to additional internal load added to calibrate the BATHTUB model. See Section 4.1.1.4.

4.1.9 TMDL Baseline Years

The TMDLs are based on water quality data through 2011. Any activities implemented during or after 2010 that lead to a reduction in phosphorus loads to the lake or stream, or an improvement in lake water quality, may be considered as progress towards meeting a WLA or LA. User perception data indicates that water quality is improving, and future monitoring efforts will verify progress toward goals.

5. Reasonable assurance

"Reasonable assurance" shows that elements are in place, for both permitted and nonpermitted sources, that are making (or will make) progress toward needed pollutant reductions.

5.1 Reduction of permitted sources

Regulatory actions fall under federal, state and local (SRWD) jurisdiction. The MPCA is responsible for applying federal and state regulations to protect and enhance water quality within the Sauk River Watershed. Regulatory load reductions for these lakes pertain to the WLA category and specifically NPDES/SDS permitted wastewater and stormwater facilities.

Reasonable assurance that the WLAs calculated for this TMDL will be implemented is provided through the NPDES/SDS permitting regulatory requirements. According to 40 CFR 122.44(d)(1)(vii)(B), NPDES permit effluent limits must be consistent with assumptions and requirements of all WLAs in an approved TMDL. The MPCA's NPDES/SDS permit program ensures that required implementation activities are initiated and maintained, and that NPDES/SDS permitted effluent limits are consistent with the WLAs calculated from the TMDLs. In addition, the NPDES/SDS program requires construction and industrial sites to create Stormwater Pollution Prevention Plans (SWPPPs), which summarize how stormwater runoff will be minimized from construction and industrial sites.

From available records, three communities have expended about $17 million for wastewater facility upgrades (Table 36), not including costs associated with the City of Melrose's WWTP upgrades implemented in the 1990s including phosphorus removal.

Table 36. Wastewater facility upgrades completed by communities located with the SRCL Watershed.

Recipient	Agreement D	Program Name	Net Award Amt
Sauk Centre	CDAP-95-0005-R-FY96	Clean Water SRF Bond Fund	$1,407,000.0
Richmond	MPFA-06-0014-R-FY07	Clean Water SRF Bond Fund	$7,264,863.0
Richmond	WIFP-06-0014-R-FY07	WIF: General-Loan	$1,051,299.0
Sauk Centre	MPFA-09-0090-R-FY10	Clean Water SRF Bond Fund	$7,058,050.0
Melrose	Not available		
Total			$16,781,212.0

Regulatory actions also stem from the SRWD's rules and standards adopted in 2010 (SRWD 2010). Existing rules expected to contribute to water quality improvement include Stormwater (Section 7), and Erosion Control (Section 8). Wetland Conservation Act implementation is conducted by counties within the project area. The SRWD is preparing for rule and standard updates following review of their 10 year plan (Sauk River Comprehensive Watershed Management Plan/One Watershed, One Plan [1W1P]) by the Board of Soil and Water Resources (BWSR). The Sauk River CWMP planning process focused on District-wide targeting and prioritizing of resources and implementation goals. This planning effort has truly been a partnership effort to create one plan for nine local units of government within the watershed. As such, the planning process has also helped partners focus on their strengths as local units of government, and the implementation actions for each entity reflect those strengths.

Regulated construction stormwater was given a categorical WLA is this study. Construction activities disturbing one acre or more are required to obtain NPDES permit coverage through the MPCA. Compliance with TMDL requirements are assumed when a construction site owner/operator meets the conditions of the Construction General Permit and properly selects, installs, and maintains all BMPs required under the permit, including any applicable additional BMPs required in Section 23 of the Construction General Permit for discharges to impaired waters, or compliance with local construction stormwater requirements if they are more restrictive than those in the State General Permit.

5.1.1 Permitted industrial stormwater

Industrial stormwater was given a categorical WLA in this study. Industrial activities require permit coverage under the state's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS Nonmetallic Mining/Associated Activities General Permit (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS permit and properly selects, installs, and maintains BMPs sufficient to meet the benchmark values in the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL report.

5.1.2 Permitted wastewater

All municipal and industrial wastewater NPDES/SDS permits in the watershed will reflect limits consistent with WLAs described herein. All but Freeport WWTP have permit limits equal to the WLAs. Freeport does not currently have a limit. Discharge monitoring is conducted by permittees and routinely submitted to the MPCA for review.

NPDES/SDS permits for discharges that may cause or have reasonable potential to cause or contribute to an exceedance of a water quality standard are required to contain water quality-based effluent limits (WQBELs) consistent with the assumptions and requirements of the WLAs in this TMDL report. Attaining the WLAs, as developed and presented in this TMDL report, is assumed to ensure meeting the water quality standards for the relevant impaired waters listings. During the permit issuance or reissuance process, wastewater discharges will be evaluated for the potential to cause or contribute to violations of water quality standards. WQBELs will be developed for facilities whose discharges are found to have a reasonable potential to cause or contribute to pollutants above the water quality standards. The WQBELs will be calculated based on low flow conditions, may vary slightly from the TMDL WLAs, and will include concentration based effluent limitations.

5.1.3 Permitted feedlots

See the discussion of the state's Feedlot Program in Section 3.5.1.1, which applies to both permitted and nonpermitted feedlots.

5.2 Reduction of nonpermitted sources

Local, state and federal partners have sponsored nutrient and sediment reduction programs over the past 25 years that have collectively reduced TP by about 68% at the Richmond inlet to the SRCL. The Sauk River was one of the first basins in Minnesota to evaluate and assign basin-wide phosphorus effluent limits. That effort resulted in significant wastewater treatment facility upgrades and reductions in phosphorus loading that have also been accompanied by substantial nonpoint source control efforts. In this regard, Walker (2009) noted that the May-September Sauk River TP load had decreased by 46 (+/- 10) metric tons between 1978 through 1990 and 1996 through 2006, with point source reductions (if evenly distributed across the months) accounting for a reduction of 31 metric tons. This suggests that nonpoint source TP loads at the Sauk River inflow to the SRCL, have been reduced by as much as 15 metric tons for these time periods for an effective reduction of approximately 18%.

Maintaining this effort at the local level are many partners including the SRWD, Stearns County Environmental Services, Stearns County Soil and Water Conservation District (SWCD), Douglas County SWCD, Todd County SWCD, the cities of Osakis, Sauk Centre, Richmond and Cold Spring, and other local entities currently implementing programs that target improving water quality. The Sauk River Basin was chosen as a Minnesota Department of Agriculture, Water Quality Certification Program pilot area. Willing landowners within this watershed have implemented hundreds of practices over the past 15 years in this watershed including: conservation tillage, feedlot upgrades, buffer strips, shoreline buffers, urban BMPs, gully stabilizations, prescribed grazing, manure management, and other practices. See Table 37 below, for a summary of projects completed in the Sauk River Watershed from 1995 through 2013. Over this time period a total of $3.2 million in grant funded and $6.7 million in loan funded projects have been completed. It is assumed that these activities will continue.

Table 37. Sauk River Watershed District completed projects using grant and loan funding sources 1995-2013.

Shore & Riparian Restoration	99
Rain Garden/ rain barrels	58
Ag-waste Storage Facility	115
Fresh Water Diversion	6
Feedlot Runoff Abatement	19
Cattle Exclusion & Rotational Grazing	1
Water/sediment Retention Basins	4
Wetland Restoration	2
Prairie Restoration	2
Veg./Buffer Strip or Filter Strips	9
Erosion and Sediment Control	12
Improvement to Drainage Ditch or tile inlets	1
Abandon Manure Facility	26
Abandon Wells	10
Storm Water Runoff	35
Conservation Equipment	7
Septic System or Cluster	286
Technical Assistance	11
TOTAL	**703**

Several nonpermitted reduction programs exist to support implementation of nonpoint source reduction BMPs in the Sauk River Watershed. These programs identify BMPs, provide means of focusing BMPs, and support their implementation via state initiatives, ordinances, and/or dedicated funding.

The following examples describe large-scale programs that have proven to be effective and/or will reduce pollutant loads going forward.

5.2.1 SSTS regulation

SSTS are regulated through Minn. Stat. §§ 115.55 and 115.56. SSTS specific rule requirements can be found in Minn. R. 7080 through 7083. Regulations include the following:

- Minimum technical standards for individual and mid-size SSTS,
- A framework for local units of government to administer SSTS programs,
- Statewide licensing and certification of SSTS professionals, SSTS product review and registration, and establishment of the SSTS Advisory Committee, and
- Various ordinances for SSTS installation, maintenance, and inspection.

Each county maintains an SSTS ordinance, in accordance with Minn. Stat. and Minn. R., establishing minimum requirements for regulation of SSTS, for: the treatment and dispersal of sewage within the applicable jurisdiction of the county, to protect public health and safety, to protect groundwater quality, and to prevent or eliminate the development of public nuisances. Ordinances serve the best interests of the county's citizens by protecting health, safety, general welfare, and natural resources. In addition, each county zoning ordinance prescribes the technical standards that on-site septic systems are required to meet for compliance, and outlines the requirements for the upgrade of systems found not to be in compliance. This includes systems subject to inspection at transfer of property, upon the addition of living space that includes a bedroom and/or a bathroom, and at discovery of the failure of an existing system. From 2002 through 2016, Stearns and Meeker counties have, on average, replaced 182 systems per year.

All known imminent threats to public health and safety (ITPHS) are recorded in a statewide database by the MPCA. From 2006 to 2019, 797 alleged straight pipes were tracked by the MPCA statewide, 765 of which were abandoned, fixed, or were found not to be a straight pipe system. The remaining known, unfixed, straight pipe systems have received a notice of noncompliance and are currently within the 10-month deadline to be fixed, have been issued Administrative Penalty Orders, or are docketed in court. The MPCA, through the Clean Water Partnership Loan Program, has awarded over $1,725,000 to counties within the Sauk River Watershed to provide low interest loans for SSTS upgrades since 2010. More information on SSTS financial assistance can be found at the following address: https://www.pca.state.mn.us/water/ssts-financial-assistance.

5.2.2 Feedlot Program

The MPCA's Feedlot Program addresses both permitted and nonpermitted feedlots. The Feedlot Program implements rules governing the collection, transportation, storage, processing, and disposal of animal manure and other livestock operation wastes. Minn. R. ch. 7020 regulates feedlots in the state of Minnesota. All feedlots capable of holding 50 or more AUs, or 10 in shoreland areas, are subject to this rule. The focus of the rule is on animal feedlots and manure storage areas that have the greatest potential for environmental impact. A feedlot holding 1,000 or more AUs is permitted in Minnesota.

The Feedlot Program is implemented through cooperation between MPCA and delegated county governments in 50 counties in the state. The MPCA works with county representatives to provide training, program oversight, policy and technical support, and formal enforcement support when needed. A county participating in the program has been delegated authority by the MPCA to administer the Feedlot Program. These delegated counties receive state grants to help fund their feedlot programs based on the number of feedlots in the county and the level of inspections they complete. In recent years, annual grants given to these counties statewide totaled about two million dollars (MPCA 2017). All of the counties in the project area are delegated counties.

From 2011 through 2019, there were 409 feedlot facility compliance inspections in the Sauk River Watershed.

5.2.3 Minnesota buffer law

Minnesota's buffer law (Minn. Stat. § 103F.48) requires perennial vegetative buffers of up to 50 feet along lakes, rivers, and streams and buffers of 16.5 feet along ditches. These buffers help filter out phosphorus, nitrogen, and sediment. Alternative practices are allowed in place of a perennial buffer in some cases. Amendments enacted in 2017 clarify the application of the buffer requirement to public waters, provide additional statutory authority for alternative practices, address concerns over the potential spread of invasive species through buffer establishment, establish a riparian protection aid program to fund local government buffer law enforcement and implementation, and allowed landowners to be granted a compliance waiver until July 1, 2018, when they filed a compliance plan with the appropriate SWCD.

The BWSR provides oversight of the buffer program, which is primarily administered at the local level. Compliance with the buffer law ranges from 94% to 100% for counties in the Sauk River Watershed as of January, 2020.

5.2.4 Minnesota Agricultural Water Quality Certification Program

The Minnesota Agricultural Water Quality Certification Program (MAWQCP) is a voluntary opportunity for farmers and agricultural landowners to take the lead in implementing conservation practices that protect our water. Those who implement and maintain approved farm management practices will be certified and, in turn, obtain regulatory certainty for a period of 10 years.

Through this program, certified producers receive:

- Regulatory certainty: certified producers are deemed to be in compliance with any new water quality rules or laws during the period of certification;
- Recognition: certified producers may use their status to promote their business as protective of water quality; and
- Priority for technical assistance: producers seeking certification can obtain specially designated technical and financial assistance to implement practices that promote water quality

Through this program, the public receives assurance that certified producers are using conservation practices to protect Minnesota's lakes, rivers, and streams. Since the start of the program in 2014, the program has achieved the following (estimates as of September 30, 2020):

- Enrolled almost 700,000 acres
- Included 955 producers
- Added more than 1,900 new conservation practices
- Kept over 37,000 tons of sediment out of Minnesota rivers
- Saved 107,000 tons of soil and 47,000 pounds of phosphorus on farms per year
- Reduced nitrogen losses by up to 49%
- Cut greenhouse gas emissions by more than 38,000 tons annually

Approximately 24,062 acres in the Sauk River Watershed are certified under the MAWQCP (through December 31, 2019).

5.2.5 Minnesota Nutrient Reduction Strategy

The Minnesota Nutrient Reduction Strategy (MPCA 2014) guides activities that support nitrogen and phosphorus reductions in Minnesota water bodies and those water bodies downstream of the state (e.g., Lake Winnipeg, Lake Superior, and the Gulf of Mexico). The Nutrient Reduction Strategy was developed by an interagency coordination team with help from public input. Fundamental elements of the Nutrient Reduction Strategy include:

- Defining progress with clear goals
- Building on current strategies and success
- Prioritizing problems and solutions
- Supporting local planning and implementation
- Improving tracking and accountability

Included within the strategy discussion are alternatives and tools for consideration by drainage authorities, information on available tools and approaches for identifying areas of phosphorus and nitrogen loading and tracking efforts within a watershed, and additional research priorities. The Nutrient Reduction Strategy is focused on incremental progress and provides meaningful and achievable nutrient load reduction milestones that allow for better understanding of incremental and adaptive progress toward final goals. The strategy has set a reduction of 45% for both phosphorus and nitrogen in the Mississippi River (relative to average 1980 through 1996 conditions).

Successful implementation of the Nutrient Reduction Strategy will require broad support, coordination, and collaboration among agencies, academia, local government, and private industry. The MPCA is implementing a framework to integrate its water quality management programs on a major watershed scale, a process that includes:

- Intensive watershed monitoring
- Assessment of watershed health
- Development of TMDL and WRAPS reports
- Management of NPDES and other regulatory and assistance programs

This framework will result in nutrient reduction for the basin as a whole and the major watersheds within the basin.

5.2.6 Conservation easements

Conservation easements are a critical component of the state’s efforts to improve water quality by reducing soil erosion, reducing phosphorus and nitrogen loading, and improving wildlife habitat and flood attenuation on private lands. Easements protect the state’s water and soil resources by permanently restoring wetlands, adjacent native grassland wildlife habitat complexes, and permanent riparian buffers. In cooperation with county SWCDs, BWSR's programs compensate landowners for granting conservation easements and establishing native vegetation habitat on economically marginal, flood prone, environmentally sensitive, or highly erodible lands. These easements vary in length of time from 10 years to permanent/perpetual easements. Types of conservation easements in Minnesota include Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), Reinvest in Minnesota (RIM), and the Wetland Reserve Program (WRP) or Permanent Wetland Preserve (PWP). As of August 2020, in the counties that are located in the Sauk River Watershed, there were 50,000 acres of short-term conservation easements such as CRP and 7,000 acres of long term or permanent easements (CREP, RIM, WRP).

5.3 Summary of local plans

Minnesota has a long history of water management by local government, which included developing water management plans along county boundaries since the 1980s. The BWSR-led 1W1P program is rooted in work initiated by the Local Government Water Roundtable (Association of Minnesota Counties, Minnesota Association of Watershed Districts, and Minnesota Association of SWCDs). The Roundtable recommended that local governments organize to develop focused implementation plans based on watershed boundaries. That recommendation was followed by the legislation (Minn. Stat. § 103B.801) that would establish the 1W1P program, which provides policy, guidance, and support for developing comprehensive watershed management plans:

- Align local water planning purposes and procedures on watershed boundaries to create a systematic, watershed-wide, science-based approach to watershed management.
- Acknowledge and build off existing local government structure, water plan services, and local capacity.
- Incorporate and make use of data and information, including WRAPS.
- Solicit input and engage experts from agencies, citizens, and stakeholder groups; focus on implementation of prioritized and targeted actions capable of achieving measurable progress.
- Serve as a substitute for a comprehensive plan, local water management plan, or watershed management plan developed or amended, approved, and adopted.

A comprehensive draft watershed management plan is in draft form as of early 2021, which will assist in continuing restoration efforts. Until the completion of a comprehensive watershed management plan in the Sauk River Watershed, watershed district and county water plans remain in effect per the Comprehensive Local Water Management Act (Minn. Stat. § 103B.301). Those plans may be updated with new information, or their expiration dates may be extended pending future participation in the 1W1P program. Local water plans incorporate implementation strategies aligned with or called for in TMDLs and WRAPS and are implemented by SWCDs, counties, state and federal agencies, and other partners.

5.4 Examples of pollution reduction efforts

A variety of projects have been implemented throughout the project area, including erosion control projects, large agricultural waste systems, as well as stormwater management in municipalities.

The Horseshoe Lake lakeshed had been dealing with erosion problems and water runoff control issues. A private landowner and Munson Township worked together with the Stearns County SWCD to implement a series of conservation practices in 2018. This included three water and sediment control basins, a grass waterway, and associated erosion control methods on the direct outlets. This resulted in a reduction of approximately 60 lbs/year of phosphorus and sediment.

The Stearns County SWCD, Minnesota Department of Agricultural, Natural Resource Conservation Service, SRWD, West Central Technical Service Area, and Stearns County Environmental Service Department teamed up with a private landowner to address feedlot runoff issues in 2017. The runoff from the feedlot flowed to a waterway that emptied into a tributary of the Sauk River. A large agricultural waste system was constructed of an earthen basin lined with a HDPE liner and a concrete stacking slab. The earthen basin collects the feedlot runoff so those nutrients do not enter waters of the state. That water is then applied through the irrigation system. The concrete stacking slab will store solid manure from the feedlot. This manure is applied to the cropland at agronomic rates to better utilize these nutrients. The landowners are also experimenting with using cover crops as a nutrient source while helping to control erosion in their cropland. This project greatly reduces the amount of chemical and biological oxygen demand in the river, and also moderates amounts of phosphorus and nitrogen.

The City of Cold Spring partnered with the SRWD in 2012 and installed a series of French drains to capture stormwater runoff and divert it to catch basins. This results in phosphorus load reduction of 120 pounds and a sediment load of 19.7 pounds per year.

5.5 Funding

Funding sources to implement TMDLs can come from local, state, federal, and/or private sources. Examples include BWSR's Watershed-based Implementation Funding, Clean Water Fund Competitive Grants (e.g., Projects and Practices), and conservation funds from NRCS (e.g., Environmental Quality Incentives Program [EQIP] and Conservation Stewardship Program).

Watershed-based implementation funding is a noncompetitive process to fund water quality improvement and protection projects for lakes, rivers/streams, and groundwater. This funding allows collaborating local governments to pursue timely solutions based on a watershed's highest priority needs. The approach depends on the completion of a comprehensive watershed management plan developed under the 1W1P program to provide assurance that actions are prioritized, targeted, and measurable. The Sauk River Watershed 1W1P process began in 2017, and the initial draft was completed at the end of 2020. The plan should be approved in mid-2021.

BWSR has begun the transition of moving toward watershed-based implementation funding to accelerate water management outcomes, enhance accountability, and improve consistency and efficiency across the state. This approach allows more clean water projects to be implemented and helps local governments spend limited resources where they are most needed.

Watershed-based implementation funding assurance measures are based on fiscal integrity and accountability for achieving measurable progress towards water quality elements of comprehensive watershed management plans. Assurance measures will be used as a means to help grantees meaningfully assess, track, and describe use of these grant funds to achieve clean water goals through prioritized, targeted, and measureable implementation. The following assurance measures are supplemental to existing reporting and on-going grant monitoring efforts:

- Understand contributions of prioritized, targeted, and measurable work in achieving clean water goals.
- Review progress of programs, projects, and practices implemented in identified priority areas.
- Complete Clean Water Fund grant work on schedule and on budget.
- Leverage funds beyond the state grant.

Prior to completion of the 1W1P process, over $100,713,000 has been spent on watershed implementation projects in the Sauk River Watershed since 2004 (Figure 9).

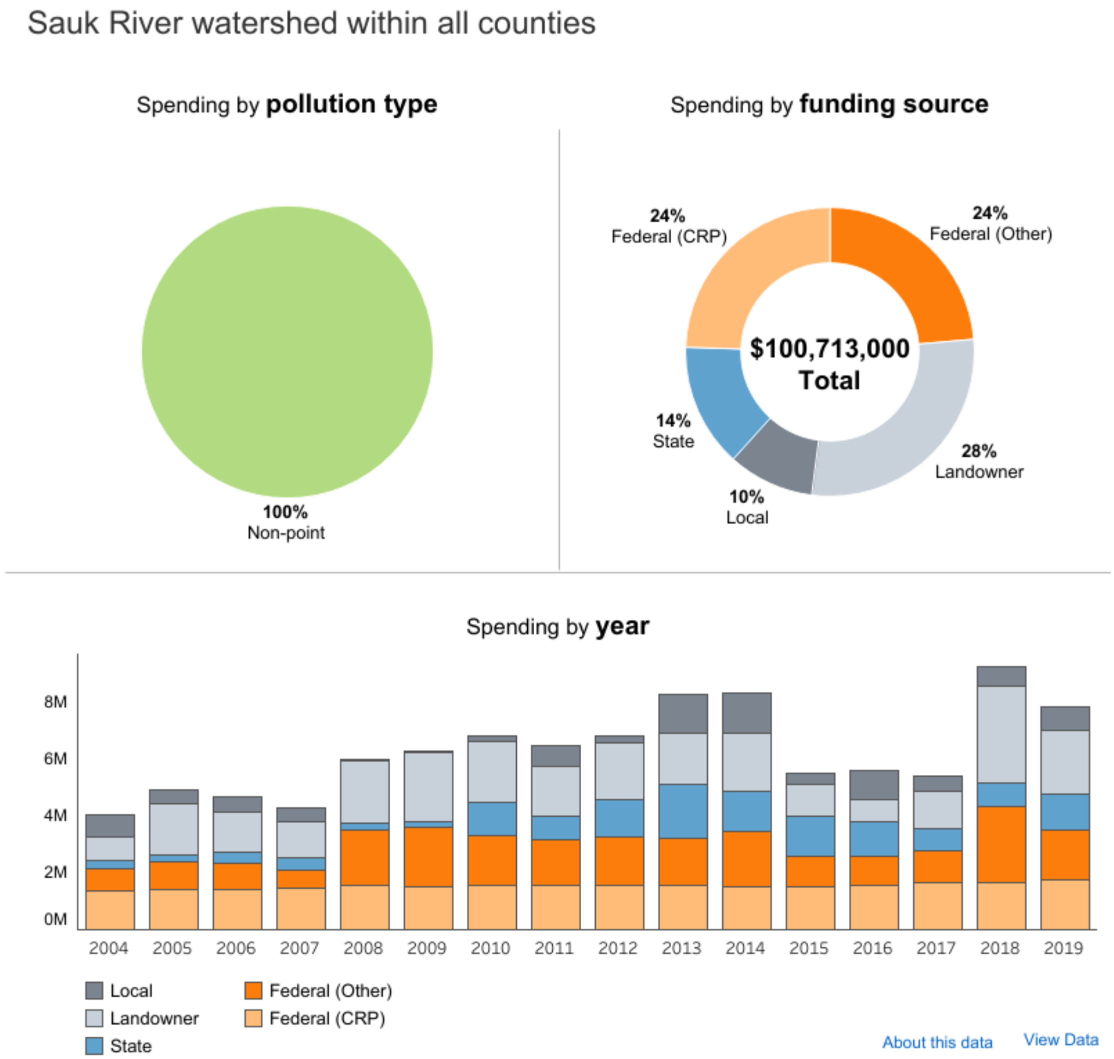

Figure 9. Spending for Sauk River Watershed implementation projects; data from the MPCA's Healthier Watersheds website

5.6 Reasonable assurance conclusion

In summary, significant time and resources have been devoted to identifying the best BMPs, providing means of focusing them in the Sauk River Watershed, and supporting their implementation via state initiatives and dedicated funding. The Sauk River WRAPS (2015b) process engaged partners to arrive at reasonable examples of BMP combinations that attain pollutant reduction goals. The implementation strategies described in this plan have been demonstrated to be effective in reducing nutrient loading to lakes and streams. They will continue these efforts to address LA sources using information gained from 25 years of experience and diagnostic assessments in implementing priority projects. They have a proven track record of securing funding from a variety of sources for on-the-ground implementation. Minnesota is a leader in watershed planning as well as monitoring and tracking progress toward water quality goals and pollutant load reductions, and completion of the 1W1P process will accelerate progress in the Sauk River Watershed.

6. Monitoring

Stream Monitoring

The primary goals of future stream monitoring are to provide information to (1) support future allocation of rehabilitation actions; (2) compare monitored conditions to stream standards; and (3) detect changes resulting from completed rehabilitation actions. The ability of the recommended monitoring program to detect such changes and the reliability of the comparisons depend upon the nature and design of the monitoring program, and the availability of funding to conduct monitoring. Continuous flows along with an MPCA Watershed Pollutant Load Monitoring Program (approximately 25 to 35 samples per year with emphasis on sampling of dynamic shifts in the hydrograph) should be continued at (1) Sauk River at Richmond; (2) Luxemberg Creek into Vails and Unnamed Creek into Vails; and (3) EVC into North Browns. At a minimum, monitored parameters should coincide with those defined by the river nutrient and total suspended solids (TSS) standards. FLUX32 software should be employed to track total and SRP and TSS loading along with associated statistics and diagnostics that can be used to refine sampling efforts.

The SRWD boundary is divided into 10 subwatersheds called Water Management Districts (WMDs). The current SRWD monitoring sites on the main Sauk River are located at the pour point, or outlet point, of each WMD (or as close to it as possible), to evaluate the water quality within each WMD. Over time, some sites have moved due to unforeseen challenges including bridge/culvert construction, backwater influence, interference between split site locations and site and/or equipment safety. Some sites have also been discontinued due to data similarities between monitoring sites, making the monitoring of both sites duplicative in nature. The three primary goals of the monitoring program are:

1. Track long term water quality trends,
2. Evaluate project and program effectiveness,
3. Utilize the monitoring results in making sound, science-based decisions on future projects/programs.

The current monitoring program, including site selection, was designed to meet these goals.

Lake Monitoring

The primary goals of future lake monitoring are to provide information to (1) support future allocation of rehabilitation actions; (2) compare monitored conditions to lake standards; and (3) detect changes from completed rehabilitation actions. The ability of the monitoring program to detect such changes and the reliability of the comparisons depend upon the nature and design of the monitoring program.

It is recommended that a long-term monitoring program should be conducted such that select flowage and nonflowage lakes of the SRCL shall be monitored approximately 8 to 10 times per growing season for Secchi transparency, TP, and Chl-*a*. Water quality of headwater and end of chain lakes including

Horseshoe North, Krays/Knaus, Vails and Long Lakes should be closely tracked for the next 25 years. Additionally, nonflowage lake quality (Cedar Island, Horseshoe West and Schneider Lakes) should similarly be monitored over time. Detailed temperature, dissolved oxygen (DO), conductivity and redox profiles should be obtained for each of these lake stations. Hypolimnetic samples should include TP and total iron. Total iron is included to gauge the availability of iron to precipitate with phosphorus in oxic waters. For this purpose, a concentration ratio of 3:1 (total iron to TP) can be used.

These lakes should form the basis of a long-term sentinel monitoring sites to track progress-to-goals over time. The continued active involvement of volunteer monitoring through the MPCA's Citizens Lake Monitoring Program should be encouraged, with a target of 8 to 10 observations per growing season for each lake site. The long-term data should provide the basis for detecting ~25% shifts in average TP. And as phosphorus concentrations decline, shifts in average Secchi transparency will become more apparent as rehabilitations occur. Nuisance algal blooms (e.g. percent of the summer with concentrations greater than 30 μg/L) will similarly be reduced. The lag in statistical power of Secchi transparency detection is due to the elevated TP values presently encountered in many of the study lakes and the relatively small shifts in Secchi transparency that may be expected until phosphorus concentration decline below 90 μg P/L (e.g. the nature of the Secchi: TP relationship.)

Current monitoring within the SRW is based on the results of a lake ranking exercise. Due to the large number of lakes within the SRWD, a lake ranking process was developed to evaluate each of the lakes against a certain set of prioritization criteria. The ranking was used to develop a rotational monitoring schedule for lake monitoring, which is currently beginning its second rotation. The SRWD also works with lake associations, including the SRCL Association, and other interested citizens to obtain water quality data upon request.

The DNR will continue to conduct macrophyte and fish surveys as allowed by their regular schedule. Currently fish surveys are conducted every 5 years and macrophyte surveys are conducted as staffing and funding allow on a 10-year rotation, unless there are special situations.

Best Management Practice Monitoring

Long-term performance of BMPs will depend upon the care and attention paid to these fundamental aspects: (1) correct design based on site conditions; (2) installation using specification materials and practices; and (3) long-term maintenance of the practices. Disregarding any of these three fundamentals is likely to cause poor BMP performance. Hence, BMP monitoring should begin with summarization of as-built plans, corroboration of designs and specifications to design goals, and assessment of maintenance practices. For agricultural areas, emphasis should be placed on reducing soluble phosphorus sources and sediment sources via cover crops that aid in reducing bare soil erosion.

Despite technical challenges associated with small site monitoring, monitoring of implementation practices should be encouraged to better assess BMP effectiveness using a variety of simple to more complex assessment methods. A variety of criteria such as land use, soil type, and other watershed characteristics, as well as monitoring feasibility, will be used to determine which BMPs to monitor. Under these criteria, monitoring of a specific type of implementation practice can be accomplished at one site and applied to similar practices under similar criteria and scenarios. Effectiveness of other BMPs can be extrapolated based on monitoring results. Urban BMP effectiveness can be assessed by use of the MPCA's Minimal Impact Design Standards (MIDS) Calculator along with adherence to BMP design criteria, construction specification materials, and scheduled maintenance. Evaluation of agricultural BMP performance can be aided by review of the Agricultural BMP Handbook for Minnesota published by the Minnesota Department of Agriculture (2012).

7. Implementation strategy summary

7.1 Permitted sources

7.1.1 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 Minnesota'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 Section 23 of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. Construction activity must also meet all local government construction stormwater requirements.

7.1.2 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. Minnesota's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) and NPDES/SDS Nonmetallic Mining/Associated Activities General Permit (MNG490000) establish benchmark concentrations for pollutants in industrial stormwater discharges. If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains BMPs sufficient to meet the benchmark values in the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL report. Industrial activity must also meet all local government stormwater requirements.

7.1.3 Wastewater

Municipal wastewater treatment facilities receive phosphorus WLAs, which will be implemented through their NPDES permits. For all facilities except for Freeport WWTP, the WLA is equal to the existing permit limit. Freeport WWTP does not currently have a phosphorus effluent limit. Freeport's WLA will be translated into a WQBEL by MPCA upon permit reissuance; such a limit would be consistent with the assumptions and requirements of the WLA.

7.2 Nonpermitted sources

Best Management Practices

A variety of BMPs to restore and protect the lakes and streams within the Sauk River Watershed are outlined and prioritized in the WRAPS report (MPCA 2015b).

The Middle Sauk River Watershed (e.g. the drainage area from Melrose to the Mississippi River) was designated as a pilot MAWQCP pilot area. MAWQCP is a state-federal partnership between the State of Minnesota, the United States Department of Agriculture (USDA) and the EPA with the purpose of accelerating voluntary adoption of agricultural practices that enhance water quality while maintaining Minnesota's productive agricultural economy. Farmers who implement and maintain approved conservation plans will be certified and in turn assured that their operation meets water quality goals and standards for a set period of time.

Figures G.5 and G.6 in Appendix G summarize MAWQCP activities in the Middle Sauk portion of the watershed.

Education and Outreach

A crucial part in the success of WRAPS report (2015b) will be participation from local citizens. In order to gain support from these citizens, education and civic engagement opportunities will be necessary. A variety of educational avenues have been employed by the SRWD over the past 20 years for community education including water festivals, school and youth events and volunteer training sessions. These efforts will continue throughout the watershed. Other events may include (but are not limited to): press releases, meetings, workshops, focus groups, trainings, websites, etc. Local staff (conservation district, watershed, county, etc.) and board members work to educate the residents of the watersheds about ways to clean up their lakes and streams on a regular basis. Education will continue throughout the watershed.

Technical Assistance

Stearns County, Stearns County SWCD and other SWCDs within the watershed provide assistance to landowners for a variety of projects that benefit water quality. Assistance provided to landowners varies from agricultural and rural BMPs to urban and lakeshore BMPs. This technical assistance includes education and one-on-one training. Many opportunities for technical assistance are as a result of educational workshops of trainings. It is important that these outreach opportunities for watershed residents continue. Conservation marketing is necessary to motivate landowners to participate in voluntary cost-share assistance programs.

Programs such as state cost share, Clean Water Legacy funding, EQIP, and CRP are available to help implement the best conservation practices that each parcel of land is eligible for, targeting the best conservation practices per site. Each of the 10 management districts should develop long-term designed BMP approaches for cumulative reduction along each flow network, relying upon a combination of source, rate and volume control practices. Conservation practices may include, but are not limited to: stormwater bioretention, septic system upgrades, feedlot improvements, invasive species control, wastewater treatment practices, agricultural and rural BMPs and internal loading reduction. More information about types of practices and implementation of BMPs are discussed in the Sauk River WPARS report (2015b).

Partnerships

Partnerships among farming groups, counties, cities, townships, citizens, businesses, watersheds, and lake associations have historically been effectively employed by the SRWD, Stearns County Environmental Services, Stearns SWCD, Douglas County SWCD, Todd County SWCD, and the cities of Osakis, Sauk Centre, Richmond and Cold Spring to protect and improve water quality. Strong partnerships with state and local government will continue to protect and improve water resources and to bring waters within the Sauk River Watershed into compliance with state standards.

7.3 Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation ("…a range of estimates") of the cost to implement a TMDL [Minn. Stat. 2007, § 114D.25]. A detailed analysis of the cost to implement this TMDL was not conducted. However, a rough approximation was based on general results from BMP cost studies across the U.S. For example, an EPA summary of several studies of predominantly developed urban landscapes showed a median cost of approximately $2,200 per pound TP removed per year (Foraste et al. 2012). A Chesapeake Bay summary (Chesapeake Bay Commission 2012) documented the cost of agricultural phosphorus removal for 13 BMPs. Median costs ranged from $250 per pound (continuous no till) to about $650 per pound (wetland restoration) and $850 per pound (off-stream watering). Multiplying this range of costs per pound of phosphorus by the needed 292,789 pound reduction for all the lakes in this study provides a total cost range of approximately $73 Million to $190 Million. Estimated expenditures for achieving the 68% reduction realized from 1985 to 2005 are in excess of $26.7million ($9.9M for nonpoint sources and $16.7 million for point sources).

7.4 Adaptive management

The response of the lakes and streams will be evaluated as management practices are implemented within each of the 10 Management Districts, including the Eden Creek chain of lakes from Vails to Long Lake. Of particular note will be tracking the changes in external and internal P loading for these lakes over time. Excessive historical (legacy) external phosphorus loading to lakes over time usually generates internal loading. When both are elevated, it becomes more difficult to distinguish sources within the lake by simple assessment methods. Therefore, the first and most important part of the rehabilitation process is to reduce the external sources of sediments, total and SRP. Attention should focus on reduction of sources of SRP and over time with flushing of the lakes via flows, internally generated SRP loading should decline. Statistical re-examination of lake and stream quality will occur every five years after the commencement of implementation actions; for the next 25 years. Data will be evaluated and decisions will be made as to how to proceed for the next five years. This management approach has been effective over the past 30 years of efforts and should be relied upon to fine-tune future approaches as new information is collected and evaluated.

8. Public participation

The SRWD was included in the development of the report, and updated throughout the process of developing and approving the site specific standard for the lakes included in this TMDL report.

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from March 1, 2021 through March 31, 2021. There were no comment letters received during the public comment period.

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Appendices

APPENDIX A. DETERMINATION OF LAKE AND TRIBUTARY CONDITIONS

A.1 Lake Water Quality

Ten-year growing season (June through September) means were calculated from the most recent 10-year (2002 through 2011) time period for TP, Chl-*a*, and Secchi transparency. Data were obtained from the MPCA Environmental Data Access database in September of 2013. The 10-year means were used to evaluate compliance with water quality standards and to calibrate the BATHTUB model.

Table 38. Lake water quality station ID and date ranges for water quality parameters

Waterbody Name (Lake ID)	MPCA Station ID	Date Range, Water Quality Data		
		TP	Chl-a	Secchi
Bolfing 73-0088-00	73-0088-00-203	2006-2009	2006-2011	2002-2011
Cedar Island- Main 73-0133-04	N/A	N/A	N/A	N/A
Cedar Island -Koetter 73-0133-03	73-0133-03-202	2006-2009	2006-2009	2002, 2006-2009
Cedar Island- Main 73-0133-01	73-0133-01-204 73-0133-01-205	2007,2008 2002-2011	2007, 2008 2003-2011	2007, 2008 2002-2011
Eden 73-0150-00	73-0150-00-203	2004, 2008, 2009	2004, 2008, 2009	2004-2005, 2007-2011
Great Northern 73-0083-00	73-0083-00-203	2002, 2006-2009	2006-2009	2002, 2006-2009
Horseshoe Lake 730-157-00 Horseshoe North Horseshoe South Horseshoe West	N/A 73-0157-00-211 73-0157-00-213	N/A 2002-2011 2002, 2007-2009	N/A 2003-2011 2007-2009	N/A 2002-2011 2002, 2007-2009
Krays 73-0087-00	73-0087-00-201	2003-2011	2003-2001	2002-2011
Knaus 73-0086-00	73-0086-00-208	2003-2011	2003-2001	2002-2011
Long 73-0139-00	73-0139-00-205	2006-2009	2006-2009	2002, 2006-2009
North Browns 73-0147-00	73-0147-00-201 73-0147-00-206	2002, 2005 2006-2009	2006-2009	2003-2011 2006-2009
Schneider 73-0082-00	73-0082-00-202	2003-2011	2003-2011	2002-2011
Vails 73-0151-00	73-0151-00-202	2004, 2008, 2009	2004, 2008, 2009	2002, 2004, 2008, 2009
Zumwalde 73-0089-00	73-0089-00-201	2003-2011	2003-2011	2002-2011

N/A = not available

A.2 Comparison of 2002-2006 and 2002-2010 Lake water quality

Lake Name	TP				Chl-*a*				Secchi			
	2002-2006		2002-2010		2002-2006		2002-2010		2002-2006		2002-2010	
	(ppb)	CV	(ppb)	CV	(ppb)	CV	(ppb)	CV	(m)	CV	(m)	CV
Site Specific Standard - Flowage			**<90**	**--**			**<45**	**--**			**>0.8**	**--**
Horseshoe – Horseshoe N	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cedar Island – East Lake	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cedar Island–Koetter Lake	174.6	0.2	126.4	0.4	65.0	0.2	78.9	0.3	0.7	0.1	0.6	0.4
Great Northern	177.0	0.2	136.0	0.4	64.8	0.2	76.8	0.3	0.6	0.1	0.6	0.2
Krays	162.2	5.7	144.0	0.5	62.8	8.2	75.6	0.5	0.6	7.4	0.6	0.4
Knaus	139.1	7.8	155.8	1.2	69.3	0.1	76.3	0.4	0.7	4.0	0.7	0.4
Zumwalde	161.1	6.9	139.8	0.4	56.8	9.1	65.2	0.5	0.6	0.1	0.6	0.4
Site Specific Standard-NonFlowage			**<55**	**--**			**<32**	**--**			**>1.4**	**--**
Bolfing	90.1	0.2	74.1	0.4	56.8	0.2	55.9	0.5	1.2	0.1	1.2	0.9
Cedar Island–Main	86.9	0.1	82.8	0.8	48.4	8.7	46.4	0.4	1.1	7.2	1.2	0.7
Horseshoe West	75.5	0.2	59.0	1.2	34.5	0.2	33.3	0.3	1.1	0.2	1.2	0.8
Horseshoe South	134.3	0.1	112.6	1.2	66.1	0.1	60.7	0.6	1.1	8.0	1.1	0.5
NCH Lakes			**<40**	**--**			**<14**	**--**			**>1.4**	**--**
Schneider	68.3	0.1	60.5	0.9	35.3	0.1	34.7	0.6	1.8	0.1	1.7	0.7
Long	82.6	0.2	89.9	0.5	51.9	0.2	62.2	0.5	1.0	0.2	1.4	0.3
North Browns	95.9	0.2	155.8	1.2	39.4	0.5	41.1	0.7	1.6	0.1	1.8	0.7
Eden	n/a	n/a	109.5	0.5	n/a	n/a	36.4	0.9	n/a	n/a	1.8	0.7
NCH Shallow Lakes			**<60**	**--**			**<20**	**--**			**>1.0**	**--**
Vails	n/a	n/a	177.8	0.5	n/a	n/a	63.3	0.8	n/a	n/a	1.6	0.5

Table 39. Flow and water quality data sources and date ranges used to estimate phosphorus loads for monitored tributaries modeled the Chain of Lakes BATHTUB model adopted from Walker (2009).

Tributary Name (AUID)	Flow Data (May-Sept)		Phosphorus Data		BATHTUB Input	
	Source	Dates	Source	Dates	May-Sept Flow (cfs)	May-Sept TP (ppb)
Sauk River at Richmond 07010202-557	Monitored flow (SRWD)	2001-2010	MPCA WQ #S000-517	2002-2010	320.0	186.0
Kolling Creek 07010202-608	Monitored flow (SRWD) Correlation with Sauk at Richmond (Walker, 2009)	2006 2001-2005, 2007-2010	MPCA WQ #S000-917	2006-2009	23.4	44.7
Kinzer Creek 07010202-565	Monitored flow (SRWD) Correlation with Sauk at Richmond (Walker, 2009)	2006 2001-2005, 2007-2010	MPCA WQ #S003-434	2006-2009	6.4	73.9
Inlet to Long from North Browns[§] 07010202-610	Monitored flow (SRWD) Correlation with Sauk at Richmond (Walker, 2009)	2006 2001-2005, 2007-2010	MPCA WQ #S003-883	2008-2009	1.8	136.0
Sauk River outlet at Cold Springs 07010202-517	Monitored flow (SRWD) Correlation with Sauk at St. Cloud (Walker, 2009) Monitored flow (SRWD)	2005-2010 2001-2004 2005-2010	MPCA WQ #S000-28	2003-2010	368.0	119.0

[§]This tributary was modeled based on modeled outflows from the BATHTUB model for North Brown in combination with estimates of watershed runoff volume and phosphorus loads found using the simple method.

Table 40. Flow and water quality data sources and date ranges used to estimate phosphorus loads for monitored tributaries modeled through individual BATHTUB models.

Tributary Name (AUID)	Flow Data (May-Sept)		Phosphorus Data		BATHTUB Input	
	Source	Dates	Source	Dates	May-Sept Flow (cfs)	May-Sept TP (ppb)
Luxembourg Creek 07010202-550	HSPF basin 383	2000-2009	MPCA WQ #S003-518	2000-2002, 2006-2009	11.0	200
Unnamed Tributary to Vails 07010202-651	HSPF basin 385	2000-2009	MPCA WQ #S005-270	2008	3.9	192
Eden Valley Creek 07010202-545	HSPF basin 389	2000-2009	MPCA WQ #S002-040 #S002-918	2006-2007 2008	16.8	122
Schneider Creek 07010202-616	HSPF basin 411	2000-2009	MPCA WQ #S003-894	2006-2009	10.4	80

APPENDIX B. SUBSURFACE SEWAGE TREATMENT SYSTEMS PHOSPHORUS LOAD ESTIMATES

Table 41. SSTS phosphorus load assumptions and summary

Parameter	Shoreline septic systems	% seasonal residence (4 months)	% permanent residence	% conforming systems	% failing systems[a]	Capita per Residence[b]	P production/ capita/ year (lbs)[b]	Non-conforming % P passing[c]	P load Non-conforming SSTS (lb/year)
Bolfing	50	30%	70%	84%	16%	2.5	1.95	0.43	**13.4**
Cedar Island–East	72			75.6%	24.4%				**18.5**
Cedar Island–Koetter	74			86%	14%				**16.8**
Cedar Island–Main	197			86%	14%				**47.0**
Eden[§]	40			78%	22%				**14.8**
Great Northern	79			82%	18%				**23.5**
Horseshoe North	32			63%	37%				**18.9**
Horseshoe South	140			63%	37%				**81.7**
Horseshoe West	129			63%	37%				**39.3**
Knaus	90			87%	13%				**20.1**
Krays	50			86%	14%				**11.7**
Long	80			80%	20%				**26.8**
North Browns[§]	125			78%	22%				**46.1**
Schneider	128			86%	12%				**25.2**
Vails[§]	10			78%	22%				**3.7**
Zumwalde	74			85%	15%				**18.5**

[a] Stearns County estimate for 2008-2012 from the U.S. Census Bureau

[b] Barr Technical Memorandum (page 4)

[c] Barr Technical Memorandum (page 15)

[§]Inspection records not available, total shoreline septic systems estimated based on Walker 2009 estimates (North Browns) and aerial imagery (Eden, Vails), failure rate taken as the average failure rate for all other.

APPENDIX C. SUPPORTING DATA FOR FLUX MODELING

C.1 FLUX Modeling, Flow Weighted Mean TP Concentration, Sauk River Inlet at Richmond

Table 42. FLUX model diagnostics for the Sauk River Inlet at Richmond

Inlet_TP_Strat2

FLOW AND LOAD SUMMARIES FOR TP

Method: Flw Wghted Conc. (2)

DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (kg/y)	SLOPE LgC/LgQ	R^2	p > C/Q
1 Flow < Mean	799	51	51	27.2	157.2904	158.0924	0.16031	22185	-0.05654	0.00	0.5407
2 Flow > Mean	640	44	44	72.8	525.1156	525.3224	0.18242	92093	0.6437	0.00	0.0038
Overall	1439	95	95	100.0	320.8819	328.1779	0.17055	53277	0.06651	0.00	0.2094

STRATUM BOUNDARIES(CFS)

STRATUM	LOWER LIMIT	UPPER LIMIT
Flow < Mean	0	320.882
Stratum 2	320.882	1303.53

DAILY FLOW STATISTICS

Daily Flow Duration 1439 Days = 3.940 Years

Daily Mean Flow Rate 320.88 (CFS)

Daily Total Flow Volume 1129.85 (Mega m^3)

Daily Flow Date Range 06/21/2001 to 09/30/2010

Samples Date Range 06/26/2001 to 09/16/2010

LOAD ESTIMATES FOR TP

	Method	Mass(kg)	Flux(kg/y)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1	Average Load	210210	53356	24287745	0.186	0.092
2	Flw Wghted Conc.	209899	53277	11234549	0.186	0.063
3	Flw Wghted IJC.	210273	53372	11374837	0.186	0.063
4	C/Q Reg1	209872	53270	8529839	0.186	0.055
5	C/Q Reg2(VarAdj)	209090	53072	8138089	0.185	0.054
6	C/Q Reg3(daily)	209978	53297	8859832	0.186	0.056
8	Time Series*	207733	52727	N/A	0.184	N/A

*Time series estimates use residual interpolation.

WARNING! The listed Time Series estimates are based on Method 2, Flw Wghted Conc.

Remember that Method 6 is the ONLY recommended approach for TIME SERIES

Maximum Interpolation Gap is set at 15.00 days

C.2 Kolling Creek

Table 43. FLUX model diagnostics for Kolling Creek

Kolling_TP_Strat2
FLOW AND LOAD SUMMARIES FOR TP

Method: Flw Wghted Conc. (2)
DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (kg/y)	SLOPE LgC/LgQ	R^2	p > C/Q
1 Flow < Mean	1074	37	37	29.3	9.786345	9.525913	0.052676	432	-0.1797	0.00	0.1942
2 Flow > Mean	456	10	10	70.7	55.48447	39.22373	0.0437	2120	-0.2009	0.00	0.7899
Overall	1530	47	47	100.0	23.40618	15.8446	0.050766	935	-0.1416	0.00	0.1414

STRATUM BOUNDARIES(CFS)

STRATUM	LOWER LIMIT	UPPER LIMIT
Flow < Mean	0	23.4062
Stratum 2	23.4062	264.062

DAILY FLOW STATISTICS

Daily Flow Duration	1530 Days = 4.189 Years
Daily Mean Flow Rate	23.41 (CFS)
Daily Total Flow Volume	87.63 (Mega m^3)
Daily Flow Date Range	05/01/2001 to 09/30/2010
Samples Date Range	05/02/2006 to 09/21/2009

LOAD ESTIMATES FOR TP

Method	Mass(kg)	Flux(kg/y)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1 Average Load	3107.7	742	8047	0.0355	0.12
2 Flw Wghted Conc.	3917.1	935	15033	0.0447	0.13
3 Flw Wghted IJC.	3903.0	932	15304	0.0445	0.13
4 C/Q Reg1	3732.9	891	60447	0.0426	0.28
5 C/Q Reg2(VarAdj)	3618.3	864	117001	0.0413	0.40
6 C/Q Reg3(daily)	3992.8	953	40379	0.0456	0.21
8 Time Series*	3914.5	934	N/A	0.0447	N/A

*Time series estimates use residual interpolation.
WARNING! The listed Time Series estimates are based on Method 2, Flw Wghted Conc.
Remember that Method 6 is the ONLY recommended approach for TIME SERIES
Maximum Interpolation Gap is set at 15.00 days

C.3 Kinzer Creek

Table 44. FLUX model diagnostics for Kinzer Creek

```
                              Kolling_TP_Strat2
                        FLOW AND LOAD SUMMARIES FOR TP

Method: Flw Wghted Conc. (2)
DISTRIBUTION OF SAMPLES VS. DAILY FLOWS
                                                Daily Flow    Smpl Flow     TP       FLUX     SLOPE
Stratum          Flows  Smpls  Evnts  Vol %         (CFS)        (CFS)   (mg/L)    (kg/y)  LgC/LgQ  R^2    p >
C/Q
1 Flow < Mean     1074     37     37   29.3      9.786345     9.525913 0.052676       432  -0.1797 0.00
0.1942
2 Flow > Mean      456     10     10   70.7      55.48447     39.22373   0.0437      2120  -0.2009 0.00
0.7899
Overall           1530     47     47  100.0      23.40618      15.8446 0.050766       935  -0.1416 0.00
0.1414

STRATUM BOUNDARIES(CFS)
--------------------------------------------------
STRATUM            LOWER LIMIT       UPPER LIMIT
Flow < Mean        0                 23.4062
Stratum 2          23.4062           264.062

--------------------------------------------------


DAILY FLOW STATISTICS
Daily Flow Duration      1530 Days = 4.189 Years
Daily Mean Flow Rate     23.41 (CFS)
Daily Total Flow Volume  87.63 (Mega m^3)
Daily Flow Date Range    05/01/2001 to 09/30/2010
Samples Date Range       05/02/2006 to 09/21/2009

LOAD ESTIMATES FOR TP                                              Flw Wgted
     Method             Mass(kg)         Flux(kg/y)   Flux Variance   Conc.(mg/L)      C.V.
1  Average Load         3107.7                742            8047        0.0355       0.12
2  Flw Wghted Conc.     3917.1                935           15033        0.0447       0.13
3  Flw Wghted IJC.      3903.0                932           15304        0.0445       0.13
4  C/Q Reg1             3732.9                891           60447        0.0426       0.28
5  C/Q Reg2(VarAdj)     3618.3                864          117001        0.0413       0.40
6  C/Q Reg3(daily)      3992.8                953           40379        0.0456       0.21
8  Time Series*         3914.5                934             N/A        0.0447        N/A

------------------------------------------------------------
*Time series estimates use residual interpolation.
 WARNING!  The listed Time Series estimates are based on Method 2, Flw Wghted Conc.
 Remember that Method 6 is the ONLY recommended approach for TIME SERIES
 Maximum Interpolation Gap is set at 15.00 days
```

C.4 Sauk River Outlet at Cold Springs

Table 45. FLUX model diagnostics for the Sauk River Outlet at Cold Springs, MN

```
                                               Outlet_TP_Strat2
                                   FLOW AND LOAD SUMMARIES FOR TP

Method: Flw Wghted Conc. (2)
DISTRIBUTION OF SAMPLES VS. DAILY FLOWS
                                             Daily Flow    Smpl Flow     TP       FLUX     SLOPE
Stratum           Flows  Smpls  Evnts  Vol %      (CFS)        (CFS)   (mg/L)    (kg/y)  LgC/LgQ  R^2    p >
C/Q
1 Flow < Mean       884     58     58   27.6   169.7854      169.046  0.14336     18452  -0.3439 0.00
0.0004
2 Flow > Mean       594     40     40   72.4   663.1133     677.3031  0.10568     70212    0.901 0.00
0.0007
Overall            1478     98     98  100.0   368.0512     376.4979  0.12798     39254   -0.198 0.00
0.0010

STRATUM BOUNDARIES(CFS)
--------------------------------------------------
STRATUM             LOWER LIMIT       UPPER LIMIT
Flow < Mean         0                 369.089
Stratum 2           369.089           1902.14

--------------------------------------------------


DAILY FLOW STATISTICS
Daily Flow Duration       1478 Days = 4.047 Years
Daily Mean Flow Rate      368.05 (CFS)
Daily Total Flow Volume   1331.06 (Mega m^3)
Daily Flow Date Range     06/21/2001 to 09/30/2010
Samples Date Range        06/26/2001 to 09/16/2010

LOAD ESTIMATES FOR TP                                               Flw Wgted
     Method             Mass(kg)        Flux(kg/y)   Flux Variance  Conc.(mg/L)      C.V.
1  Average Load         161093              39810        19020370        0.121       0.110
2  Flw Wghted Conc.     158844              39254         8206562        0.119       0.073
3  Flw Wghted IJC.      159250              39355         8315521         0.12       0.073
4  C/Q Reg1             156619              38704         4851188        0.118       0.057
5  C/Q Reg2(VarAdj)     156051              38564         7640525        0.117       0.072
6  C/Q Reg3(daily)      160907              39764         7791942        0.121       0.070
8  Time Series*         157685              38968             N/A        0.118         N/A

--------------------------------------------------------
*Time series estimates use residual interpolation.
 WARNING!  The listed Time Series estimates are based on Method 2, Flw Wghted Conc.
 Remember that Method 6 is the ONLY recommended approach for TIME SERIES
 Maximum Interpolation Gap is set at 15.00 days
```

C.5 Luxembourg Creek

Table 46. FLUX model diagnostics for the Luxembourg Creek

```
                         Unnamed II_Cty 9_Strat2
                    FLOW AND LOAD SUMMARIES FOR TP

Method: Flw Wghted Conc. (2)
DISTRIBUTION OF SAMPLES VS. DAILY FLOWS
                                                 Daily Flow    Smpl Flow      TP        FLUX      SLOPE
Stratum           Flows  Smpls  Evnts  Vol %         (CFS)        (CFS)    (mg/L)    (kg/y)  LgC/LgQ  R²    p >
C/Q
1 Flow < Mean      1092     22     22   34.2       5.33274     7.232587    0.2485      1166 -0.00732 0.00
0.9703
2 Flow > Mean       437     25     25   65.8      25.61829     27.83921   0.14248      4032   0.2225 0.00
0.2151
Overall            1529     47     47  100.0      11.13051     18.19356   0.19211      1985  -0.1855 0.00
0.0834

STRATUM BOUNDARIES(CFS)
--------------------------------------------------
STRATUM              LOWER LIMIT       UPPER LIMIT
Flow < Mean          0                 11.3594
Stratum 2            11.3594           358.05

--------------------------------------------------


DAILY FLOW STATISTICS
Daily Flow Duration       1529 Days = 4.186 Years
Daily Mean Flow Rate      11.13 (CFS)
Daily Total Flow Volume   41.64 (Mega m³)
Daily Flow Date Range     05/01/2000 to 09/30/2009
Samples Date Range        05/25/2000 to 09/29/2009

LOAD ESTIMATES FOR TP                                            Flw Wgted
     Method             Mass(kg)        Flux(kg/y)  Flux Variance   Conc.(mg/L)      C.V.
1  Average Load         9969.7               2382         187424        0.239        0.18
2  Flw Wghted Conc.     8309.8               1985          54203          0.2        0.12
3  Flw Wghted IJC.      8387.9               2004          56521        0.201        0.12
4  C/Q Reg1             8229.1               1966          47801        0.198        0.11
5  C/Q Reg2(VarAdj)     8319.5               1987          57693          0.2        0.12
6  C/Q Reg3(daily)      7950.2               1899          41312        0.191        0.11
8  Time Series*         8254.4               1972            N/A        0.198         N/A

--------------------------------------------------------
*Time series estimates use residual interpolation.
 WARNING!  The listed Time Series estimates are based on Method 2, Flw Wghted Conc.
 Remember that Method 6 is the ONLY recommended approach for TIME SERIES
 Maximum Interpolation Gap is set at 7.22 days
```

C.6 Unnamed Tributary to Vails Lake

Table 47. FLUX model diagnostics for Unnamed Tributary to Vails Lake

Unnamed I_Hutch
FLOW AND LOAD SUMMARIES FOR TP

Method: Flw Wghted Conc. (2)
DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (kg/y)	SLOPE LgC/LgQ	R^2	p > C/Q
Overall	1529	9	9	100.0	3.890133	10.48834	0.192	667.03	-0.0909	0.00	0.7129

DAILY FLOW STATISTICS

Daily Flow Duration	1529 Days = 4.186 Years
Daily Mean Flow Rate	3.89 (CFS)
Daily Total Flow Volume	14.55 (Mega m^3)
Daily Flow Date Range	05/02/2000 to 09/30/2009
Samples Date Range	05/06/2008 to 07/10/2008

LOAD ESTIMATES FOR TP

	Method	Mass(kg)	Flux(kg/y)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1	Average Load	7528.4	1798.41	722407	0.517	0.47
2	Flw Wghted Conc.	2792.3	667.03	10680	0.192	0.15
3	Flw Wghted IJC.	2858.6	682.87	14256	0.196	0.17
4	C/Q Reg1	3055.7	729.96	23008	0.21	0.21
5	C/Q Reg2(VarAdj)	2813.9	672.19	33060	0.193	0.27
6	C/Q Reg3(daily)	2896.6	691.94	17098	0.199	0.19
8	Time Series*	2790.2	666.53	N/A	0.192	N/A

----

*Time series estimates use residual interpolation.
WARNING! The listed Time Series estimates are based on Method 2, Flw Wghted Conc.
Remember that Method 6 is the ONLY recommended approach for TIME SERIES
Maximum Interpolation Gap is set at 7.22 days

C.7 Eden Valley Creek

Table 48. FLUX model diagnostics for Eden Valley Creek

EVC_TP

FLOW AND LOAD SUMMARIES FOR TP

Method: Flw Wghted Conc. (2)

DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (kg/y)	SLOPE LgC/LgQ	R^2	p > C/Q
Overall	1530	15	15	100.0	16.8403	24.9452	0.18513	1843.3	-0.6468	0.01	0.0609

DAILY FLOW STATISTICS

Daily Flow Duration	1530 Days = 4.189 Years
Daily Mean Flow Rate	16.84 (CFS)
Daily Total Flow Volume	63.05 (Mega m^3)
Daily Flow Date Range	05/01/2000 to 09/30/2009
Samples Date Range	05/02/2006 to 08/11/2008

LOAD ESTIMATES FOR TP

	Method	Mass(kg)	Flux(kg/y)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1	Average Load	11437	2730.4	497105	0.181	0.26
2	Flw Wghted Conc.	7721	1843.3	441739	0.122	0.36
3	Flw Wghted IJC.	7348	1754.1	420838	0.117	0.37
4	C/Q Reg1	9955	2376.6	543850	0.158	0.31
5	C/Q Reg2(VarAdj)	7041	1680.9	457221	0.112	0.40
6	C/Q Reg3(daily)	9055	2161.6	406646	0.144	0.30
8	Time Series*	7554	1803.2	N/A	0.12	N/A

----

*Time series estimates use residual interpolation.

WARNING! The listed Time Series estimates are based on Method 2, Flw Wghted Conc.

Remember that Method 6 is the ONLY recommended approach for TIME SERIES

Maximum Interpolation Gap is set at 15.00 days

C.8 Schneider Creek

Table 49. FLUX model diagnostics for the Schneider Creek

SchneiderHSPF_TP_Strat2
FLOW AND LOAD SUMMARIES FOR TP

Method: Flw Wghted Conc. (2)
DISTRIBUTION OF SAMPLES VS. DAILY FLOWS

Stratum	Flows	Smpls	Evnts	Vol %	Daily Flow (CFS)	Smpl Flow (CFS)	TP (mg/L)	FLUX (kg/y)	SLOPE LgC/LgQ	R^2	p > C/Q
1 Flow < Mean	1122	34	34	36.3	5.106329	5.486247	0.083412	374	-0.1105	0.00	0.5077
2 Flow > Mean	408	12	12	63.7	24.60698	27.67377	0.073667	1721	0.2583	0.00	0.2831
Overall	1530	46	46	100.0	10.3065	11.2743	0.08087	733	-0.0625	0.00	0.4423

STRATUM BOUNDARIES(CFS)

STRATUM	LOWER LIMIT	UPPER LIMIT
Flow < Mean	0	10.3065
Stratum 2	10.3065	429.548

DAILY FLOW STATISTICS

Daily Flow Duration	1530 Days = 4.189 Years
Daily Mean Flow Rate	10.31 (CFS)
Daily Total Flow Volume	38.59 (Mega m^3)
Daily Flow Date Range	05/01/2000 to 09/30/2009
Samples Date Range	05/02/2006 to 09/21/2009

LOAD ESTIMATES FOR TP

Method	Mass(kg)	Flux(kg/y)	Flux Variance	Flw Wgted Conc.(mg/L)	C.V.
1 Average Load	3396.1	811	22888	0.088	0.187
2 Flw Wghted Conc.	3071.0	733	3921	0.0796	0.085
3 Flw Wghted IJC.	3077.9	735	3498	0.0798	0.080
4 C/Q Reg1	3022.8	722	4806	0.0783	0.096
5 C/Q Reg2(VarAdj)	3306.2	789	7001	0.0857	0.106
6 C/Q Reg3(daily)	3117.9	744	9121	0.0808	0.128
8 Time Series*	3002.4	717	N/A	0.0778	N/A

*Time series estimates use residual interpolation.
WARNING! The listed Time Series estimates are based on Method 2, Flw Wghted Conc.
Remember that Method 6 is the ONLY recommended approach for TIME SERIES
Maximum Interpolation Gap is set at 26.91 days

APPENDIX D. SUPPORTING DATA, BATHTUB MODELING – CHAIN OF LAKES MODEL

BATHTUB modeling diagnostics (results) and segment balances (water and phosphorus budgets) are presented for the calibrated (benchmark/existing) model, the LC scenario, individual TMDL scenarios, and the *comprehensive TMDL scenario for the SRCL*. In-lake water quality concentrations for the calibrated and TMDL scenarios were evaluated to the nearest tenth for TP. The tributary goal reported in the BATHTUB model output does not take into account the MOS, and is therefore larger than the loading goals listed in the individual lake TMDL and allocation tables in Section 4.1.8. In the following tables, lakeshed drainage loads have three different components: lakeshed runoff (LS), runoff from shoreline lots (R), and septic tanks (ST). The three components make up the overall lakeshed drainage (see Section 3.5.12).

D.1 Horseshoe Lake North Calibrated Model

Table 50. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Horseshoe Lake North

Segment:	1	HS North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	162.7	0.10	91.3%			

Table 51. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake North

Component:		TOTAL P		Segment:	1	HS North	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	SRCL Inflow	286.5	87.8%	53289.0	94.1%	186
5	1	LS_HS North	0.3	0.1%	15.3	0.0%	54
17	1	R__HS North	0.0	0.0%	7.7	0.0%	7746
29	1	ST_HS North	0.0	0.0%	12.1	0.0%	12080
PRECIPITATION			0.3	0.1%	8.5	0.0%	30
TRIBUTARY INFLOW			286.8	87.9%	53324.2	94.1%	186
ADVECTIVE INFLOW			39.3	12.0%	3307.5	5.8%	84
***TOTAL INFLOW			326.3	100.0%	56640.2	100.0%	174
ADVECTIVE OUTFLOW			326.0	99.9%	53092.8	93.7%	163
NET DIFFUSIVE OUTFLOW			0.0	0.0%	1171.3	2.1%	
***TOTAL OUTFLOW			326.0	99.9%	54264.1	95.8%	166
***EVAPORATION			0.4	0.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	2376.2	4.2%	
Hyd. Residence Time =			0.0012	yrs			
Overflow Rate =			1283.5	m/yr			
Mean Depth =			1.5	m			

D 2. Horseshoe Lake North Loading Capacity Model

Table 52. Loading capacity scenario BATHTUB model diagnostics (model results) for Horseshoe Lake North

Segment:	1	HS North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	90.0	0.09	75.8%			

Table 53. Loading capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake North

Component:		TOTAL P		Segment:	1	HS North	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	SRCL Inflow	286.5	87.8%	28893.5	92.6%	101
5	1	LS_HS North	0.3	0.1%	15.3	0.0%	54
17	1	R__HS North	0.0	0.0%	7.7	0.0%	7746
29	1	ST_HS North	0.0	0.0%	12.1	0.0%	12080
PRECIPITATION			0.3	0.1%	8.5	0.0%	30
TRIBUTARY INFLOW			286.8	87.9%	28928.7	92.7%	101
ADVECTIVE INFLOW			39.3	12.0%	2264.2	7.3%	58
***TOTAL INFLOW			326.3	100.0%	31201.4	100.0%	96
ADVECTIVE OUTFLOW			326.0	99.9%	29342.2	94.0%	90
NET DIFFUSIVE OUTFLOW			0.0	0.0%	546.0	1.7%	
***TOTAL OUTFLOW			326.0	99.9%	29888.2	95.8%	92
***EVAPORATION			0.4	0.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	1313.2	4.2%	
Hyd. Residence Time =			0.0012	yrs			
Overflow Rate =			1283.5	m/yr			
Mean Depth =			1.5	m			

D.3 Horseshoe Lake North TMDL Model

Table 54. TMDL scenario BATHTUB model diagnostics (model results) for Horseshoe Lake North

Segment:	1	HS North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	89.3	0.09	75.6%			

Table 55. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake North

Component:		TOTAL P		Segment:	1	HS North	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	SRCL Inflow	286.5	87.8%	28650.0	92.6%	100
5	1	LS_HS North	0.3	0.1%	15.3	0.0%	54
17	1	R__HS North	0.0	0.0%	7.7	0.0%	7746
29	1	ST_HS North	0.0	0.0%	12.1	0.0%	12080
PRECIPITATION			0.3	0.1%	8.5	0.0%	30
TRIBUTARY INFLOW			286.8	87.9%	28685.2	92.7%	100
ADVECTIVE INFLOW			39.3	12.0%	2256.9	7.3%	57
***TOTAL INFLOW			326.3	100.0%	30950.6	100.0%	95
ADVECTIVE OUTFLOW			326.0	99.9%	29109.9	94.1%	89
NET DIFFUSIVE OUTFLOW			0.0	0.0%	537.9	1.7%	
***TOTAL OUTFLOW			326.0	99.9%	29647.8	95.8%	91
***EVAPORATION			0.4	0.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	1302.8	4.2%	
Hyd. Residence Time =			0.0012	yrs			
Overflow Rate =			1283.5	m/yr			
Mean Depth =			1.5	m			

D.4 Horseshoe Lake North, Comprehensive TMDL Scenario (SRCL)

Table 56. Chain of Lakes comprehensive TMDL scenario BATHTUB model diagnostics (model results) for Horseshoe Lake North

Segment:	1	HS North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	89.2	0.09	75.5%			

Table 57. Chain of Lakes comprehensive TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake North

Component:		TOTAL P		Segment:	1	HS North	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	SRCL Inflow	286.5	87.8%	28650.0	92.8%	100
5	1	LS_HS North	0.3	0.1%	15.3	0.0%	54
17	1	R__HS North	0.0	0.0%	7.7	0.0%	7746
29	1	ST_HS North	0.0	0.0%	12.1	0.0%	12080
PRECIPITATION			0.3	0.1%	8.5	0.0%	30
TRIBUTARY INFLOW			286.8	87.9%	28685.2	92.9%	100
ADVECTIVE INFLOW			39.3	12.0%	2190.2	7.1%	56
***TOTAL INFLOW			326.3	100.0%	30884.0	100.0%	95
ADVECTIVE OUTFLOW			326.0	99.9%	29060.5	94.1%	89
NET DIFFUSIVE OUTFLOW			0.0	0.0%	522.9	1.7%	
***TOTAL OUTFLOW			326.0	99.9%	29583.4	95.8%	91
***EVAPORATION			0.4	0.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	1300.6	4.2%	
Hyd. Residence Time =			0.0012	yrs			
Overflow Rate =			1283.5	m/yr			
Mean Depth =			1.5	m			

D.5 Cedar Island–East Lake Calibrated Model

Table 58. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Cedar Island-East Lake

Segment:	**2**	**East**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	138.2	0.11	88.0%			

Table 59. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Cedar Island–East Lake

Component:		**TOTAL P**		**Segment:**	**2**	**East**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
6	1	LS_East	0.0	0.0%	2.1	0.0%	54
19	1	R__East	0.0	0.0%	17.4	0.0%	17444
32	1	ST_East	0.0	0.0%	30.0	0.1%	30034
PRECIPITATION			1.2	0.4%	36.7	0.1%	30
TRIBUTARY INFLOW			0.0	0.0%	49.6	0.1%	1229
ADVECTIVE INFLOW			325.1	99.6%	53026.7	99.8%	163
***TOTAL INFLOW			326.3	100.0%	53113.1	100.0%	163
ADVECTIVE OUTFLOW			324.7	99.5%	44879.6	84.5%	138
***TOTAL OUTFLOW			324.7	99.5%	44879.6	84.5%	138
***EVAPORATION			1.6	0.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	8233.4	15.5%	
Hyd. Residence Time =			0.0051	yrs			
Overflow Rate =			297.5	m/yr			
Mean Depth =			1.5	m			

D.6 Cedar Island–East Lake Loading Capacity Model

Table 60. Loading capacity scenario BATHTUB model diagnostics (model results) for Cedar Island–East Lake

Segment:	**2**	**East**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	90.0	0.09	75.8%			

Table 61. Loading capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Cedar Island–East Lake

Component:		**TOTAL P**		**Segment:**	**2**	**East**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
7	1	LS_East	0.0	0.0%	2.1	0.0%	54
20	1	R__East	0.0	0.0%	17.4	0.1%	17444
33	1	ST_East	0.0	0.0%	30.0	0.1%	30034
PRECIPITATION			1.2	0.4%	36.7	0.1%	30
INTERNAL LOAD			0.0	0.0%	5343.0	15.4%	
TRIBUTARY INFLOW			0.0	0.0%	49.6	0.1%	1229
ADVECTIVE INFLOW			327.2	99.6%	29347.2	84.4%	90
***TOTAL INFLOW			328.5	100.0%	34776.5	100.0%	106
ADVECTIVE OUTFLOW			326.9	99.5%	29416.0	84.6%	90
***TOTAL OUTFLOW			326.9	99.5%	29416.0	84.6%	90
***EVAPORATION			1.6	0.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	5360.6	15.4%	
Hyd. Residence Time =			0.0051	yrs			
Overflow Rate =			299.5	m/yr			
Mean Depth =			1.5	m			

D.7 Cedar Island–East Lake TMDL Model

Table 62. TMDL scenario BATHTUB model diagnostics (model results) for Cedar Island–East Lake

Segment:	2	East				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	76.4	0.11	69.8%			

Table 63. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Koetter Lake

Component:		TOTAL P		Segment:	2	East	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
6	1	LS_East	0.0	0.0%	2.1	0.0%	54
18	1	R__East	0.0	0.0%	17.4	0.1%	17444
30	1	ST_East	0.0	0.0%	30.0	0.1%	30034
PRECIPITATION			1.2	0.4%	36.7	0.1%	30
TRIBUTARY INFLOW			0.0	0.0%	49.6	0.2%	1229
ADVECTIVE INFLOW			326.0	99.6%	29331.6	99.7%	90
***TOTAL INFLOW			327.2	100.0%	29418.0	100.0%	90
ADVECTIVE OUTFLOW			325.6	99.5%	24868.5	84.5%	76
***TOTAL OUTFLOW			325.6	99.5%	24868.5	84.5%	76
***EVAPORATION			1.6	0.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	4549.5	15.5%	
Hyd. Residence Time =			0.0051	yrs			
Overflow Rate =			298.3	m/yr			
Mean Depth =			1.5	m			

D.8 Cedar Island–East Lake, Comprehensive TMDL Scenario (SRCL)

Table 64. Chain of Lakes comprehensive TMDL scenario BATHTUB model diagnostics (model results) for Cedar Island–Main Lake

Segment:	**2**	**East**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	75.7	0.11	69.4%			

Table 65. Chain of Lakes comprehensive TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Cedar Island–Main Lake

Component:		**TOTAL P**		**Segment:**	**2**	**East**		
			Flow	**Flow**	**Load**	**Load**	**Conc**	
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**	
6	1	LS_East	0.0	0.0%	2.1	0.0%	54	
18	1	R__East	0.0	0.0%	17.4	0.1%	17444	
30	1	ST_East	0.0	0.0%	30.0	0.1%	30034	
PRECIPITATION			1.2	0.4%	36.7	0.1%	30	
TRIBUTARY INFLOW			0.0	0.0%	49.6	0.2%	1229	
ADVECTIVE INFLOW			326.0	99.6%	29060.5	99.7%	89	
***TOTAL INFLOW			327.2	100.0%	29146.8	100.0%	89	
ADVECTIVE OUTFLOW			325.6	99.5%	24639.3	84.5%	76	
***TOTAL OUTFLOW			325.6	99.5%	24639.3	84.5%	76	
***EVAPORATION			1.6	0.5%	0.0	0.0%		
***RETENTION			0.0	0.0%	4507.5	15.5%		
Hyd. Residence Time =			0.0051	yrs				
Overflow Rate =			298.3	m/yr				
Mean Depth =			1.5	m				

D.9 Cedar Island–Koetter Lake Calibrated Model

Table 66. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Koetter Lake North

Segment:	3	Koetter				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
CONSERVATIVE SUB	21908.0	0.06		21908.0	0.06	
TOTAL P MG/M3	126.4	0.12	86.0%	126.4	0.40	86.0%

Table 67. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Koetter Lake

Component:		TOTAL P		Segment:	3	Koetter	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
7	1	LS_Koetter	0.2	0.1%	10.1	0.0%	54
19	1	R__Koetter	0.0	0.0%	13.5	0.0%	13519
31	1	ST_Koetter	0.0	0.0%	30.2	0.1%	30195
PRECIPITATION			0.6	0.2%	17.6	0.0%	30
TRIBUTARY INFLOW			0.2	0.1%	53.9	0.1%	285
ADVECTIVE INFLOW			330.2	99.8%	45336.0	99.8%	137
***TOTAL INFLOW			331.0	100.0%	45407.5	100.0%	137
ADVECTIVE OUTFLOW			330.3	99.8%	41763.3	92.0%	126
NET DIFFUSIVE OUTFLOW			0.0	0.0%	417.4	0.9%	
***TOTAL OUTFLOW			330.3	99.8%	42180.7	92.9%	128
***EVAPORATION			0.8	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	3226.8	7.1%	
Hyd. Residence Time =			0.0024	yrs			
Overflow Rate =			631.9	m/yr			
Mean Depth =			1.5	m			

D.10 Cedar Island–Koetter Lake Loading Capacity Model

Table 68. Loading Capacity scenario BATHTUB model diagnostics (model results) for Koetter Lake North

Segment:	3	Koetter				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	90.0	0.09	75.8%	126.4	0.40	86.0%

Table 69. Loading Capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Koetter Lake

Component:		TOTAL P		Segment:	3	Koetter	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
7	1	LS_Koetter	0.2	0.1%	10.1	0.0%	54
19	1	R__Koetter	0.0	0.0%	13.5	0.0%	13519
31	1	ST_Koetter	0.0	0.0%	30.2	0.1%	30195
PRECIPITATION			0.6	0.2%	17.6	0.1%	30
INTERNAL LOAD			0.0	0.0%	2634.1	8.1%	
TRIBUTARY INFLOW			0.2	0.1%	53.9	0.2%	285
ADVECTIVE INFLOW			330.2	99.8%	29647.1	91.6%	90
***TOTAL INFLOW			331.0	100.0%	32352.7	100.0%	98
ADVECTIVE OUTFLOW			330.3	99.8%	29721.4	91.9%	90
NET DIFFUSIVE OUTFLOW			0.0	0.0%	334.9	1.0%	
***TOTAL OUTFLOW			330.3	99.8%	30056.3	92.9%	91
***EVAPORATION			0.8	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	2296.4	7.1%	
Hyd. Residence Time =			0.0024	yrs			
Overflow Rate =			631.9	m/yr			
Mean Depth =			1.5	m			

D.11 Cedar Island–Koetter Lake TMDL Model

Table 70. TMDL scenario BATHTUB model diagnostics (model results) for Koetter Lake

Segment:	3	Koetter				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	82.6	0.10	72.8%	126.4	0.40	86.0%

Table 71. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Koetter Lake

Component:		TOTAL P		Segment:	3	Koetter	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
7	1	LS_Koetter	0.2	0.1%	10.1	0.0%	54
19	1	R__Koetter	0.0	0.0%	13.5	0.0%	13519
31	1	ST_Koetter	0.0	0.0%	30.2	0.1%	30195
PRECIPITATION			0.6	0.2%	17.6	0.1%	30
TRIBUTARY INFLOW			0.2	0.1%	53.9	0.2%	285
ADVECTIVE INFLOW			330.2	99.8%	29620.4	99.8%	90
***TOTAL INFLOW			331.0	100.0%	29691.9	100.0%	90
ADVECTIVE OUTFLOW			330.3	99.8%	27290.3	91.9%	83
NET DIFFUSIVE OUTFLOW			0.0	0.0%	293.0	1.0%	
***TOTAL OUTFLOW			330.3	99.8%	27583.4	92.9%	84
***EVAPORATION			0.8	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	2108.5	7.1%	
Hyd. Residence Time =			0.0024	yrs			
Overflow Rate =			631.9	m/yr			
Mean Depth =			1.5	m			

D.12 Cedar Island–Koetter Lake, Comprehensive TMDL Scenario (SRCL)

Table 72. Chain of Lakes comprehensive TMDL scenario BATHTUB model diagnostics (model results) for Koetter Lake North

Segment:	3	Koetter				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
CONSERVATIVE SUB	21908.0	0.06		21908.0	0.06	

Table 73. Chain of Lakes comprehensive TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Koetter Lake

Component:		TOTAL P		Segment:	3	Koetter	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
7	1	LS_Koetter	0.2	0.1%	10.1	0.0%	54
19	1	R__Koetter	0.0	0.0%	13.5	0.1%	13519
31	1	ST_Koetter	0.0	0.0%	30.2	0.1%	30195
PRECIPITATION			0.6	0.2%	17.6	0.1%	30
TRIBUTARY INFLOW			0.2	0.1%	53.9	0.2%	285
ADVECTIVE INFLOW			330.2	99.8%	24916.5	99.7%	75
***TOTAL INFLOW			331.0	100.0%	24988.0	100.0%	75
ADVECTIVE OUTFLOW			330.3	99.8%	23109.7	92.5%	70
NET DIFFUSIVE OUTFLOW			0.0	0.0%	92.7	0.4%	
***TOTAL OUTFLOW			330.3	99.8%	23202.4	92.9%	70
***EVAPORATION			0.8	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	1785.5	7.1%	
Hyd. Residence Time =			0.0024	yrs			
Overflow Rate =			631.9	m/yr			
Mean Depth =			1.5	m			

D.13 Zumwalde Lake Calibrated Model

Table 74. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Zumwalde Lake

Segment:	**4**	**Zumwalde**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	139.8	0.11	88.3%	139.8	0.40	88.3%

Table 75. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Zumwalde Lake

Component:		**TOTAL P**		**Segment:**	**4**	**Zumwalde**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
9	1	LS_Zumwalde	0.1	0.0%	7.9	0.0%	54
22	1	R__Zumwalde	0.0	0.0%	11.2	0.0%	11193
35	1	ST_Zumwalde	0.0	0.0%	30.6	0.1%	30602
PRECIPITATION			0.5	0.2%	16.4	0.0%	30
INTERNAL LOAD			0.0	0.0%	4697.2	10.1%	
TRIBUTARY INFLOW			0.1	0.0%	49.7	0.1%	338
ADVECTIVE INFLOW			331.5	99.8%	41915.7	89.8%	126
***TOTAL INFLOW			332.2	100.0%	46679.1	100.0%	141
ADVECTIVE OUTFLOW			331.5	99.8%	46352.4	99.3%	140
***TOTAL OUTFLOW			331.5	99.8%	46352.4	99.3%	140
***EVAPORATION			0.7	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	326.7	0.7%	
Hyd. Residence Time =			0.0022	yrs			
Overflow Rate =			679.2	m/yr			
Mean Depth =			1.5	m			

D.14 Zumwalde Lake Loading Capacity Model

Table 76. Loading capacity scenario BATHTUB model diagnostics (model results) for Zumwalde Lake

Segment:	**4**	**Zumwalde**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	90.0	0.09	75.8%	139.8	0.40	88.3%

Table 77. Loading capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Zumwalde Lake

Component:		**TOTAL P**		**Segment:**	**4**	**Zumwalde**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
8	1	LS_Zumwalde	0.1	0.0%	7.9	0.0%	54
20	1	R__Zumwalde	0.0	0.0%	11.2	0.0%	11193
32	1	ST_Zumwalde	0.0	0.0%	30.6	0.1%	30602
PRECIPITATION			0.5	0.2%	16.4	0.1%	30
INTERNAL LOAD			0.0	0.0%	142.6	0.5%	
TRIBUTARY INFLOW			0.1	0.0%	49.7	0.2%	338
ADVECTIVE INFLOW			330.3	99.8%	29721.4	99.3%	90
***TOTAL INFLOW			330.9	100.0%	29930.1	100.0%	90
ADVECTIVE OUTFLOW			330.2	99.8%	29719.8	99.3%	90
***TOTAL OUTFLOW			330.2	99.8%	29719.8	99.3%	90
***EVAPORATION			0.7	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	210.3	0.7%	
Hyd. Residence Time =			0.0023	yrs			
Overflow Rate =			676.6	m/yr			
Mean Depth =			1.5	m			

D.15 Zumwalde Lake TMDL Model

For Zumwalde Lake the load capacity and TMDL scenarios are the same.

D.16 Zumwalde Lake, Comprehensive TMDL Scenario (SRCL)

Table 78. Chain of Lakes comprehensive TMDL scenario BATHTUB model diagnostics (model results) for Zumwalde Lake

Segment:	4	Zumwalde				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	83.8	0.09	73.0%	139.8	0.40	88.3%

Table 79. Chain of Lakes comprehensive TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Zumwalde Lake

Component:		TOTAL P		Segment:	4	Zumwalde	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
8	1	LS_Zumwalde	0.1	0.0%	7.9	0.0%	54
20	1	R__Zumwalde	0.0	0.0%	11.2	0.0%	11193
32	1	ST_Zumwalde	0.0	0.0%	30.6	0.1%	30602
PRECIPITATION			0.5	0.2%	16.4	0.1%	30
INTERNAL LOAD			0.0	0.0%	4697.2	16.9%	
TRIBUTARY INFLOW			0.1	0.0%	49.7	0.2%	338
ADVECTIVE INFLOW			330.3	99.8%	23109.7	82.9%	70
***TOTAL INFLOW			330.9	100.0%	27873.1	100.0%	84
ADVECTIVE OUTFLOW			330.2	99.8%	27677.2	99.3%	84
***TOTAL OUTFLOW			330.2	99.8%	27677.2	99.3%	84
***EVAPORATION			0.7	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	195.8	0.7%	
Hyd. Residence Time =			0.0023	yrs			
Overflow Rate =			676.6	m/yr			
Mean Depth =			1.5	m			

D.17 Great Northern Lake Calibrated Model

Table 80. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Great Northern Lake

Segment:	5	Gt North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	136.0	0.11	87.7%	136.0	0.40	87.7%

Table 81. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Great Northern Lake

Component:		TOTAL P		Segment:	5	Gt North	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
9	1	LS_Gt North	0.4	0.1%	22.9	0.0%	54
21	1	R__Gt North	0.0	0.0%	10.9	0.0%	10902
33	1	ST_Gt North	0.0	0.0%	33.5	0.1%	33527
42	1	Inflow from Schneiders	9.3	2.7%	562.7	1.2%	61
PRECIPITATION			0.8	0.2%	25.4	0.1%	30
TRIBUTARY INFLOW			9.7	2.9%	630.0	1.3%	65
ADVECTIVE INFLOW			330.2	96.9%	46199.8	98.6%	140
***TOTAL INFLOW			340.8	100.0%	46855.3	100.0%	137
ADVECTIVE OUTFLOW			339.7	99.7%	46215.3	98.6%	136
***TOTAL OUTFLOW			339.7	99.7%	46215.3	98.6%	136
***EVAPORATION			1.1	0.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	639.9	1.4%	
Hyd. Residence Time =			0.0034	yrs			
Overflow Rate =			449.4	m/yr			
Mean Depth =			1.5	m			

D.18 Great Northern Lake Loading Capacity Model

Table 82. Loading Capacity scenario BATHTUB model diagnostics (model results) for Great Northern Lake

Segment:	5	Gt North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	90.0	0.09	75.8%	136.0	0.40	87.7%

Table 83. Loading Capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Great Northern Lake

Component:		TOTAL P		Segment:	5	Gt North	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
9	1	LS_Gt North	0.4	0.1%	22.9	0.1%	54
21	1	R__Gt North	0.0	0.0%	10.9	0.0%	10902
33	1	ST_Gt North	0.0	0.0%	33.5	0.1%	33527
42	1	Inflow from Schneiders	9.3	2.7%	372.0	1.2%	40
PRECIPITATION			0.8	0.2%	25.4	0.1%	30
INTERNAL LOAD			0.0	0.0%	800.7	2.6%	
TRIBUTARY INFLOW			9.7	2.9%	439.4	1.4%	45
ADVECTIVE INFLOW			330.2	96.9%	29719.8	95.9%	90
***TOTAL INFLOW			340.8	100.0%	30985.3	100.0%	91
ADVECTIVE OUTFLOW			339.7	99.7%	30562.1	98.6%	90
***TOTAL OUTFLOW			339.7	99.7%	30562.1	98.6%	90
***EVAPORATION			1.1	0.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	423.2	1.4%	
Hyd. Residence Time =			0.0034	yrs			
Overflow Rate =			449.4	m/yr			
Mean Depth =			1.5	m			

D.19 Great Northern Lake TMDL Model

Table 84. TMDL scenario BATHTUB model diagnostics (model results) for Great Northern Lake

Segment:	5	Gt North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	87.6	0.09	74.9%	136.0	0.40	87.7%

Table 85. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Great Northern Lake

Component:		TOTAL P		Segment:	5	Gt North	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
9	1	LS_Gt North	0.4	0.1%	22.9	0.1%	54
21	1	R__Gt North	0.0	0.0%	10.9	0.0%	10902
33	1	ST_Gt North	0.0	0.0%	33.5	0.1%	33527
42	1	Inflow from Schneiders	9.3	2.7%	372.0	1.2%	40
PRECIPITATION			0.8	0.2%	25.4	0.1%	30
TRIBUTARY INFLOW			9.7	2.9%	439.4	1.5%	45
ADVECTIVE INFLOW			330.2	96.9%	29707.5	98.5%	90
***TOTAL INFLOW			340.8	100.0%	30172.3	100.0%	89
ADVECTIVE OUTFLOW			339.7	99.7%	29760.2	98.6%	88
***TOTAL OUTFLOW			339.7	99.7%	29760.2	98.6%	88
***EVAPORATION			1.1	0.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	412.1	1.4%	
Hyd. Residence Time =			0.0034	yrs			
Overflow Rate =			449.4	m/yr			
Mean Depth =			1.5	m			

D.20 Great Northern Lake, Comprehensive TMDL Scenario (SRCL)

Table 86. Chain of Lakes comprehensive TMDL scenario BATHTUB model diagnostics (model results) for Great Northern Lake

Segment:	5	Gt North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	81.7	0.10	72.4%	136.0	0.40	87.7%

Table 87. Chain of Lakes comprehensive TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Great Northern Lake

Component:		TOTAL P		Segment:	5	Gt North	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
9	1	LS_Gt North	0.4	0.1%	22.9	0.1%	54
21	1	R__Gt North	0.0	0.0%	10.9	0.0%	10902
33	1	ST_Gt North	0.0	0.0%	33.5	0.1%	33527
42	1	Inflow from Schneiders	9.3	2.7%	372.0	1.3%	40
PRECIPITATION			0.8	0.2%	25.4	0.1%	30
TRIBUTARY INFLOW			9.7	2.9%	439.4	1.6%	45
ADVECTIVE INFLOW			330.2	96.9%	27677.2	98.3%	84
***TOTAL INFLOW			340.8	100.0%	28142.0	100.0%	83
ADVECTIVE OUTFLOW			339.7	99.7%	27757.7	98.6%	82
***TOTAL OUTFLOW			339.7	99.7%	27757.7	98.6%	82
***EVAPORATION			1.1	0.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	384.4	1.4%	
Hyd. Residence Time =			0.0034	yrs			
Overflow Rate =			449.4	m/yr			
Mean Depth =			1.5	m			

D.21 Krays Lake Calibrated Model

Table 88. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Krays Lake

Segment:	6	Krays				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	144.0	0.10	88.9%	144.0	0.50	88.9%

Table 89. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Krays Lake

Component:		TOTAL P		Segment:	6	Krays	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
10	1	LS_Krays	0.1	0.0%	6.9	0.0%	54
22	1	R__Krays	0.0	0.0%	7.1	0.0%	7123
34	1	ST_Krays	0.0	0.0%	20.5	0.0%	20455
PRECIPITATION			0.4	0.1%	12.3	0.0%	30
INTERNAL LOAD			0.0	0.0%	2936.0	6.0%	
TRIBUTARY INFLOW			0.1	0.0%	34.5	0.1%	266
ADVECTIVE INFLOW			339.7	99.8%	46215.3	93.9%	136
***TOTAL INFLOW			340.2	100.0%	49198.1	100.0%	145
ADVECTIVE OUTFLOW			339.7	99.8%	48946.1	99.5%	144
***TOTAL OUTFLOW			339.7	99.8%	48946.1	99.5%	144
***EVAPORATION			0.5	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	252.0	0.5%	
Hyd. Residence Time =			0.0016	yrs			
Overflow Rate =			929.8	m/yr			
Mean Depth =			1.5	m			

D.22 Krays Lake Loading Capacity Model

Table 90. Loading Capacity scenario BATHTUB model diagnostics (model results) for Krays Lake

Segment:	6	Krays				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	90.0	0.09	75.8%	144.0	0.50	88.9%

Table 91. Loading Capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Krays Lake

Component:		TOTAL P		Segment:	6	Krays	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
10	1	LS_Krays	0.1	0.0%	6.9	0.0%	54
22	1	R__Krays	0.0	0.0%	7.1	0.0%	7123
34	1	ST_Krays	0.0	0.0%	20.5	0.1%	20455
PRECIPITATION			0.4	0.1%	12.3	0.0%	30
INTERNAL LOAD			0.0	0.0%	107.4	0.3%	
TRIBUTARY INFLOW			0.1	0.0%	34.5	0.1%	266
ADVECTIVE INFLOW			339.7	99.8%	30562.1	99.5%	90
***TOTAL INFLOW			340.2	100.0%	30716.4	100.0%	90
ADVECTIVE OUTFLOW			339.7	99.8%	30559.0	99.5%	90
***TOTAL OUTFLOW			339.7	99.8%	30559.0	99.5%	90
***EVAPORATION			0.5	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	157.3	0.5%	
Hyd. Residence Time =			0.0016	yrs			
Overflow Rate =			929.8	m/yr			
Mean Depth =			1.5	m			

D.23 Krays Lake TMDL Model

For Krays Lake the load capacity and TMDL scenarios are the same.

D.24 Krays Lake, Comprehensive TMDL Scenario (SRCL)

Table 92. Chain of Lakes comprehensive TMDL scenario BATHTUB model diagnostics (model results) for Krays Lake

Segment:	6	Krays				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	90.0	0.10	75.8%	144.0	0.50	88.9%

Table 93. Chain of Lakes comprehensive TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Krays Lake

Component:		TOTAL P		Segment:	6	Krays	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
10	1	LS_Krays	0.1	0.0%	6.9	0.0%	54
22	1	R__Krays	0.0	0.0%	7.1	0.0%	7123
34	1	ST_Krays	0.0	0.0%	20.5	0.1%	20455
PRECIPITATION			0.4	0.1%	12.3	0.0%	30
INTERNAL LOAD			0.0	0.0%	2936.0	9.6%	
TRIBUTARY INFLOW			0.1	0.0%	34.5	0.1%	266
ADVECTIVE INFLOW			339.7	99.8%	27757.7	90.3%	82
***TOTAL INFLOW			340.2	100.0%	30740.5	100.0%	90
ADVECTIVE OUTFLOW			339.7	99.8%	30583.0	99.5%	90
***TOTAL OUTFLOW			339.7	99.8%	30583.0	99.5%	90
***EVAPORATION			0.5	0.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	157.5	0.5%	
Hyd. Residence Time =			0.0016	yrs			
Overflow Rate =			929.8	m/yr			
Mean Depth =			1.5	m			

D.25 Knaus Lake Calibrated Model

Table 94. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Knaus Lake

Segment:	**7**	**Knaus/Park**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	155.8	0.10	90.5%	155.8	1.20	90.5%

Table 95. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Knaus Lake

Component:		**TOTAL P**		**Segment:**	**7**	**Knaus/Park**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
3	1	Kinzer Creek	5.8	1.7%	439.3	0.8%	76
4	4	SRCL Outflow	336.0	96.7%	52395.6	95.6%	156
11	1	LS_Knaus/Park	0.3	0.1%	16.2	0.0%	54
23	1	R__Knaus/Park	0.0	0.0%	52.6	0.1%	52621
35	1	ST_Knaus/Park	0.0	0.0%	36.7	0.1%	36689
PRECIPITATION			1.0	0.3%	28.8	0.1%	30
INTERNAL LOAD			0.0	0.0%	5211.1	9.5%	
TRIBUTARY INFLOW			6.1	1.7%	544.8	1.0%	90
ADVECTIVE INFLOW			340.5	98.0%	49003.8	89.4%	144
***TOTAL INFLOW			347.5	100.0%	54788.5	100.0%	158
GAUGED OUTFLOW			336.0	96.7%	52395.6	95.6%	156
ADVECTIVE OUTFLOW			10.3	2.9%	1598.5	2.9%	156
NET DIFFUSIVE OUTFLOW			0.0	0.0%	156.6	0.3%	
***TOTAL OUTFLOW			346.3	99.6%	54150.8	98.8%	156
***EVAPORATION			1.2	0.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	637.7	1.2%	

D.26 Knaus Lake Loading Capacity Model

Table 96. Loading capacity scenario BATHTUB model diagnostics (model results) for Knaus Lake

Segment:	7	Knaus/Park				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	90.0	0.09	75.8%	155.8	1.20	90.5%

Table 97. Loading capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Knaus Lake

Component:	TOTAL P			Segment:	7	Knaus/Park	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
3	1	Kinzer Creek	5.8	1.7%	439.3	1.4%	76
4	4	SRCL Outflow	336.0	96.7%	30253.9	95.7%	90
11	1	LS_Knaus/Park	0.3	0.1%	16.2	0.1%	54
23	1	R__Knaus/Park	0.0	0.0%	52.6	0.2%	52621
35	1	ST_Knaus/Park	0.0	0.0%	36.7	0.1%	36689
PRECIPITATION			1.0	0.3%	28.8	0.1%	30
INTERNAL LOAD			0.0	0.0%	436.9	1.4%	
TRIBUTARY INFLOW			6.1	1.7%	544.8	1.7%	90
ADVECTIVE INFLOW			340.5	98.0%	30601.8	96.8%	90
***TOTAL INFLOW			347.5	100.0%	31612.2	100.0%	91
GAUGED OUTFLOW			336.0	96.7%	30253.9	95.7%	90
ADVECTIVE OUTFLOW			10.3	2.9%	923.0	2.9%	90
NET DIFFUSIVE OUTFLOW			0.0	0.0%	67.1	0.2%	
***TOTAL OUTFLOW			346.3	99.6%	31244.0	98.8%	90
***EVAPORATION			1.2	0.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	368.2	1.2%	
Hyd. Residence Time =			0.0038	yrs			
Overflow Rate =			405.3	m/yr			
Mean Depth =			1.5	m			

D.27 Knaus Lake TMDL Model

For Knaus Lake the load capacity, TMDL scenarios, and comprehensive TMDL scenario for the SRCL are the same.

D.28 Horseshoe Lake South Calibrated Model

Table 98. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Horseshoe Lake South

Segment:	10	HS South				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	112.6	0.11	82.9%	112.6	1.20	82.9%

Table 99. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake South

Component:		TOTAL P		Segment:	10	HS South	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
14	1	LS_HS South	0.0	0.1%	0.9	0.0%	54
26	1	R__HS South	0.0	0.0%	15.9	0.6%	15939
38	1	ST_HS South	0.0	0.0%	60.4	2.2%	60401
41	1	Inflow from Long	18.4	92.7%	1654.2	61.0%	90
PRECIPITATION			1.4	7.2%	42.7	1.6%	30
INTERNAL LOAD			0.0	0.0%	454.5	16.8%	
TRIBUTARY INFLOW			18.4	92.8%	1731.4	63.9%	94
NET DIFFUSIVE INFLOW			0.0	0.0%	481.4	17.8%	
***TOTAL INFLOW			19.8	100.0%	2710.1	100.0%	137
ADVECTIVE OUTFLOW			18.0	90.7%	2025.7	74.7%	113
***TOTAL OUTFLOW			18.0	90.7%	2025.7	74.7%	113
***EVAPORATION			1.9	9.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	684.4	25.3%	

D.29 Horseshoe Lake South Loading Capacity Model

Table 100. Loading capacity scenario BATHTUB model diagnostics (model results) for Horseshoe Lake South

Segment:	10	HS South				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	55.0	0.10	56.1%	112.6	1.20	82.9%

Table 101. Loading capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake South

Component:		TOTAL P		Segment:	10	HS South	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
14	1	LS_HS South	0.0	0.1%	0.9	0.1%	54
26	1	R__HS South	0.0	0.0%	15.9	1.2%	15939
38	1	ST_HS South	0.0	0.0%	60.4	4.6%	60401
41	1	Inflow from Long	18.4	92.7%	736.0	55.6%	40
PRECIPITATION			1.4	7.2%	42.7	3.2%	30
INTERNAL LOAD			0.0	0.0%	132.2	10.0%	
TRIBUTARY INFLOW			18.4	92.8%	813.3	61.4%	44
NET DIFFUSIVE INFLOW			0.0	0.0%	335.3	25.3%	
***TOTAL INFLOW			19.8	100.0%	1323.5	100.0%	67
ADVECTIVE OUTFLOW			18.0	90.7%	989.3	74.7%	55
***TOTAL OUTFLOW			18.0	90.7%	989.3	74.7%	55
***EVAPORATION			1.9	9.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	334.2	25.3%	
Hyd. Residence Time =			0.2483	yrs			
Overflow Rate =			14.2	m/yr			
Mean Depth =			3.5	m			

D.30 Horseshoe Lake South TMDL Model

For Horseshoe Lake South the Load capacity and TMDL scenarios are the same. In the TMDL (Table 27), the lakeshed load (‘LS_HSSouth’ + ‘R_HSSouth’ + ‘ST_HSSouth’) was further reduced to 153 lb/yr (69.4 kg/yr) and the internal load was further reduced to 171.9 lb/yr (78.0 kg/yr) to include a 5% MOS.

D.31 Horseshoe Lake South, Comprehensive TMDL Scenario (SRCL)

For Horseshoe Lake South, the diffusive inflow is reduced by 14.8 kg/yr (32.6 lb/yr) compared to the TMDL model when the Sauk River inflow concentration is lowered to 100 ppb. This allows Horseshoe Lake South to meet the water quality goal (55 ppb) with a lower % reduction to the internal/residual load compared to the TMDL scenario.

Table 102. Chain of Lakes comprehensive TMDL scenario BATHTUB model diagnostics (model results) for Horseshoe Lake South

	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	55.0	0.09	56.1%	112.6	1.20	82.9%

Table 103. Chain of Lakes comprehensive TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake South

Component:		TOTAL P		Segment:	10	HS South	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
14	1	LS_HS South	0.0	0.1%	0.9	0.1%	54
26	1	R__HS South	0.0	0.0%	15.9	1.2%	15939
38	1	ST_HS South	0.0	0.0%	60.4	4.6%	60401
41	1	Inflow from Long	18.4	92.7%	736.0	55.5%	40
PRECIPITATION			1.4	7.2%	42.7	3.2%	30
INTERNAL LOAD			0.0	0.0%	148.4	11.2%	
TRIBUTARY INFLOW			18.4	92.8%	813.3	61.4%	44
NET DIFFUSIVE INFLOW			0.0	0.0%	320.5	24.2%	
***TOTAL INFLOW			19.8	100.0%	1325.0	100.0%	67
ADVECTIVE OUTFLOW			18.0	90.7%	990.4	74.7%	55
***TOTAL OUTFLOW			18.0	90.7%	990.4	74.7%	55
***EVAPORATION			1.9	9.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	334.6	25.3%	
Hyd. Residence Time =			0.2483	yrs			
Overflow Rate =			14.2	m/yr			
Mean Depth =			3.5	m			

D.32 Horseshoe Lake West Calibrated Model

Table 104. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Horseshoe Lake West

Segment:	9	HS West				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	59.0	0.26	59.1%	59.0	1.20	59.2%

Table 105. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake West

Component:		TOTAL P		Segment:	9	HS West	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
13	1	LS_HS West	0.8	40.6%	42.4	11.9%	54
25	1	R__HS West	0.0	0.1%	33.3	9.3%	33297
37	1	ST_HS West	0.0	0.1%	48.3	13.5%	48321
PRECIPITATION			1.1	59.3%	34.2	9.6%	30
TRIBUTARY INFLOW			0.8	40.7%	124.0	34.7%	158
NET DIFFUSIVE INFLOW			0.0	0.0%	198.8	55.7%	
***TOTAL INFLOW			1.9	100.0%	357.0	100.0%	186
ADVECTIVE OUTFLOW			0.4	22.9%	26.0	7.3%	59
***TOTAL OUTFLOW			0.4	22.9%	26.0	7.3%	59
***EVAPORATION			1.5	77.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	331.0	92.7%	
Hyd. Residence Time =			13.5284	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			5.9	m			

D.33 Horseshoe Lake West Loading Capacity Model

Table 106. Loading Capacity BATHTUB model diagnostics (model results) for Horseshoe Lake West

Segment:	9	HS West				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
CONSERVATIVE SUB	27019.0	0.04		27019.0	0.04	
TOTAL P MG/M3	55.0	0.18	56.1%	59.0	1.20	59.2%

Table 107. Loading Capacity BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake West

Component:		TOTAL P		Segment:	9	HS West	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
14	1	LS_HS West	0.8	40.6%	42.4	12.8%	54
27	1	R__HS West	0.0	0.1%	33.3	10.0%	33297
40	1	ST_HS West	0.0	0.1%	51.5	15.5%	51540
PRECIPITATION			1.1	59.3%	34.2	10.3%	30
INTERNAL LOAD			0.0	0.0%	103.9	31.3%	
TRIBUTARY INFLOW			0.8	40.7%	127.2	38.3%	163
NET DIFFUSIVE INFLOW			0.0	0.0%	67.0	20.2%	
***TOTAL INFLOW			1.9	100.0%	332.4	100.0%	173
ADVECTIVE OUTFLOW			0.4	22.9%	24.2	7.3%	55
***TOTAL OUTFLOW			0.4	22.9%	24.2	7.3%	55
***EVAPORATION			1.5	77.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	308.1	92.7%	
Hyd. Residence Time =			13.5284	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			5.9	m			

D.34 Horseshoe Lake West TMDL Model

Table 108. TMDL scenario BATHTUB model diagnostics (model results) for Horseshoe Lake West

Segment:	9	HS West				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	41.4	0.22	43.5%	59.0	1.20	59.2%

Table 109. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Horseshoe Lake West

Component:		TOTAL P		Segment:	9	HS West	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
13	1	LS_HS West	0.8	40.6%	42.4	17.0%	54
25	1	R__HS West	0.0	0.1%	33.3	13.3%	33297
37	1	ST_HS West	0.0	0.1%	48.3	19.3%	48321
PRECIPITATION			1.1	59.3%	34.2	13.7%	30
TRIBUTARY INFLOW			0.8	40.7%	124.0	49.6%	158
NET DIFFUSIVE INFLOW			0.0	0.0%	91.6	36.7%	
***TOTAL INFLOW			1.9	100.0%	249.8	100.0%	130
ADVECTIVE OUTFLOW			0.4	22.9%	18.2	7.3%	41
***TOTAL OUTFLOW			0.4	22.9%	18.2	7.3%	41
***EVAPORATION			1.5	77.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	231.6	92.7%	
Hyd. Residence Time =			13.5284	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			5.9	m			

D.35 Horseshoe Lake West, Comprehensive TMDL Scenario (SRCL)

For Horseshoe Lake West there is no difference between the TMDL model and the comprehensive TMDL scenario for the SRCL.

D.36 Cedar Island–Main Lake Calibrated Model

Table 110. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Cedar Island–Main Lake

Segment:	11	Cedar				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	82.9	0.17	72.9%	82.8	0.80	72.8%

Table 111. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Cedar Island–Main Lake

Component:		TOTAL P		Segment:	11	Cedar	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
15	1	LS_Cedar	5.3	69.7%	287.0	24.1%	54
27	1	R__Cedar	0.0	0.0%	31.3	2.6%	31253
39	1	ST_Cedar	0.0	0.0%	81.3	6.8%	81252
PRECIPITATION			2.3	30.2%	68.8	5.8%	30
INTERNAL LOAD			0.0	0.0%	306.1	25.7%	
TRIBUTARY INFLOW			5.3	69.8%	399.6	33.5%	76
NET DIFFUSIVE INFLOW			0.0	0.0%	417.4	35.0%	
***TOTAL INFLOW			7.6	100.0%	1191.8	100.0%	157
ADVECTIVE OUTFLOW			4.6	60.7%	381.1	32.0%	83
***TOTAL OUTFLOW			4.6	60.7%	381.1	32.0%	83
***EVAPORATION			3.0	39.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	810.7	68.0%	
Hyd. Residence Time =			1.9295	yrs			
Overflow Rate =			2.3	m/yr			
Mean Depth =			4.3	m			

D.37 Cedar Island–Main Lake Loading Capacity Model

Table 112. Loading capacity scenario BATHTUB model diagnostics (model results) for Cedar Island–Main Lake

Segment:	**11**	**Cedar**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	55.0	0.18	56.1%	82.8	0.80	72.8%

Table 113. Loading capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Cedar Island–Main Lake

Component:		**TOTAL P**		**Segment:**	**11**	**Cedar**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
15	1	LS_Cedar	5.3	69.7%	274.9	34.7%	52
27	1	R__Cedar	0.0	0.0%	31.3	4.0%	31325
39	1	ST_Cedar	0.0	0.0%	81.3	10.3%	81252
PRECIPITATION			2.3	30.2%	68.8	8.7%	30
TRIBUTARY INFLOW			5.3	69.8%	387.4	49.0%	73
NET DIFFUSIVE INFLOW			0.0	0.0%	334.9	42.3%	
***TOTAL INFLOW			7.6	100.0%	791.2	100.0%	104
ADVECTIVE OUTFLOW			4.6	60.7%	253.0	32.0%	55
***TOTAL OUTFLOW			4.6	60.7%	253.0	32.0%	55
***EVAPORATION			3.0	39.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	538.2	68.0%	
Hyd. Residence Time =			1.9295	yrs			
Overflow Rate =			2.3	m/yr			
Mean Depth =			4.3	m			

D.38 Cedar Island–Main Lake TMDL Model

For Cedar Island-Main Lake the load capacity and TMDL scenarios are the same. In the TMDL (Table 27), the lakeshed load (‘LS_Cedar’ + ‘R_Cedar’ + ‘ST_Cedar’) was further reduced to 681.1 lb/yr (308.9 kg/yr) while the internal load was reduced to only 85.3 lb/yr (38.7) to include a 5% MOS.

D.39 Cedar Island–Main Lake, Comprehensive TMDL Scenario (SRCL)

For Cedar Island-Main Lake, the diffusive inflow is reduced by 193.2 kg/yr (425.9 lb/yr) compared to the TMDL model when the Sauk River inflow concentration is lowered to 100 ppb. This allows Cedar Island-Main Lake to meet the water quality goal (55 ppb) with a lower % reduction to the internal/residual load compared to the TMDL scenario.

Table 114. Chain of Lakes comprehensive TMDL scenario BATHTUB model diagnostics (model results) for Cedar Island-Main Lake

Segment:	11	Cedar				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	55.0	0.15	56.1%	82.8	0.80	72.8%

Table 115. Chain of Lakes comprehensive TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Cedar Island–Main Lake

Component:		TOTAL P		Segment:	11	Cedar	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
15	1	LS_Cedar	5.3	69.7%	287.0	36.3%	54
27	1	R__Cedar	0.0	0.0%	31.3	4.0%	31253
39	1	ST_Cedar	0.0	0.0%	81.3	10.3%	81252
PRECIPITATION			2.3	30.2%	68.8	8.7%	30
INTERNAL LOAD			0.0	0.0%	180.7	22.8%	
TRIBUTARY INFLOW			5.3	69.8%	399.6	50.5%	76
NET DIFFUSIVE INFLOW			0.0	0.0%	141.7	17.9%	
***TOTAL INFLOW			7.6	100.0%	790.7	100.0%	104
ADVECTIVE OUTFLOW			4.6	60.7%	252.8	32.0%	55
***TOTAL OUTFLOW			4.6	60.7%	252.8	32.0%	55
***EVAPORATION			3.0	39.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	537.8	68.0%	
Hyd. Residence Time =			1.9295	yrs			
Overflow Rate =			2.3	m/yr			
Mean Depth =			4.3	m			

D.40 Bolfing Lake Calibrated Model

Table 116. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Bolfing Lake

Segment:	**12**	**Bolfung**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	74.1	0.23	68.6%	74.1	0.40	68.6%

Table 117. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Bolfing Lake

Component:		**TOTAL P**		**Segment:**	**12**	**Bolfung**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
16	1	LS_Bolfung	0.9	65.4%	50.1	19.7%	54
28	1	R__Bolfung	0.0	0.1%	11.5	4.5%	11484
40	1	ST_Bolfung	0.0	0.1%	20.9	8.2%	20862
PRECIPITATION			0.5	34.5%	14.6	5.7%	30
TRIBUTARY INFLOW			0.9	65.5%	82.4	32.5%	89
NET DIFFUSIVE INFLOW			0.0	0.0%	156.6	61.8%	
***TOTAL INFLOW			1.4	100.0%	253.6	100.0%	180
ADVECTIVE OUTFLOW			0.8	55.2%	57.7	22.8%	74
***TOTAL OUTFLOW			0.8	55.2%	57.7	22.8%	74
***EVAPORATION			0.6	44.8%	0.0	0.0%	
***RETENTION			0.0	0.0%	195.9	77.2%	
Hyd. Residence Time =			2.2407	yrs			
Overflow Rate =			1.8	m/yr			
Mean Depth =			4.0	m			

D.41 Bolfing Lake Loading Capacity Model

Table 118. Loading capacity scenario BATHTUB model diagnostics (model results) for Bolfing Lake

Segment:	12	Bolfung				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	55.0	0.18	56.1%	74.1	0.40	68.6%

Table 119. Loading Capacity scenario BATHTUB model segment balances (water and phosphorus budgets) for Bolfing Lake

Component:		TOTAL P		Segment:	12	Bolfung	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
16	1	LS_Bolfung	0.9	65.4%	50.1	26.6%	54
28	1	R__Bolfung	0.0	0.1%	11.5	6.1%	11484
40	1	ST_Bolfung	0.0	0.1%	20.9	11.1%	20862
PRECIPITATION			0.5	34.5%	14.6	7.7%	30
INTERNAL LOAD			0.0	0.0%	24.0	12.8%	
TRIBUTARY INFLOW			0.9	65.5%	82.4	43.8%	89
NET DIFFUSIVE INFLOW			0.0	0.0%	67.1	35.7%	
***TOTAL INFLOW			1.4	100.0%	188.2	100.0%	133
ADVECTIVE OUTFLOW			0.8	55.2%	42.8	22.8%	55
***TOTAL OUTFLOW			0.8	55.2%	42.8	22.8%	55
***EVAPORATION			0.6	44.8%	0.0	0.0%	
***RETENTION			0.0	0.0%	145.3	77.2%	
Hyd. Residence Time =			2.2407	yrs			
Overflow Rate =			1.8	m/yr			
Mean Depth =			4.0	m			

D.42 Bolfing Lake TMDL Model

Table 120. TMDL scenario BATHTUB model diagnostics (model results) for Bolfing Lake

Segment:	12	Bolfung				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	50.5	0.20	52.3%	74.1	0.40	68.6%

Table 121. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Bolfing Lake

Component:		TOTAL P		Segment:	12	Bolfung	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
16	1	LS_Bolfung	0.9	65.4%	50.1	29.0%	54
28	1	R__Bolfung	0.0	0.1%	11.5	6.7%	11484
40	1	ST_Bolfung	0.0	0.1%	20.9	12.1%	20862
PRECIPITATION			0.5	34.5%	14.6	8.4%	30
TRIBUTARY INFLOW			0.9	65.5%	82.4	47.7%	89
NET DIFFUSIVE INFLOW			0.0	0.0%	75.6	43.8%	
***TOTAL INFLOW			1.4	100.0%	172.7	100.0%	122
ADVECTIVE OUTFLOW			0.8	55.2%	39.3	22.8%	50
***TOTAL OUTFLOW			0.8	55.2%	39.3	22.8%	50
***EVAPORATION			0.6	44.8%	0.0	0.0%	
***RETENTION			0.0	0.0%	133.4	77.2%	
Hyd. Residence Time =			2.2407	yrs			
Overflow Rate =			1.8	m/yr			
Mean Depth =			4.0	m			

D.43 Bolfing Lake, Comprehensive TMDL Scenario (SRCL)

For Bolfing Lake there is no difference between the TMDL model and the comprehensive TMDL scenario for the SRCL.

APPENDIX E. SUPPORTING DATA FOR INDEPENDENT BATHTUB MODELS

BATHTUB modeling diagnostics (results) and segment balances (water and phosphorus budgets) are presented for both the calibrated (benchmark/existing) model and the TMDL scenario. In-lake water quality concentrations for the calibrated and TMDL scenarios were evaluated to the nearest tenth for TP. The tributary goal reported in the BATHTUB model output does not take into account the MOS, and is therefore larger than the loading goals listed in the individual lake TMDL and allocation tables in Section 4.1.8.

E.1 Schneider Lake Calibrated Model

Table 122. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Schneider Lake

Segment:	1	Schneider				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.5	0.16	60.2%	60.5	0.90	60.2%

Table 123. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Schneider Lake

Component:		TOTAL P		Segment:	1	Schneider	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Schneider Inflow	9.2	99.4%	732.3	90.8%	80
2	1	Schneider LS	0.1	0.6%	9.9	1.2%	169
3	1	Schneider ST	0.0	0.0%	51.5	6.4%	51540
PRECIPITATION			0.0	0.0%	7.4	0.9%	
INTERNAL LOAD			0.0	0.0%	5.6	0.7%	
TRIBUTARY INFLOW			9.3	100.0%	793.8	98.4%	86
***TOTAL INFLOW			9.3	100.0%	806.8	100.0%	87
ADVECTIVE OUTFLOW			9.3	100.0%	560.2	69.4%	60
***TOTAL OUTFLOW			9.3	100.0%	560.2	69.4%	60
***RETENTION			0.0	0.0%	246.7	30.6%	
Hyd. Residence Time =			0.1452	yrs			
Overflow Rate =			42.1	m/yr			
Mean Depth =			6.1	m			

E.2 Schneider Lake TMDL Model

Table 124. TMDL scenario BATHTUB model diagnostics (model results) for Schneider Lake

Segment:	**1**	**Schneider**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	40.0	0.14	42.0%	60.5	0.90	60.2%

Table 125. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Schneider Lake

Component:		**TOTAL P**		**Segment:**	**1**	**Schneider**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
1	1	Schneider Inflow	9.2	99.4%	446.2	89.1%	49
2	1	Schneider LS	0.1	0.6%	5.9	1.2%	100
3	1	Schneider ST	0.0	0.0%	41.5	8.3%	41531
PRECIPITATION			0.0	0.0%	7.4	1.5%	
TRIBUTARY INFLOW			9.3	100.0%	493.6	98.5%	53
***TOTAL INFLOW			9.3	100.0%	501.0	100.0%	54
ADVECTIVE OUTFLOW			9.3	100.0%	370.0	73.9%	40
***TOTAL OUTFLOW			9.3	100.0%	370.0	73.9%	40
***RETENTION			0.0	0.0%	131.0	26.1%	
Hyd. Residence Time =			0.1452	yrs			
Overflow Rate =			42.1	m/yr			
Mean Depth =			6.1	m			

E.3 Vails Lake Calibrated Model

Table 126. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Vails Lake

Segment:	1	Vails				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	177.8	0.19	92.7%	177.8	0.51	92.7%

Table 127. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Vails Lake

Component:		TOTAL P		Segment:	1	Vails	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Vails Direct Drainage	0.7	4.7%	154.4	3.6%	220
2	1	ST Vails	0.0	0.0%	4.4	0.1%	4433
3	1	HSPF 383	3.5	23.4%	666.2	15.7%	192
4	1	HSPF 385	9.9	67.2%	1990.0	47.0%	200
PRECIPITATION			0.7	4.6%	20.4	0.5%	30
INTERNAL LOAD			0.0	0.0%	1399.0	33.0%	
TRIBUTARY INFLOW			14.1	95.4%	2815.1	66.5%	199
***TOTAL INFLOW			14.8	100.0%	4234.5	100.0%	286
ADVECTIVE OUTFLOW			13.9	94.0%	2474.9	58.4%	178
***TOTAL OUTFLOW			13.9	94.0%	2474.9	58.4%	178
***EVAPORATION			0.9	6.0%	0.0	0.0%	
***RETENTION			0.0	0.0%	1759.6	41.6%	
Hyd. Residence Time =			0.1221	yrs			
Overflow Rate =			22.9	m/yr			
Mean Depth =			2.8	m			

E.4 Vails Lake TMDL Model

Table 128. TMDL scenario BATHTUB model diagnostics (model results) for Vails Lake

Segment:	**1**	**Vails**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	60.0	0.15	59.9%	177.8	0.51	92.7%

Table 129. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Vails Lake

Component:		**TOTAL P**		**Segment:**	**1**	**Vails**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Vails Direct Drainage	0.7	4.7%	87.8	7.5%	125
2	1	ST Vails	0.0	0.0%	4.4	0.4%	4433
3	1	HSPF 383	3.5	23.4%	272.4	23.4%	79
4	1	HSPF 385	9.9	67.2%	766.1	65.8%	77
PRECIPITATION			0.7	4.6%	20.4	1.8%	30
INTERNAL LOAD			0.0	0.0%	13.3	1.1%	
TRIBUTARY INFLOW			14.1	95.4%	1130.7	97.1%	80
***TOTAL INFLOW			14.8	100.0%	1164.5	100.0%	79
ADVECTIVE OUTFLOW			13.9	94.0%	835.6	71.8%	60
***TOTAL OUTFLOW			13.9	94.0%	835.6	71.8%	60
***EVAPORATION			0.9	6.0%	0.0	0.0%	
***RETENTION			0.0	0.0%	328.9	28.2%	
Hyd. Residence Time =			0.1221	yrs			
Overflow Rate =			22.9	m/yr			
Mean Depth =			2.8	m			

E.5 Eden Lake Calibrated Model

Table 130. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Eden Lake

Segment:	1	Eden				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	109.5	0.26	82.1%	109.5	0.49	82.1%

Table 131. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Eden Lake

Component:		TOTAL P		Segment:	1	Eden	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Eden Direct Drainage	1.0	6.0%	177.4	4.9%	186
2	1	ST Eden	0.0	0.0%	17.7	0.5%	17733
3	1	Eden Inlet	13.9	86.7%	2471.4	67.9%	178
PRECIPITATION			1.2	7.4%	35.4	1.0%	30
INTERNAL LOAD			0.0	0.0%	937.7	25.8%	
TRIBUTARY INFLOW			14.9	92.6%	2666.6	73.3%	179
***TOTAL INFLOW			16.0	100.0%	3639.7	100.0%	227
ADVECTIVE OUTFLOW			14.5	90.4%	1588.1	43.6%	110
***TOTAL OUTFLOW			14.5	90.4%	1588.1	43.6%	110
***EVAPORATION			1.5	9.6%	0.0	0.0%	
***RETENTION			0.0	0.0%	2051.7	56.4%	
Hyd. Residence Time =			0.4324	yrs			
Overflow Rate =			13.8	m/yr			
Mean Depth =			6.0	m			

E.6 Eden Lake TMDL Model

Table 132. TMDL scenario BATHTUB model diagnostics (model results) for Eden Lake

Segment:	1	Eden				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	40.0	0.20	42.1%	109.5	0.49	82.1%

Table 133. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Eden Lake

Component:		TOTAL P		Segment:	1	Eden	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Eden Direct Drainage	1.0	6.0%	76.4	7.7%	80
2	1	ST Eden	0.0	0.0%	17.7	1.8%	17733
3	1	Eden Inlet	13.9	86.7%	834.0	83.9%	60
PRECIPITATION			1.2	7.4%	35.4	3.6%	30
INTERNAL LOAD			0.0	0.0%	30.7	3.1%	
TRIBUTARY INFLOW			14.9	92.6%	928.1	93.3%	62
***TOTAL INFLOW			16.0	100.0%	994.3	100.0%	62
ADVECTIVE OUTFLOW			14.5	90.4%	580.4	58.4%	40
***TOTAL OUTFLOW			14.5	90.4%	580.4	58.4%	40
***EVAPORATION			1.5	9.6%	0.0	0.0%	
***RETENTION			0.0	0.0%	413.9	41.6%	
Hyd. Residence Time =			0.4324	yrs			
Overflow Rate =			13.8	m/yr			
Mean Depth =			6.0	m			

E.7 North Browns Lake Calibrated Model

Table 134. Calibrated (benchmark) BATHTUB model diagnostics (model results) for North Browns Lake

Segment:	1	NBrowns				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	155.8	0.28	90.5%	155.8		90.5%

Table 135. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for North Browns Lake

Component:		TOTAL P		Segment:	1	NBrowns	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	EV Creek	16.8	88.2%	2049.6	29.9%	122
2	1	NBrowns Direct Drainage	0.8	4.4%	158.0	2.3%	189
3	1	NBrowns Septic	0.0	0.0%	55.4	0.8%	55414
PRECIPITATION			1.4	7.4%	42.5	0.6%	30
INTERNAL LOAD			0.0	0.0%	4538.3	66.3%	
TRIBUTARY INFLOW			17.6	92.6%	2263.0	33.1%	128
***TOTAL INFLOW			19.1	100.0%	6843.8	100.0%	359
ADVECTIVE OUTFLOW			17.2	90.3%	2681.3	39.2%	156
***TOTAL OUTFLOW			17.2	90.3%	2681.3	39.2%	156
***EVAPORATION			1.8	9.7%	0.0	0.0%	
***RETENTION			0.0	0.0%	4162.5	60.8%	
Hyd. Residence Time =			0.4114	yrs			
Overflow Rate =			13.6	m/yr			
Mean Depth =			5.6	m			

E.8 North Browns Lake TMDL Model

Table 136. TMDL scenario BATHTUB model diagnostics (model results) for North Browns Lake

Segment:	1	NBrowns				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	40.0	0.29	42.0%	155.8		90.5%

Table 137. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for North Browns Lake

Component:		TOTAL P		Segment:	1	NBrowns	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	EV Creek	16.8	88.2%	915.6	78.6%	55
2	1	NBrowns Direct Drainage	0.8	4.4%	150.8	13.0%	180
3	1	NBrowns Septic	0.0	0.0%	55.4	4.8%	55414
PRECIPITATION			1.4	7.4%	42.5	3.7%	30
TRIBUTARY INFLOW			17.6	92.6%	1121.9	96.3%	64
***TOTAL INFLOW			19.1	100.0%	1164.4	100.0%	61
ADVECTIVE OUTFLOW			17.2	90.3%	689.1	59.2%	40
***TOTAL OUTFLOW			17.2	90.3%	689.1	59.2%	40
***EVAPORATION			1.8	9.7%	0.0	0.0%	
***RETENTION			0.0	0.0%	475.3	40.8%	
Hyd. Residence Time =			0.4114	yrs			
Overflow Rate =			13.6	m/yr			
Mean Depth =			5.6	m			

E.9 Long Lake Calibrated Model

Table 138. Calibrated (benchmark) BATHTUB model diagnostics (model results) for Long Lake

Segment:	13	Long				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	89.9	0.22	75.8%	89.9	0.50	75.8%

Table 139. Calibrated (benchmark) BATHTUB model segment balances (water and phosphorus budgets) for Long Lake

Component:		TOTAL P		Segment:	1	Long Lake	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Inflow from N.Browns	17.7	82.9%	2779.3	86.6%	157
2	1	LS_Long	1.4	6.7%	270.4	8.4%	189
3	1	ST_Long	0.0	0.0%	34.9	1.1%	34908
PRECIPITATION			2.2	10.4%	66.4	2.1%	30
INTERNAL LOAD			0.0	0.0%	57.6	1.8%	
TRIBUTARY INFLOW			19.1	89.6%	3084.6	96.1%	161
***TOTAL INFLOW			21.3	100.0%	3208.6	100.0%	150
ADVECTIVE OUTFLOW			18.4	86.5%	1657.4	51.7%	90
***TOTAL OUTFLOW			18.4	86.5%	1657.4	51.7%	90
***EVAPORATION			2.9	13.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	1551.2	48.3%	
Hyd. Residence Time =			0.3253	yrs			
Overflow Rate =			9.4	m/yr			
Mean Depth =			3.0	m			

E.10 Long Lake TMDL Model

Table 140. TMDL scenario BATHTUB model diagnostics (model results) for Long Lake

Segment:	**13**	**Long**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	40.0	0.17	42.1%	89.9	0.50	75.8%

Table 141. TMDL scenario BATHTUB model segment balances (water and phosphorus budgets) for Long Lake

Component:		**TOTAL P**		**Segment:**	**1**	**Long Lake**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
1	1	Inflow from N.Browns	17.7	82.9%	799.1	68.0%	45
2	1	LS_Long	1.4	6.7%	270.4	23.0%	189
3	1	ST_Long	0.0	0.0%	34.9	3.0%	34908
PRECIPITATION			2.2	10.4%	66.4	5.7%	30
INTERNAL LOAD			0.0	0.0%	3.6	0.3%	
TRIBUTARY INFLOW			19.1	89.6%	1104.5	94.0%	58
***TOTAL INFLOW			21.3	100.0%	1174.4	100.0%	55
ADVECTIVE OUTFLOW			18.4	86.5%	738.3	62.9%	40
***TOTAL OUTFLOW			18.4	86.5%	738.3	62.9%	40
***EVAPORATION			2.9	13.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	436.1	37.1%	
Hyd. Residence Time =			0.3253	yrs			
Overflow Rate =			9.4	m/yr			
Mean Depth =			3.0	m			

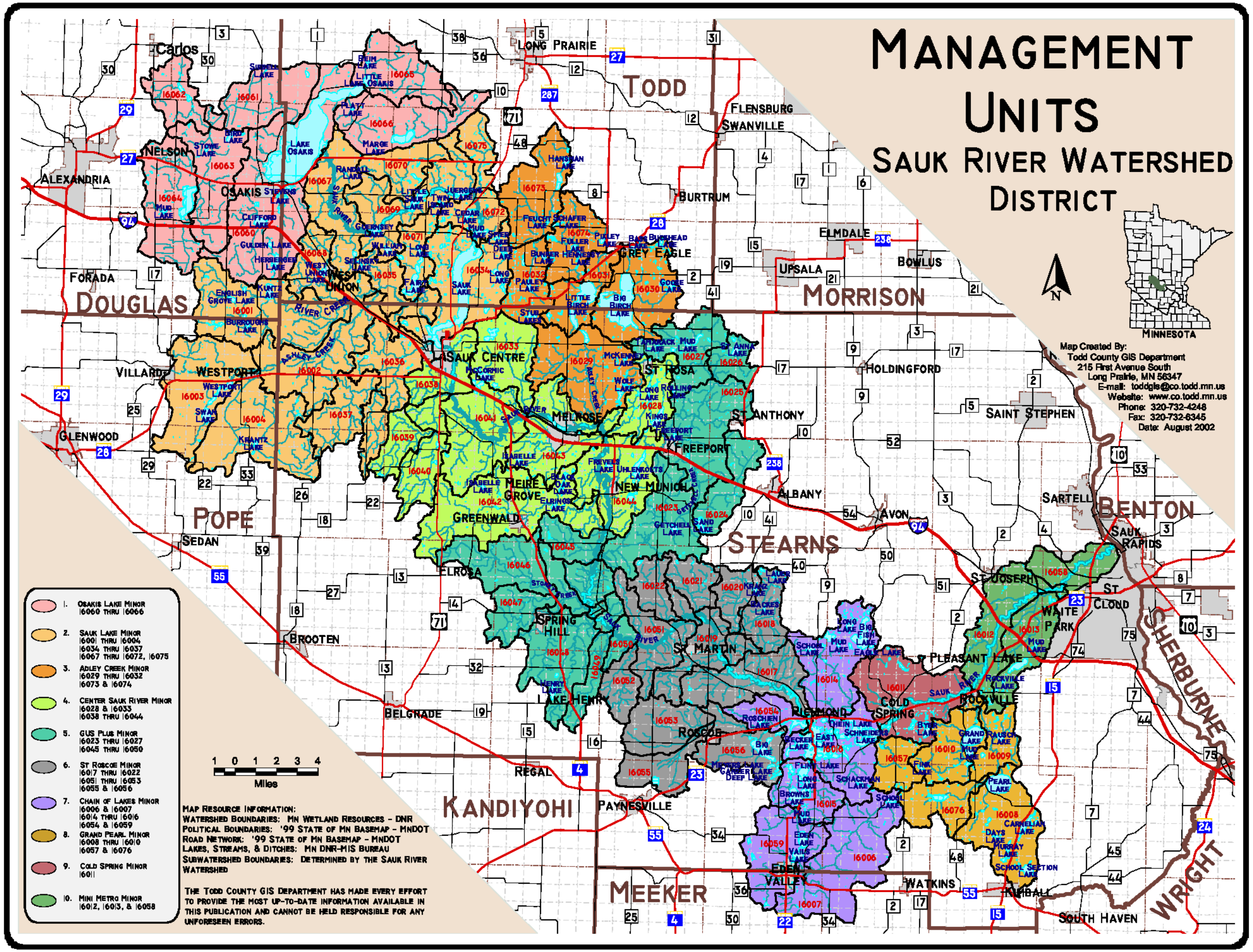
APPENDIX F. PHOSPHORUS LOADING FROM UPSTREAM IMPAIRED LAKES

Existing phosphorus loads from upstream impaired lakes were estimated using average annual flow volumes multiplied by the most recent 10-year GSM TP concentrations. Flow and water quality sources and dates are shown in Table 142 along with estimates of load reductions associated with improved water quality in impaired lakes located upstream of the SRCL.

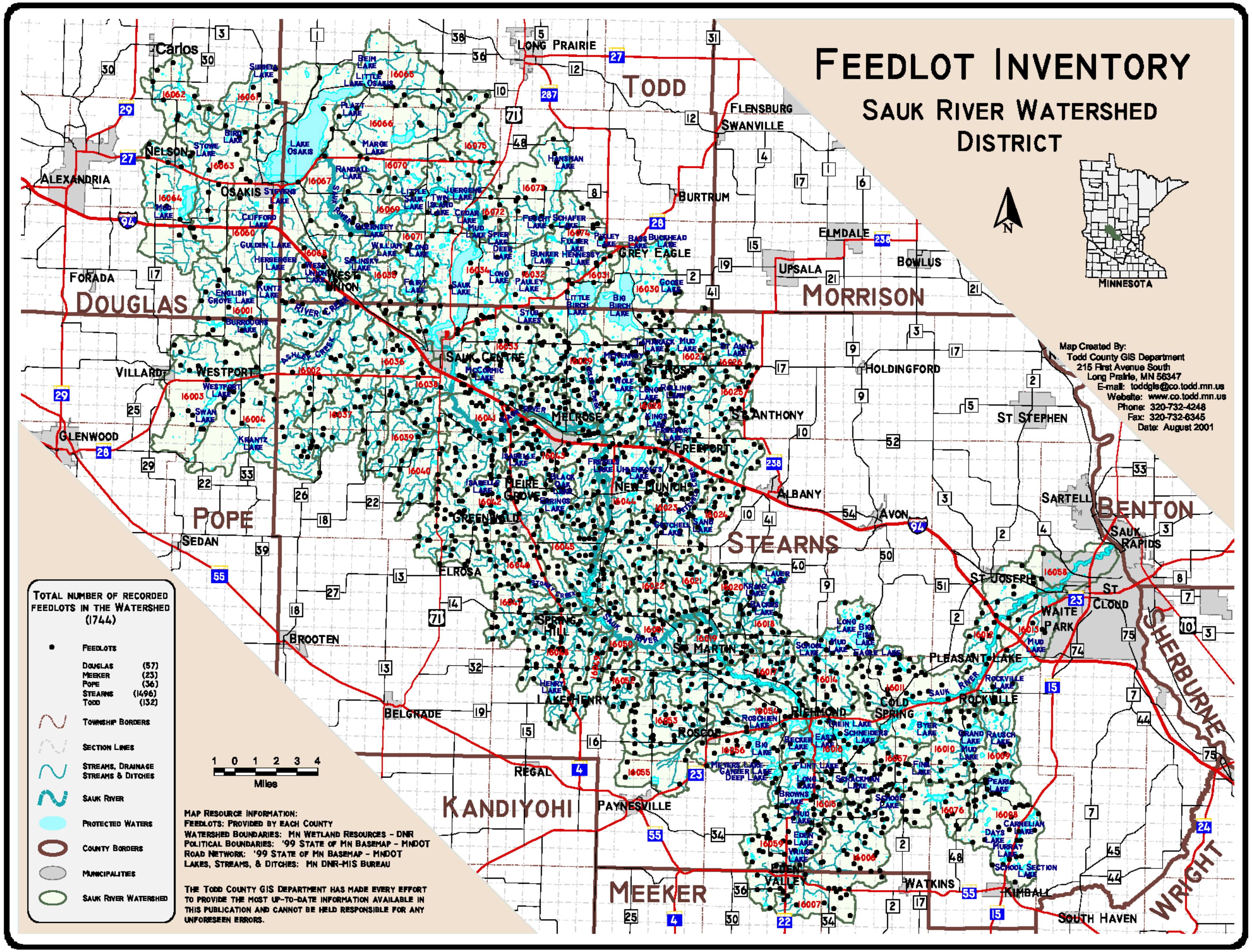
Table 142. Load reductions to the Sauk River from impaired lakes located up stream of the inlet to the SRCL.

Lake Name AUID	Water Quality Data Source	Flow Data Source	Current GSM Mean TP (mg/L)	Water Quality Standard (mg/L)	Annual Outflow Volume (ac-ft/yr)	Current Condition TP Outflow (lb/yr)	TMDL Goal TP Outflow (lb/yr)	Expected Load Reduction to the Sauk River (lb/yr)
Ellering 73-0244-00	EQuIS 2009-2010	HSPF 2000-2009	84	40	6,984	1595	760	835
Maria 73-0215-00	EQuIS 2002, 2003, 2005, 2007		109	40	319	95	35	60
McCormic Lake 73-0273-00	EQuIS 2003, 2008, 2009		80	60	113	24	18	6
Sauk Lake 77-0150-01	EQuIS 2007, 2008		136	40	105,132	38,863	11,436	12,441
Uhlenkolts 73-0208-00	EQuIS 2008, 2009, 2010		262	40	948	675	103	572
							TOTAL	13,914

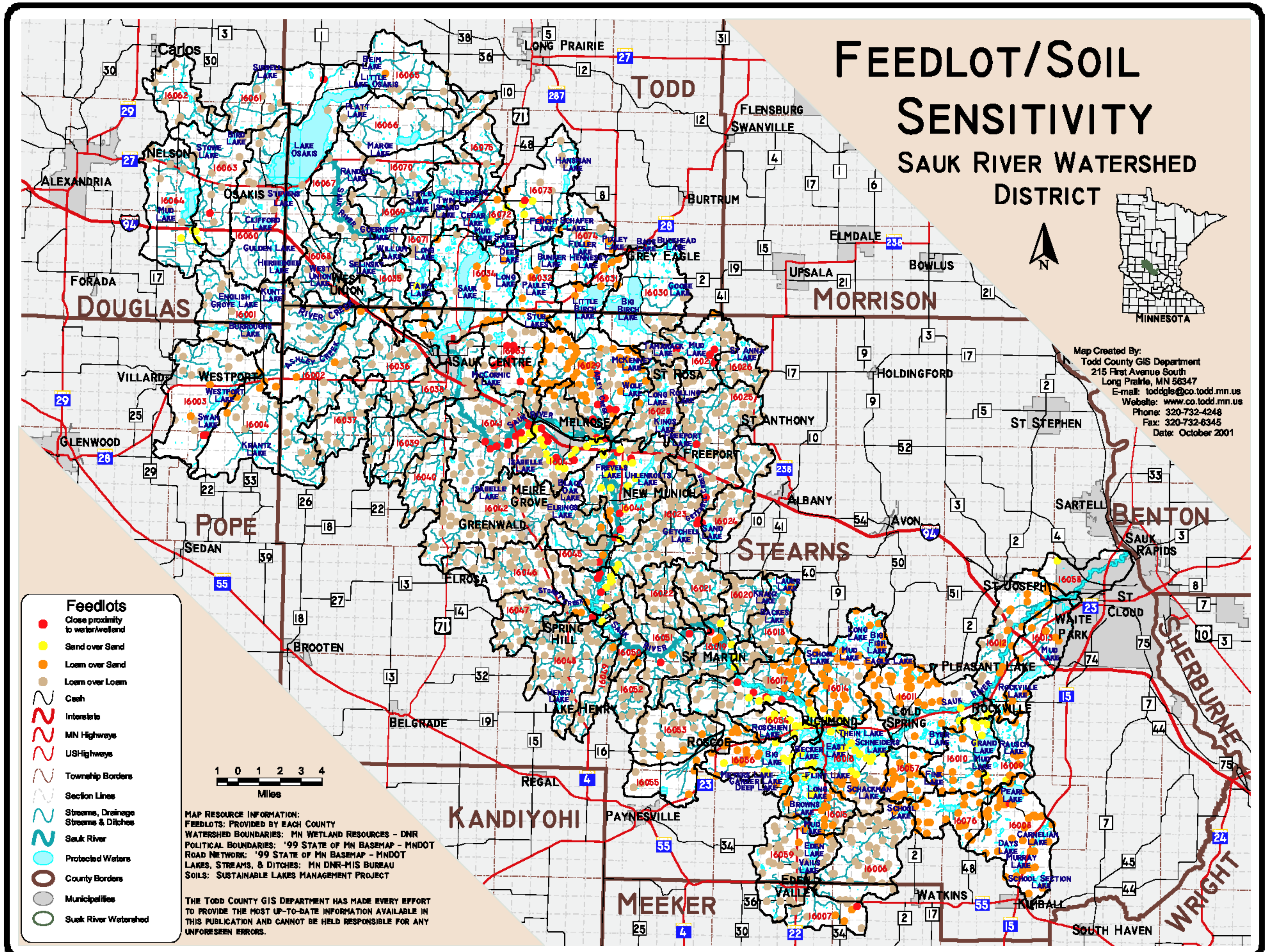
G.1 Sauk River Watershed Management Units



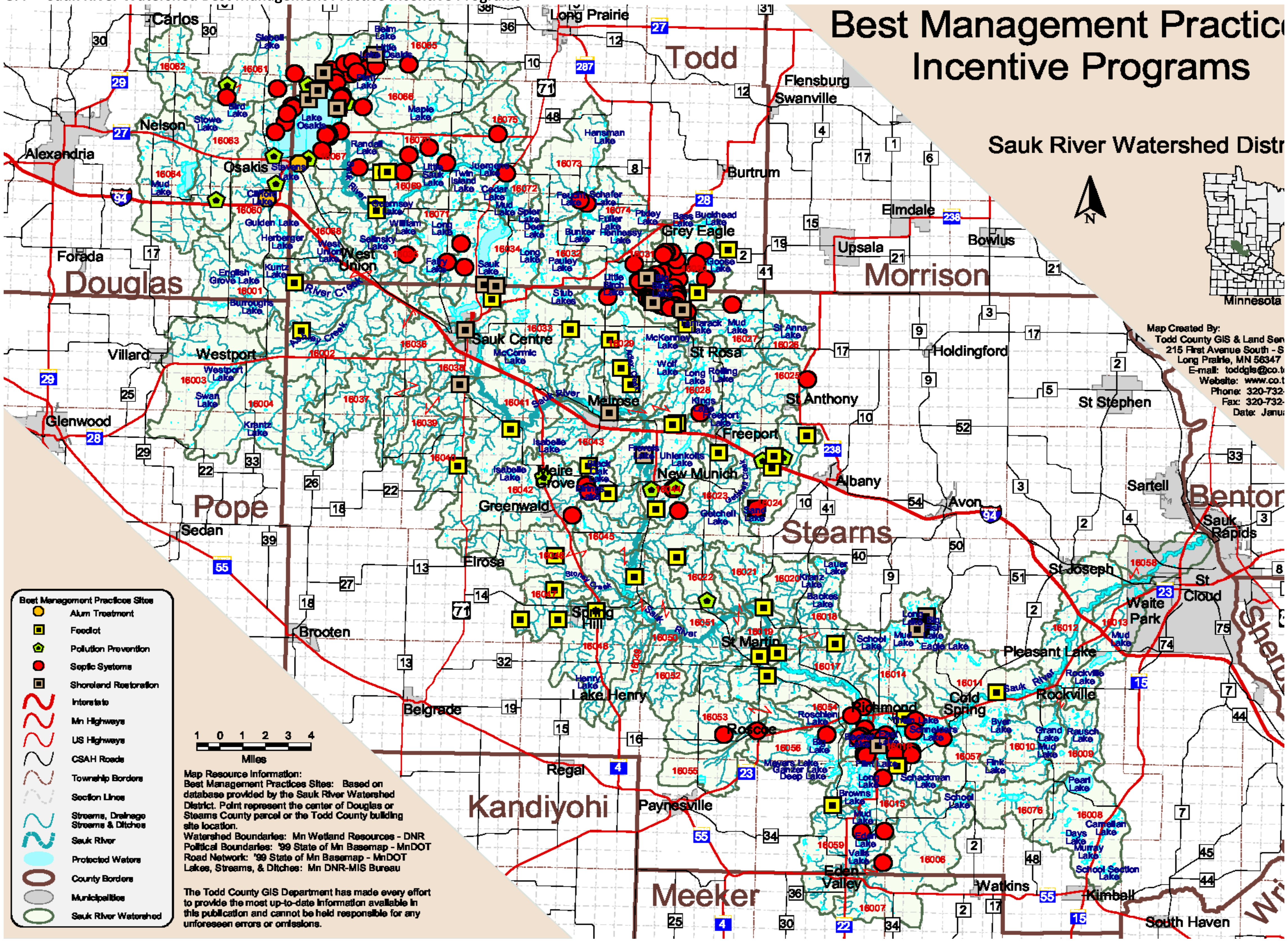
G.2 Sauk River Feedlot Inventory



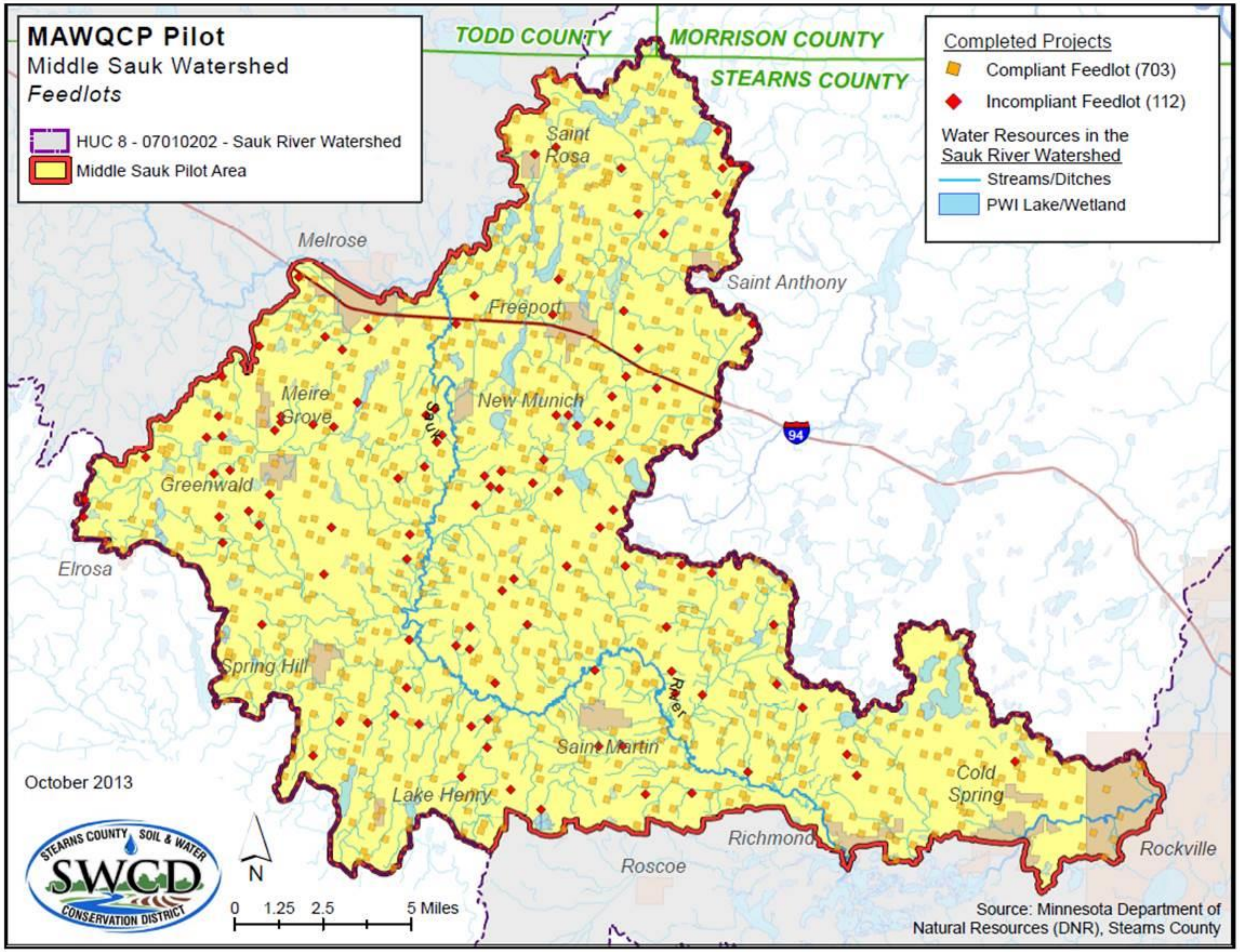
G.3 Sauk River Watershed Feedlot Soil/Sensitivity



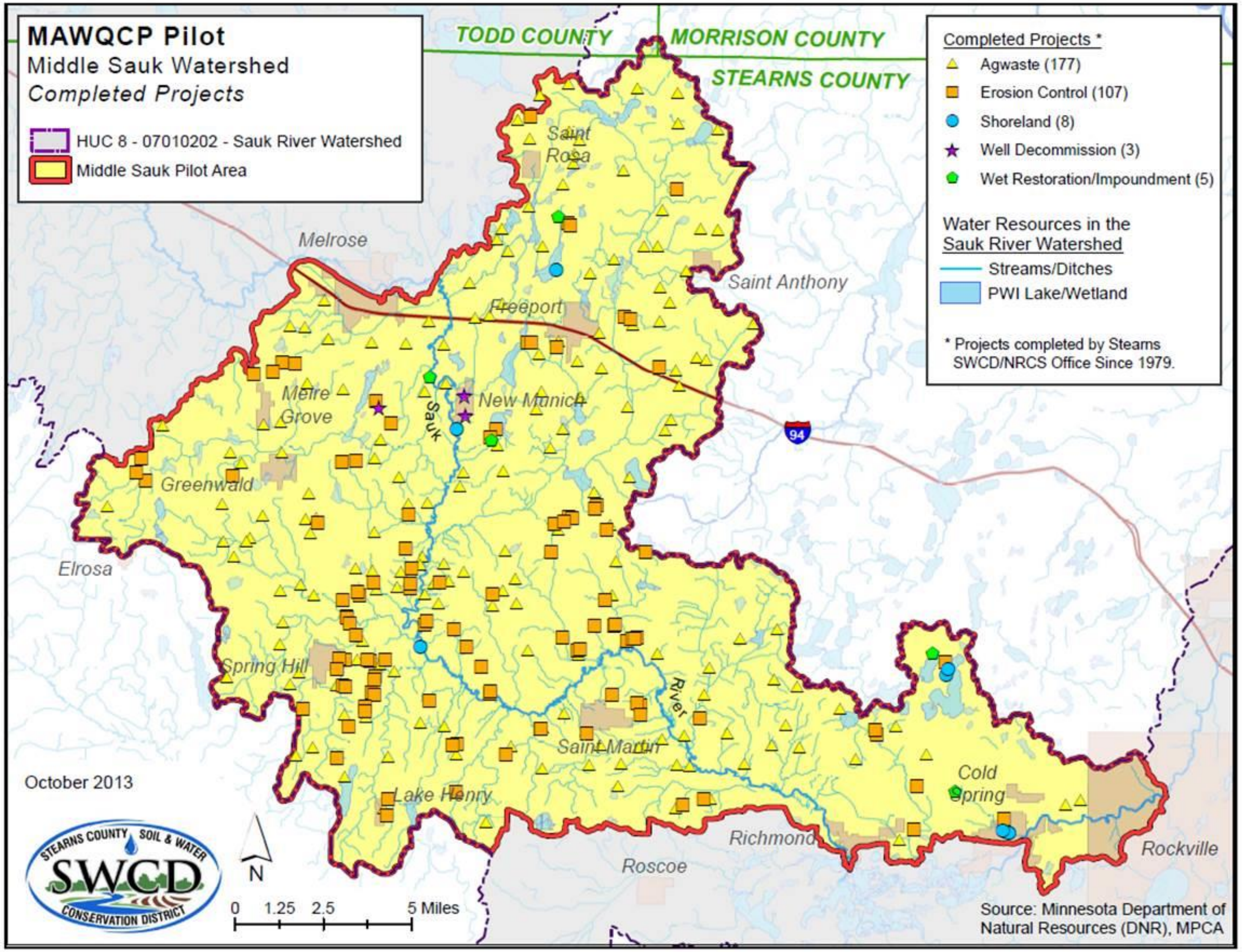
G.4 Sauk River Watershed Best Management Practice Incentive Programs



G.5 **Minnesota Department of Agriculture, Water Quality Certification Program, feedlot inventories**

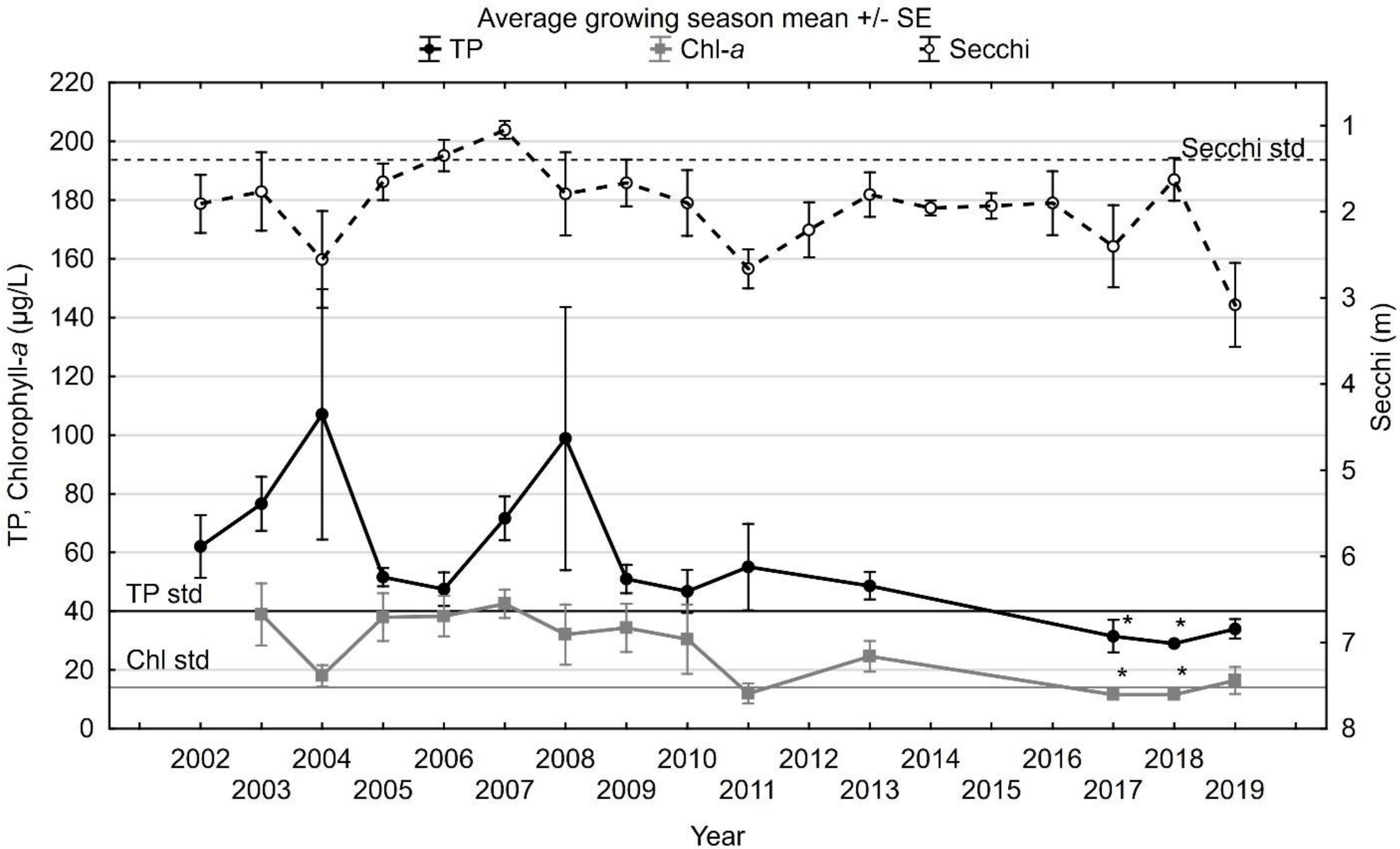


G.6 Minnesota Department of Agriculture, Water Quality Certification Program, BMP implementation inventory.



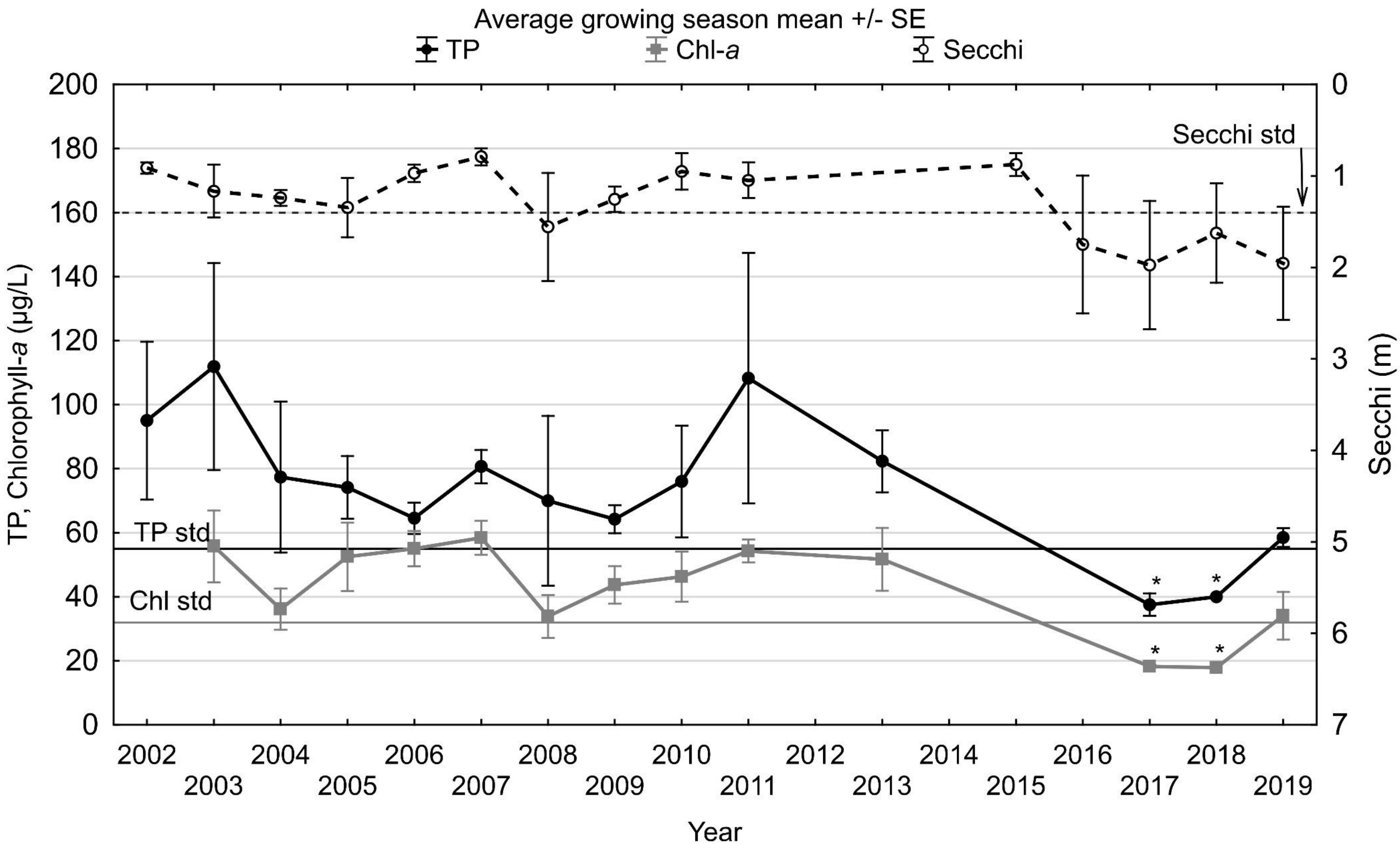
APPENDIX H. 2020 WATER QUALITY UPDATE

The following graphs present water quality data for select lakes that were evaluated in this TMDL report. Because of the time line of the report's review, a substantial amount of water quality data were collected on some of the impaired lakes after the TMDLs were developed and the report was written.

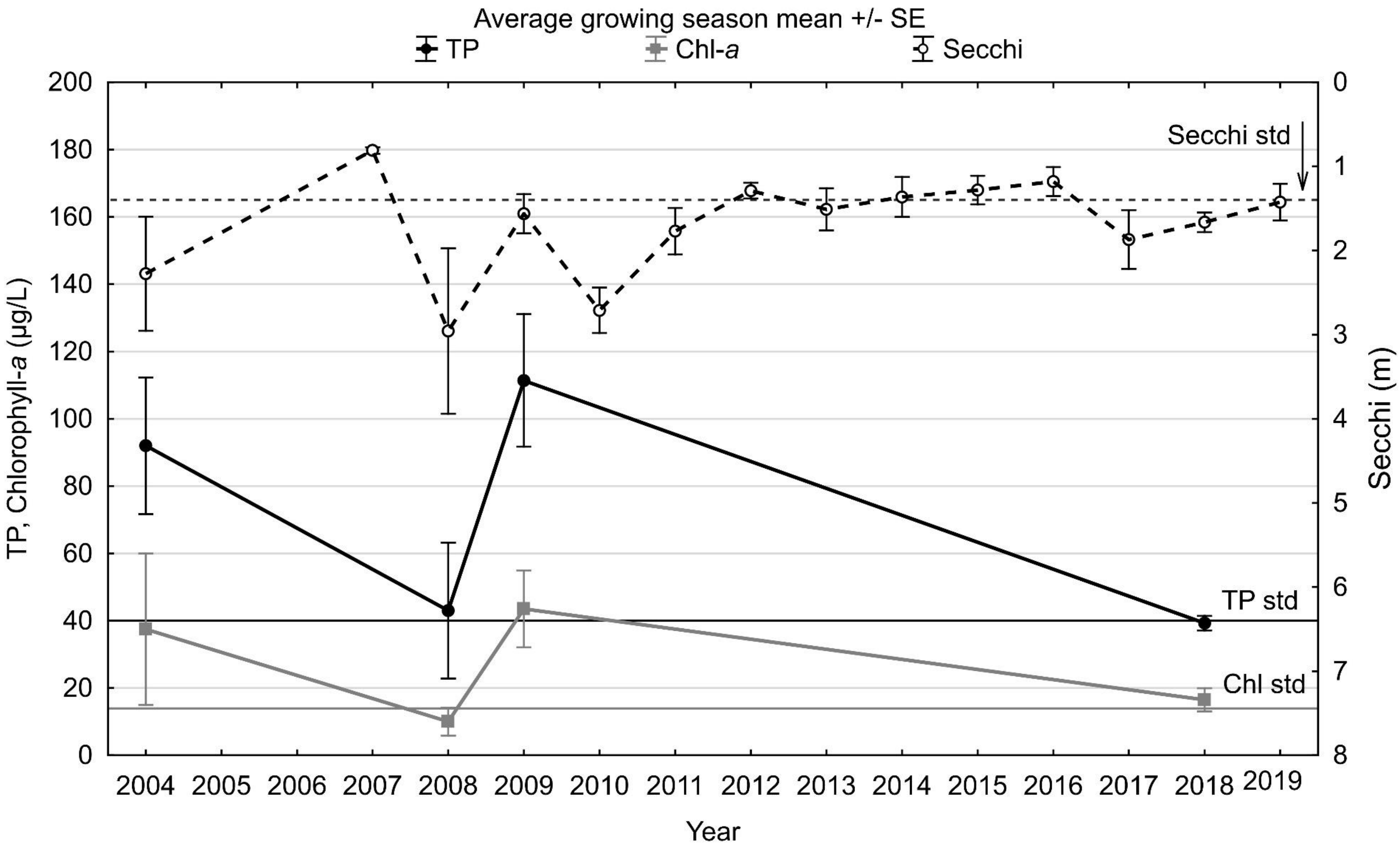


- Schneider Lake (site 73-0082-00-202)

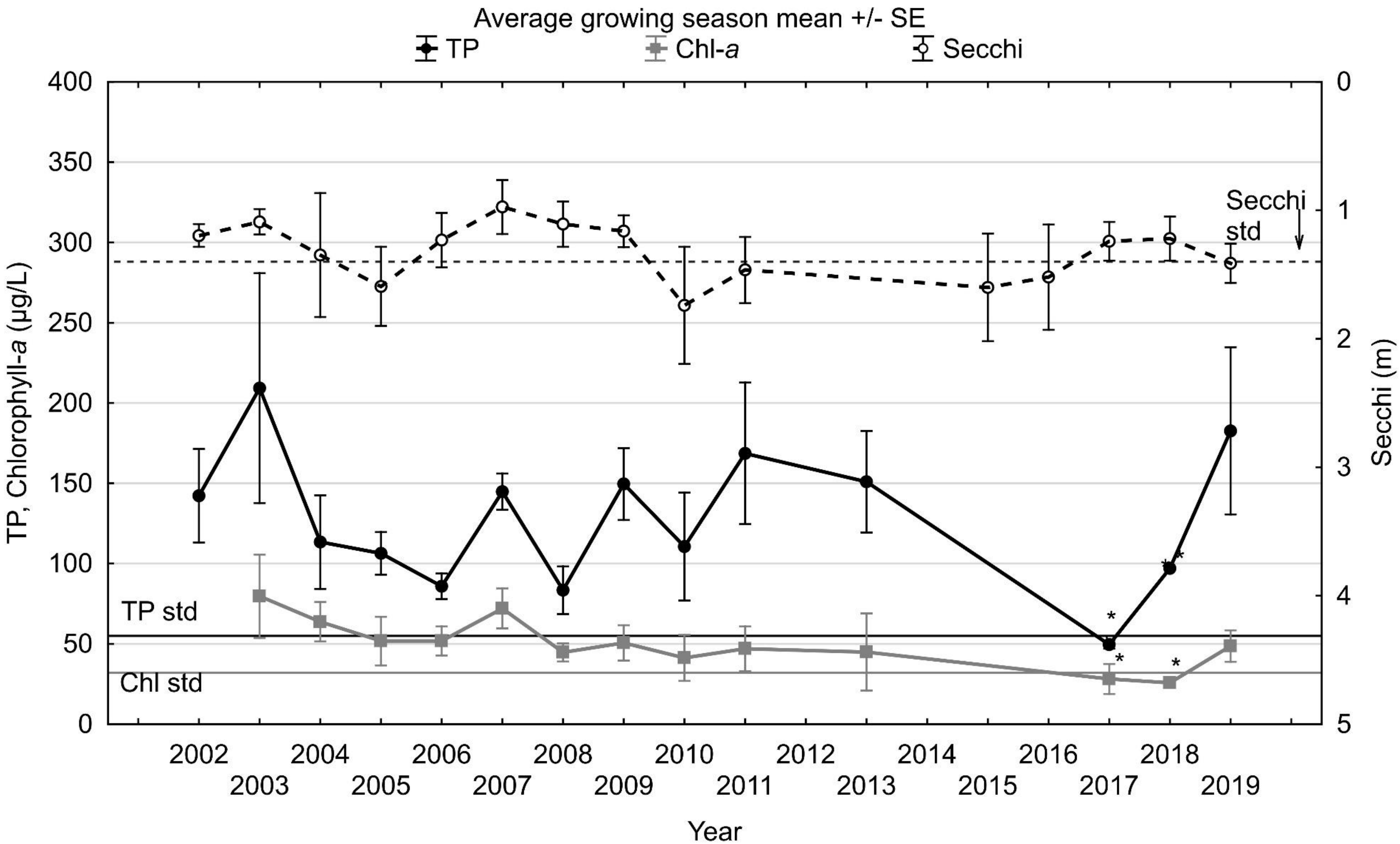
  * sample size < 3



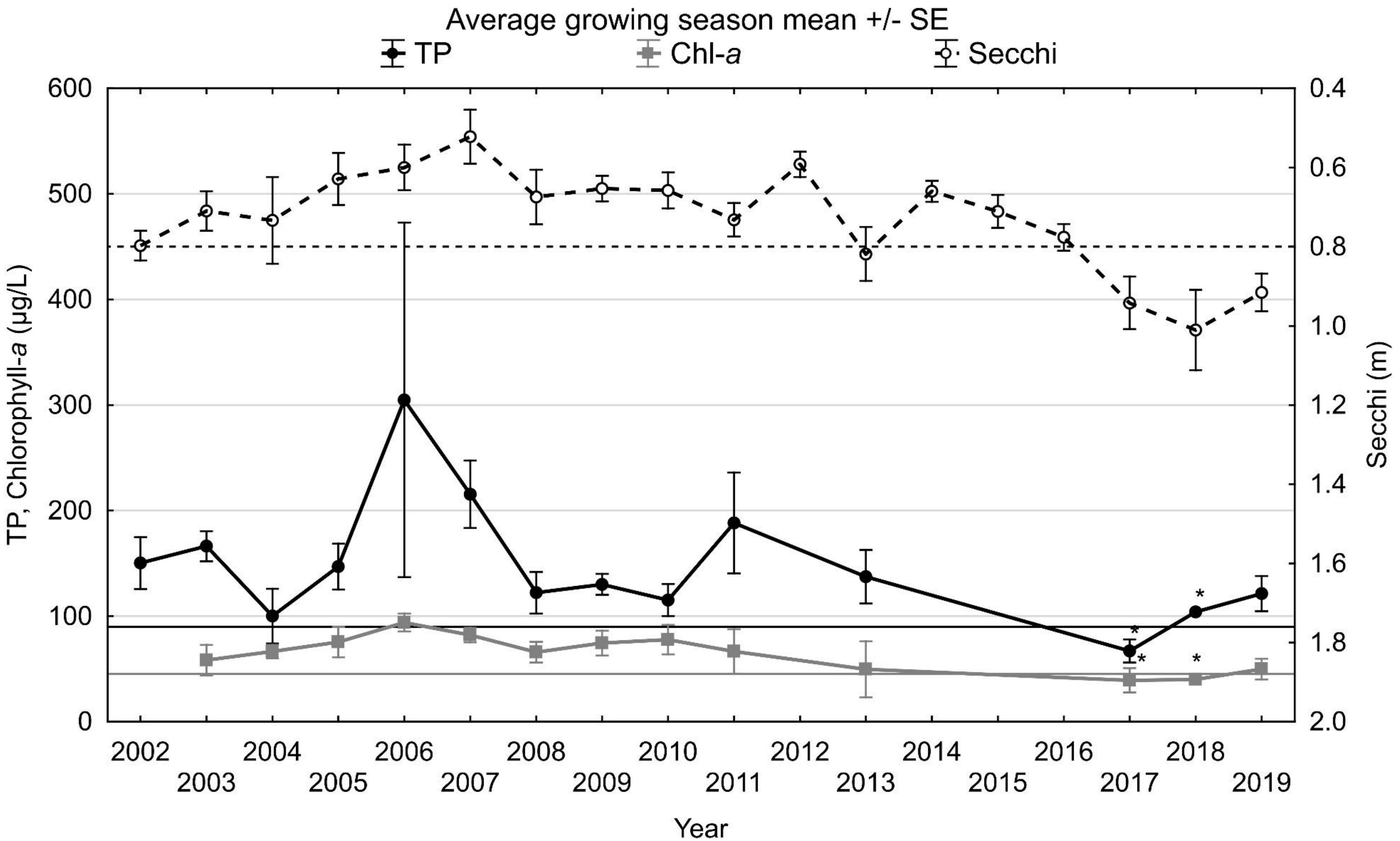
- Cedar Island (Main Bay): 73-0133-01-205



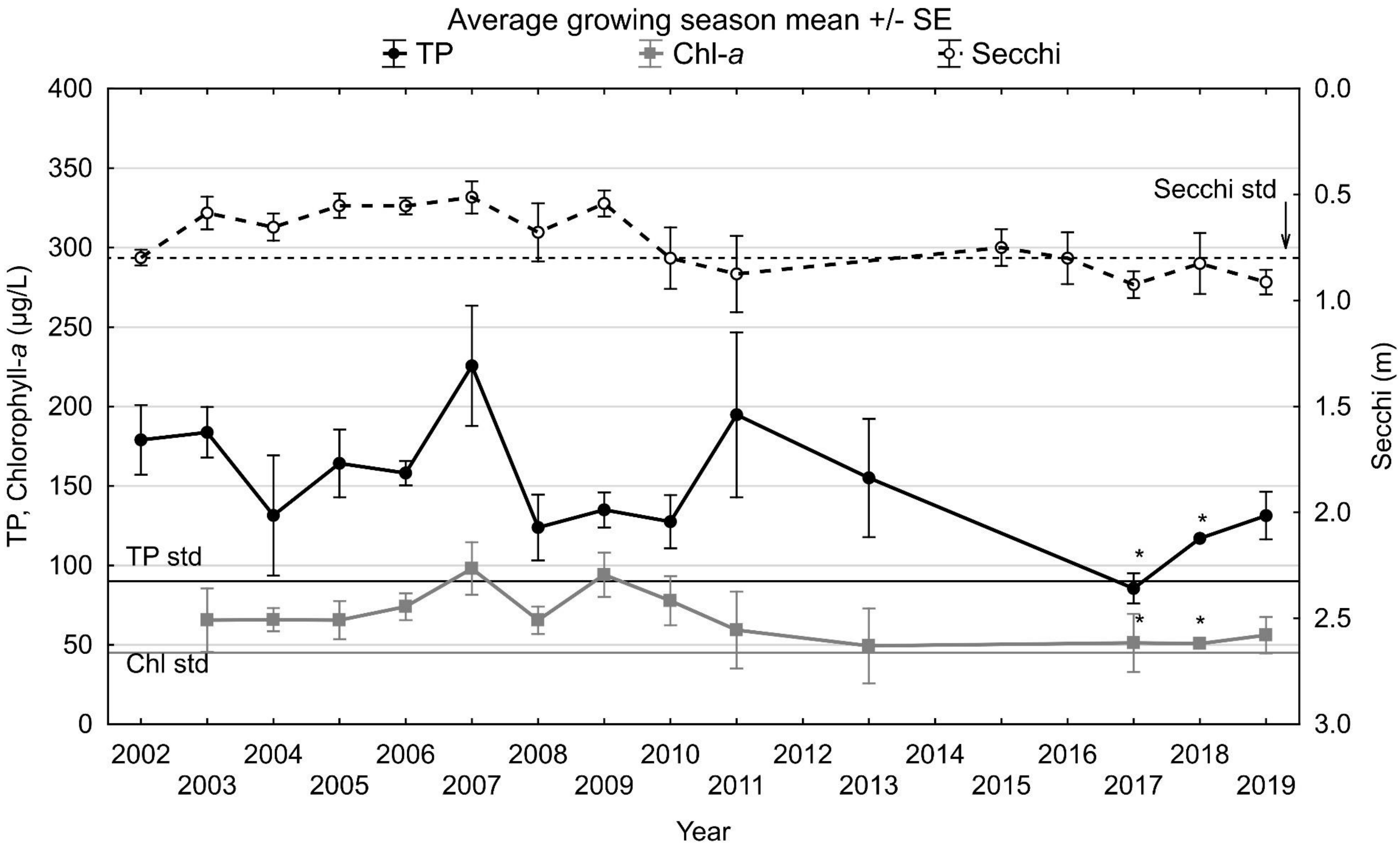
- Eden: 73-0150-00-203



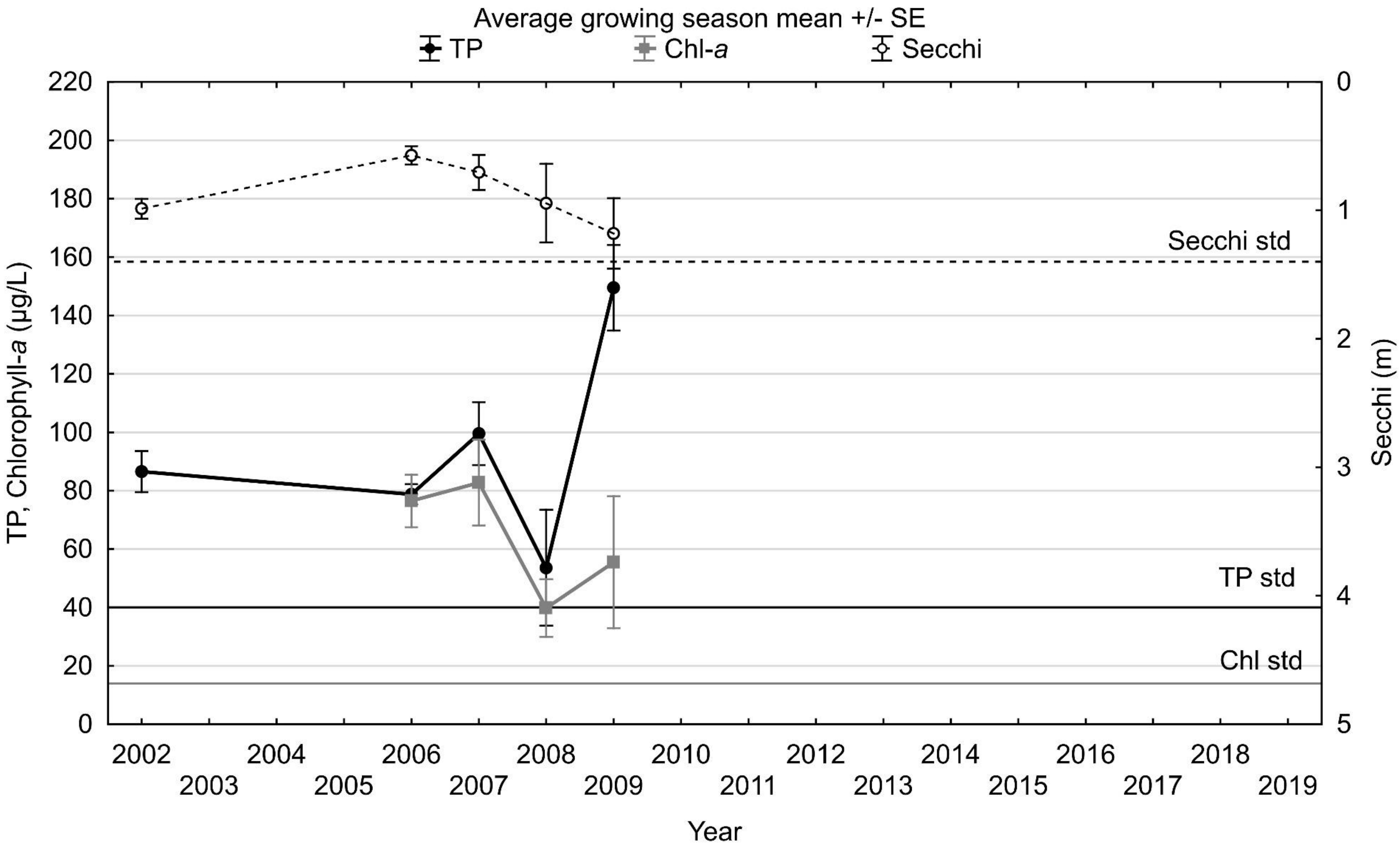
- Horseshoe (South): 73-0157-00-211



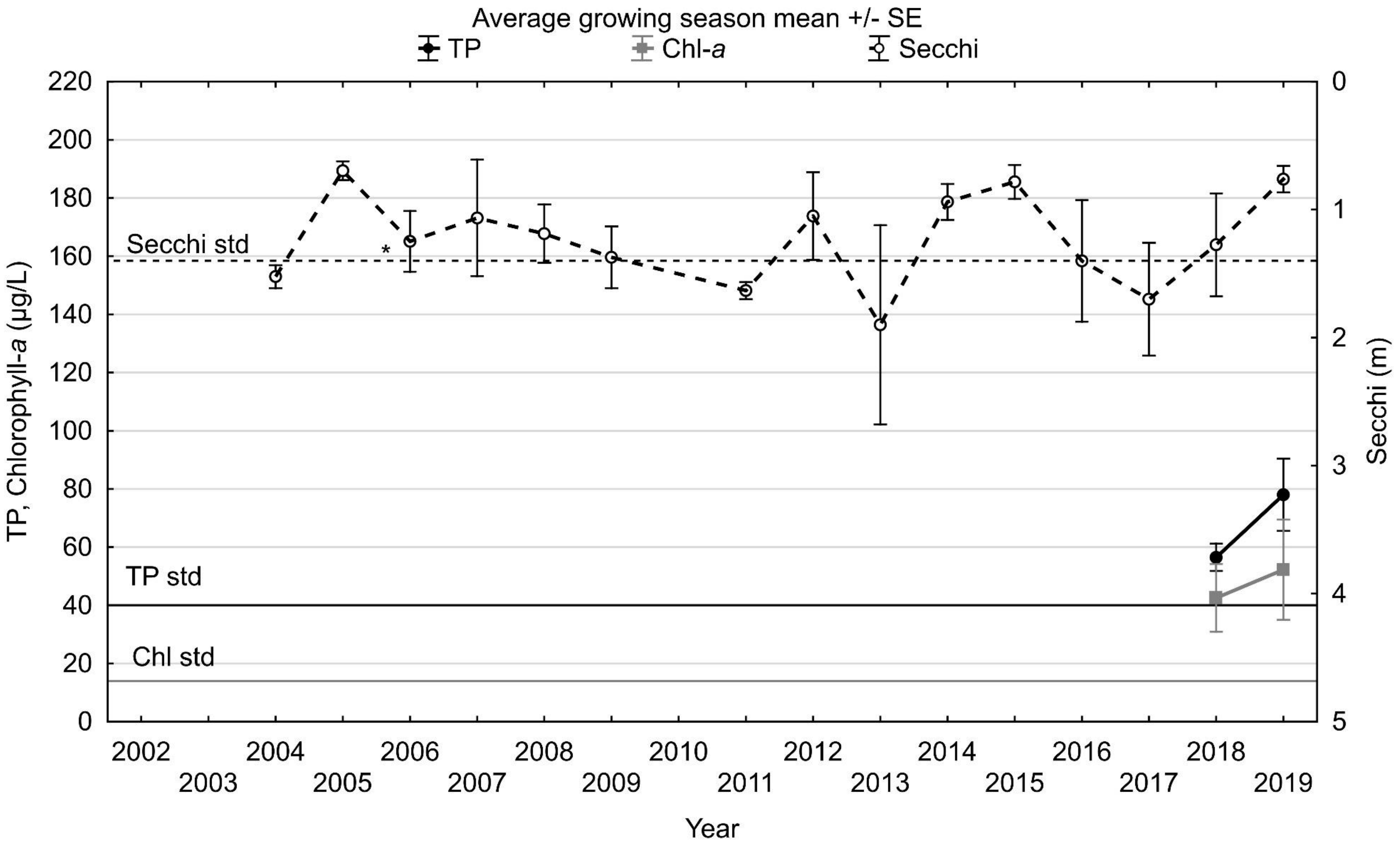
- Knaus: 73-0086-00-204, 205, 206, 208



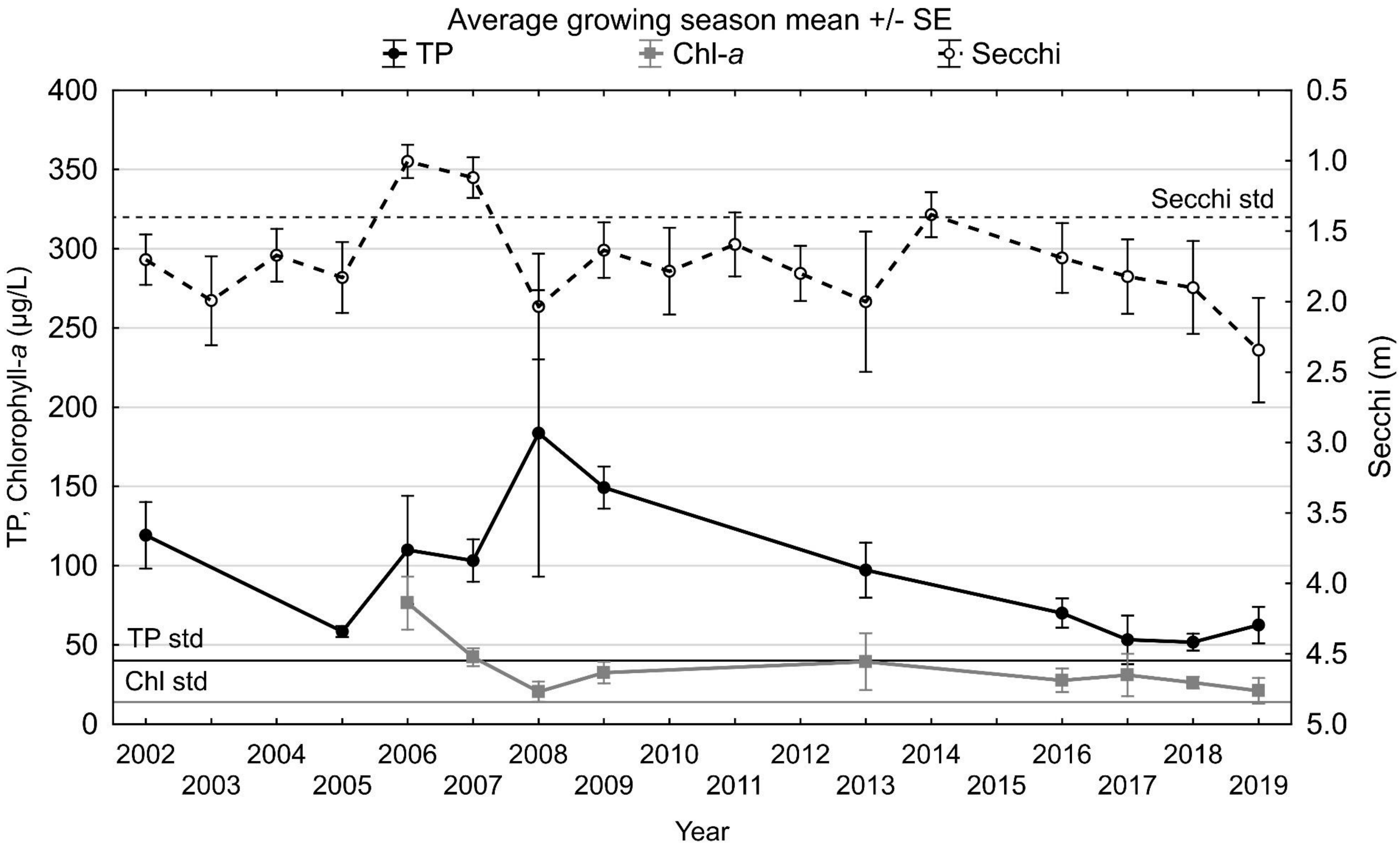
- Krays: 73-0087-00-201



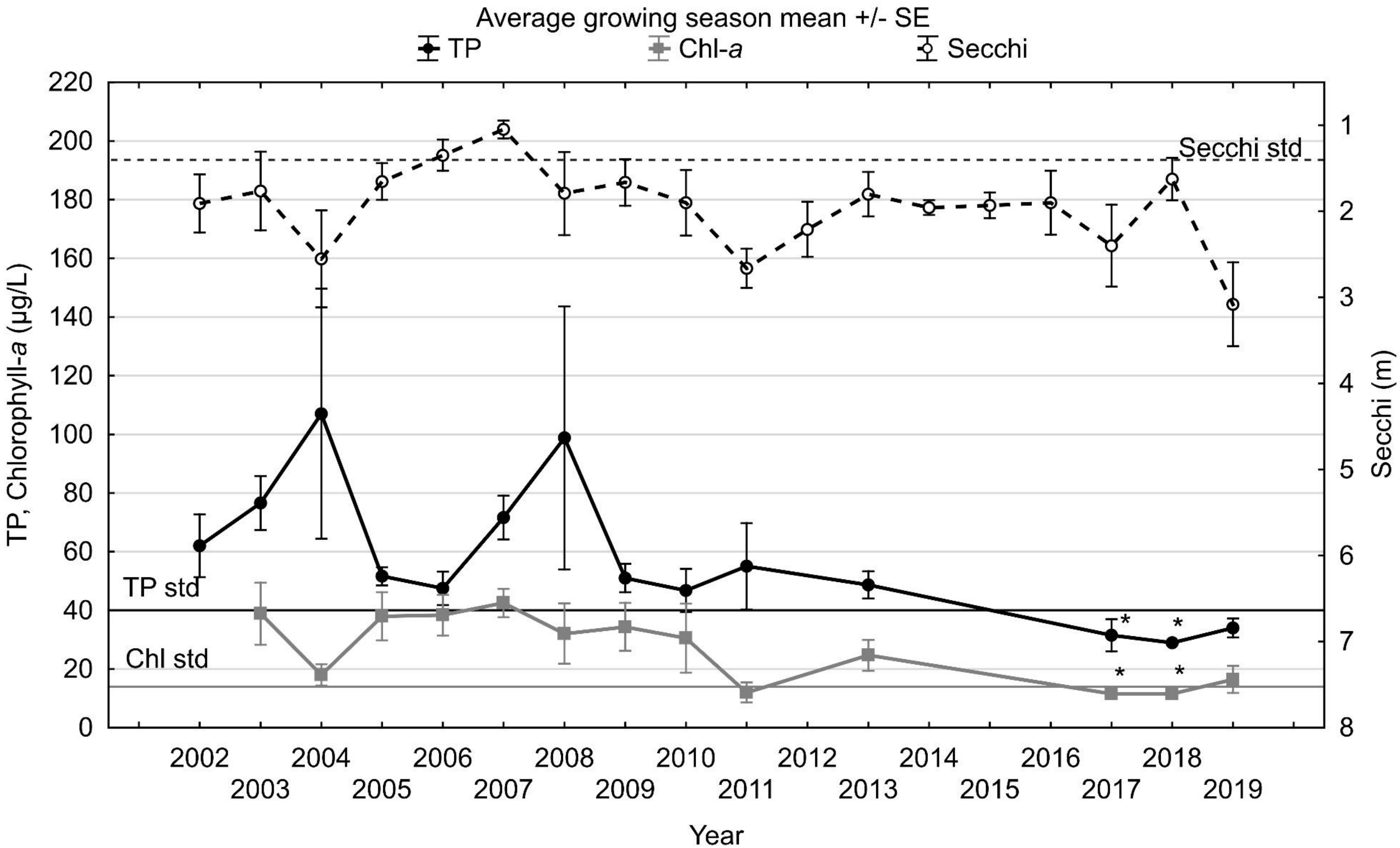
Long: —73-0139-00-205



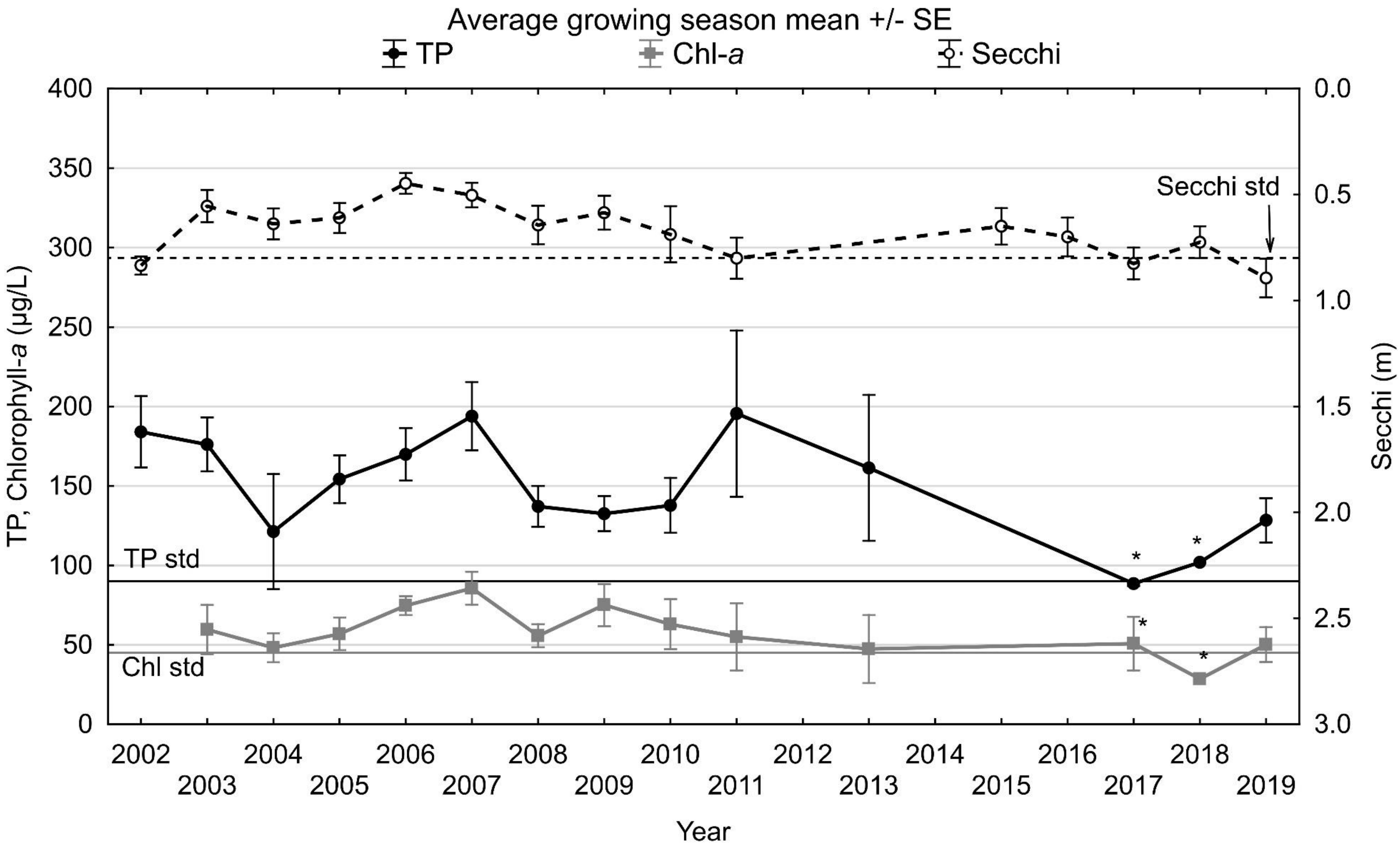
- Long: —73-0139-00-204



- North Browns: 73-0147-00-101, 201, 205, 206



- Schneider: 73-0082-00-202



Zumwalde: 73-0089-00-201