Osakis Lake Area
Excess Nutrients Total Maximum Daily Load Report

Prepared for:

Sauk River Watershed District

Minnesota Pollution Control Agency

Minnesota Pollution Control Agency

May 2013
Revised December 2023

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SAUK RIVER WATERSHED DISTRICT

MINNESOTA POLLUTION CONTROL AGENCY

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Abbreviations

AUs	animal units
BMP	best management practice
CAFO	Concentrated Animal Feeding Operation
DNR	Department of Natural Resources
DO	Dissolved oxygen
EPA	United States Environmental Protection Agency
GIS	Geographical Information System
HRU	Hydrologic Response Unit
LA	Load Allocation
LWMP	Local Water Management Plan
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NASS	National Agricultural Statistics Service
NCHF	North Central Hardwood Forest
NPDES	National Pollutant Discharge Elimination System
NWI	National Wetland Inventory
P	Phosphorus
ROW	Right of Way
SRWD	Sauk River Watershed District
SSTS	Subsurface Sewage Treatment Systems
SWCD	Soil and Water Conservation District
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSA	Technical Service Area
TSS	Total Suspended Solids
UAL	Unit-area Load
WLA	Wasteload Allocation
WWTF	Wastewater Treatment Facility

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments for Smith Lake (DNR # 21-0016), Faille Lake (DNR # 77-0195) and Lake Osakis (DNR Lake # 77-0215), located near the headwaters of the Sauk River (07010202) in the Upper Mississippi River Basin in Todd and Douglas Counties, Minnesota. The goal of this TMDL is to quantify the pollutant reductions needed for these lakes to meet State water quality standards for nutrients. The numeric water quality standards for Smith Lake and Osakis Lake, both deep lakes, are a summer average total phosphorus (TP) maximum concentration of 40 µg/L and 14 µg/L chlorophyll-a, and greater than 1.4 meter in Secchi depth. The numeric water quality standards for Faille Lake, a shallow lake, are a maximum summer average TP concentration of 60 µg/L and 20 µg/L chlorophyll-a, and greater than one meter in Secchi depth. Water quality for all three lakes does not meet deep/shallow lake state standards for nutrient concentrations in the North Central Hardwood Forest (NCHF) ecoregion.

Land use in the Smith-Faille-Osakis Lake Watersheds is predominantly agriculture (greater than 68%) including pastureland and row crops (mostly corn/soybean rotations). Faille Lake is a shallow lake with an average depth of 3.6 feet and a maximum depth of 7 feet. Smith and Osakis Lakes are deep lakes with average depths of 14 feet and 17 feet, and maximum depths of 30 feet and 73 feet, respectively. Lake Osakis is the most downstream lake in this study area and receives water from several upstream lakes including both Smith Lake and Faille Lake. The outlet of Lake Osakis represents the headwaters of the Sauk River. Smith Lake and Osakis Lake have a long history of carp and curly-leaf pondweed infestation. Faille Lake currently has no published plant or fish data/information.

Nutrient budgets were developed for all three lakes, along with lake response models, to set the Load Allocations (LAs) and Wasteload Allocations (WLAs). Phosphorus (P) sources to Smith Lake include watershed runoff (86%), failing septic systems (9%) and atmospheric deposition (5%). Faille Lake receives most of its P from upstream lakes including intermediate wetlands, with 6% of the load coming from the Osakis WWTF and its own drainage area (2%) with the remaining P coming from failing septic systems (1%), internal loading (less than 1%) and atmospheric deposition (less than 1%). A majority of the Lake Osakis P budget comes from direct drainage to the lake (52%) which includes inputs from Judicial Ditch #2 and several smaller tributaries, which flow directly to Lake Osakis. The remainder of the P load to Lake Osakis comes from four upstream lakes (22%), failing septic systems (14%), atmospheric deposition (10%) and internal loading (2%). The TMDL allocations for the lakes to meet state water quality standards were 1,901 pounds per year (31% reduction) for Smith Lake, 962 pounds per year (71% reduction) for Faille Lake, and 10,704 pounds per year (41% reduction) for Lake Osakis.

The primary sources of P for all three lakes include runoff from their agricultural watershed, with both row crops and animal agriculture. There are over 13,000 animal units (AUs) throughout the entire Lake Osakis Watershed, producing more than 1.1 million pounds of P in the form of manure each year. A large proportion of this manure is land applied throughout the watershed, some of which eventually makes its way into surface waters. Nutrient management in the watershed will need to focus on manure management.

Another major source of P to Faille Lake (89%) and Lake Osakis (22%) comes from upstream lakes, so restoration of all impaired waterbodies throughout the watershed will benefit Faille and Osakis Lake tremendously. Vegetation and fish management to control curly-leaf pondweed and carp populations will also be important factors, particularly in Smith and Faille Lake, in controlling water quality and creating balanced and healthy ecosystems.

2023 Revisions to Faille Lake TMDL

Following the Osakis Lake Area Excess Nutrient TMDL approved in 2013, there remained an additional impaired lake, “Clifford Lake,” in the watershed. The lake was a small, shallow lake for which limited information on its physical characteristics existed. The lake is the receiving water for the city of Osakis Wastewater Treatment Facility (WWTF).

Given the limited amount of physical characteristic data available, the development of a TMDL for the lake was postponed until additional information could be obtained on depth and size. Further examination revealed that the water body was much shallower than previous data had indicated. The lake morphometry and characteristics were determined to describe a wetland rather than a shallow lake. Clifford Lake was delisted (removed from the state’s 303d list) and defined as a wetland. Currently there are no numeric eutrophication standards for wetlands in Minnesota. Any previous references to Clifford Lake have been revised to Clifford Wetland.

A new Faille Lake TMDL table was created, so there is an original table and a revised table (Tables 4.2 and 4.3) in this TMDL report. The attached addendum contains the revisions to the Faille Lake TMDL tables. In the original 2013 TMDL, Faille Lake did not have the discharge of a WWTF in its allocations. The allocations and modeling were reassessed and are shown and described in the addendum found at the end of this document.

1.0 Introduction

1.1 PURPOSE

This TMDL study addresses nutrient impairments in Smith Lake, Faille Lake and Lake Osakis. The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for nutrients in these three lakes. The Smith-Faille-Osakis Nutrient TMDL is being established in accordance with section 303(d) of the Clean Water Act, because the state of Minnesota has determined these lakes exceed the state-established standards for nutrients.

This TMDL provides WLAs and LAs for Smith Lake, Faille Lake and Lake Osakis. Based on the current state standard for nutrients, the TMDL establishes a deep lake numeric target of 40 µg/L for Lake Osakis and Smith Lake, and a 60 µg/L TP concentration for Faille Lake which is a shallow lake, in the NCHF ecoregion.

1.2 PROBLEM IDENTIFICATION

Smith Lake (DNR # 21-0016), Faille Lake (DNR # 77-0195) and Lake Osakis (DNR Lake # 77-0215) are located in central Minnesota in the Upper Mississippi River Basin along the border of Todd and Douglas Counties. Faille Lake and Smith Lake are located upstream of Lake Osakis, which is the headwaters of the Sauk River Watershed. Lake Osakis was placed on the 2004 state of Minnesota’s 303(d) list of impaired waters. Faille Lake was placed on the 303(d) list in 2006 and Smith Lake was placed on this list in 2008. All three lakes were identified for impairment of aquatic recreation. Water quality does not meet state standards for nutrient concentration for deep (Osakis and Smith) and shallow lakes (Faille) in the NCHF ecoregion.

The primary recreation activities supported by the lakes include boating and fishing. These lakes are recreational water bodies within Todd (Osakis and Faille) and Douglas (Smith) Counties. Water quality degradation of these lakes has impacted recreational activities and led to efforts to improve the overall water quality within the Lake Osakis Watershed. As a result, the Lake Osakis Watershed, including Lake Osakis, Faille Lake and Smith Lake, was given a priority ranking for TMDL development. Priority was also given to these waterbodies to protect downstream water resources in the Sauk River Watershed since Lake Osakis represents the headwaters of the Sauk River. It was also determined these TMDLs could be completed in an efficient and expedient manner due to a strong base of existing data and the technical capability and willingness of local partners.

2.0 Watershed and Lake Characterization

2.1 IMPAIRED WATERS AND MINNESOTA WATER QUALITY STANDARDS

Smith Lake, Faille Lake and Lake Osakis are located in the NCHF ecoregion and are designated as class 2B waters. The Class 2B designation specifies aquatic life and recreation as the protected beneficial use of the water body.

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

The numeric target used to list these lakes were the P standards for Class 2B deep and shallow lakes in the NCHF ecoregion (40 and 60 mg/L, respectively); this TMDL presents load and WLAs and estimated load reductions for the 40 µg/L and 60 mg/L targets. Although the TMDL is set for the TP standards, the two other lake eutrophication standards (chlorophyll-a and Secchi depth) must also be met (Table 2.1). All three of these parameters were assessed in this TMDL to ensure that the TMDL will result in compliance with state standards. Lake Osakis and Smith Lake are considered deep lakes and are subject to the chlorophyll-a and Secchi depth numeric standards of 14 mg/L and 1.4 meters, respectively. Faille Lake is a shallow lake and must meet the chlorophyll-a and Secchi depth numeric standards of 20 µg/L and 1.0 meters, respectively. All values are growing season means.

Table 2.1 Numeric targets for deep and shallow lakes in the North Central Hardwood Forest ecoregion.

Parameters	North Central Hardwood Forest (Deep Lakes)[1]	North Central Hardwood Forest (Shallow Lakes)[2]
Phosphorus Concentration (mg/L)	40	60
Chlorophyll-a Concentration (mg/L)	14	20
Secchi disk transparency (meters)	>1.4	>1.0

[1] Deep lakes are defined as enclosed basins with a maximum depth greater than 15 feet.

[2] Shallow lakes are defined as lakes with a maximum depth less than 15 feet, or with more than 80% of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

2.2 LAKE AND WATERSHED DESCRIPTIONS

Smith Lake (DNR # 21-0016), Faille Lake (DNR # 77-0195) and Lake Osakis (DNR Lake # 77-0215) are located in central Minnesota in the Upper Mississippi River Basin along the border of Todd and Douglas Counties (Figure 2.1). Faille and Smith Lake are located upstream of Osakis Lake, which is the headwaters of the Sauk River Watershed. Thus, the water quality and ecological condition of these lakes have a profound impact on the Sauk River and other downstream resources.

Smith Lake represents the headwaters of Judicial Ditch #2, which drains to Lake Osakis. Smith Lake is a relatively large (550 acres), deep (max depth of 30 feet) lake with a long residence time (1.9 years) meaning that the lake flushes about every two years (Table 2.2). Smith Lake ultimately drains into Lake

Osakis through Judicial Ditch #2. Approximately half of Smith Lake can be expected to support submerged aquatic vegetation growth.

Table 2.2 Osakis area lakes morphometric and watershed characteristics

Parameter	Smith Lake	Faille Lake	Lake Osakis
Surface Area (acres)	550	78	6,361
Average Depth (ft)	14.4	3.6	17.0
Maximum Depth (ft)	30	7	73
Volume (ac-ft)	7,928	278	108,389
Residence Time (years)	1.9	0.05	5
Littoral Area (acres)	265	78	2,939
Littoral Area (%)	48%	100%	46%
Watershed (acres)	11,931	14,722	88,722

Faille Lake is also a shallow lake (max depth of 3.6 feet) with an extremely short residence time (~18 days) that receives drainage from Clifford Wetland via Stevens Lake (Figure 2.2). Clifford Wetland discharges to a channel that travels through a large unnamed wetland prior to discharging to Stevens Lake. Faille Lake is located in Todd County; however, a majority of the watershed is located in Douglas County. Faille Lake is small in size (78 acres) and would be expected to have submerged aquatic vegetation from shore to shore. Faille Lake discharges a short distance (less than 0.5 miles) to Lake Osakis through a channel commonly referred to as Blacks Channel. Both Faille Lake and Blacks Channel received alum treatments in spring of 2002 to reduce internal P loading.

Lake Osakis represents the headwaters of Sauk River and has a relatively large drainage area (88,722 acres). A majority of Lake Osakis is located in Todd County, however; most of the watershed is located in Douglas County. The Judicial Ditch #2 watershed west of Lake Osakis is approximately 26,702 acres and accounts for a large portion (30%) of the lake's total watershed. The remainder of the Lake Osakis Watershed is made up of direct drainage to the lake (23%) and outflow from Faille Lake (17%), Smith Lake (13%), Little Osakis Lake (10%), and Maple Lake (7%; Figure 2.2). Lake Osakis is a large, deep (max depth 73 feet) lake with an extremely long residence time of approximately five years. About half of the lake is shallow enough to support submerged aquatic vegetation. The lake is highly sought by recreationalists, particularly anglers, sail boaters and water skiers.

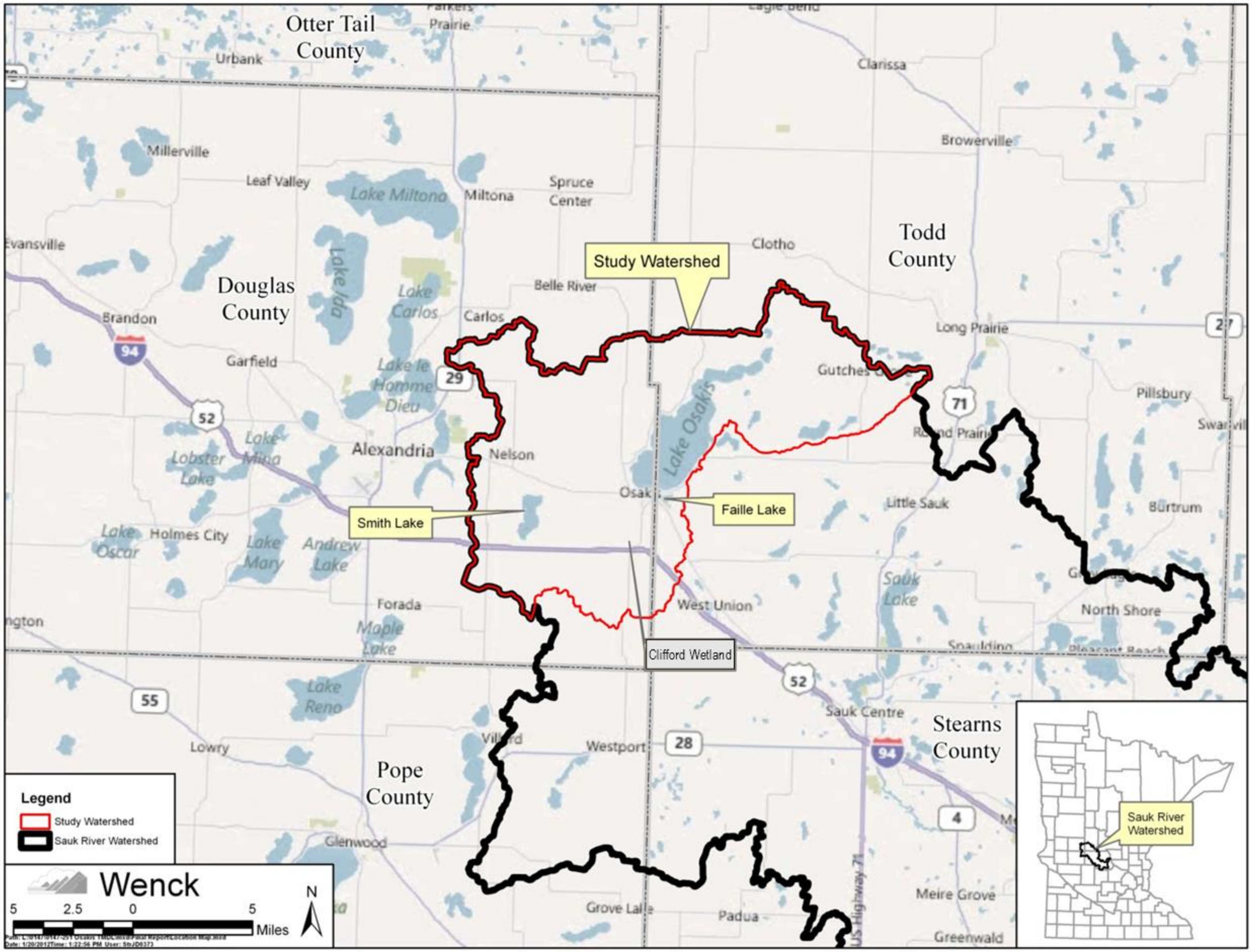

Figure 2.1. Osakis Lake Watershed location map.

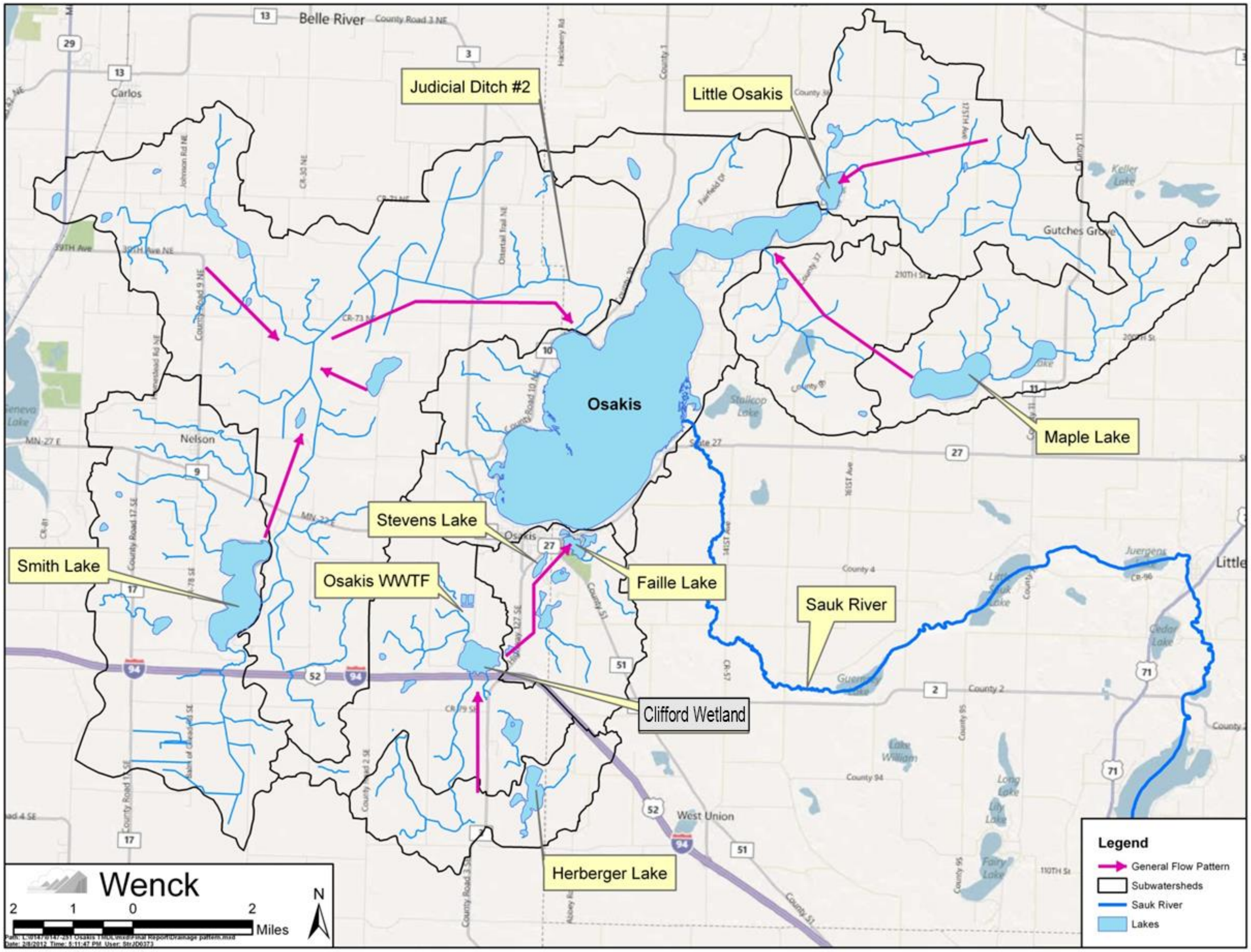

Figure 2.2. Osakis Lake Subwatersheds and drainage pattern.

2.3 LAND USE

Land use for each impaired lake watershed was defined in GIS using the 2009 National Agricultural Statistics Service Land Cover (NASS) file. In order to define all wetland boundaries more accurately, the U.S. Fish and Wildlife Service National Wetland Inventory (NWI) shapefile was burned into the 2009 NASS GIS file. Also, any 2009 NASS wetland land-cover not delineated in the NWI layer was assigned a different land-use classification based on the 2008 NASS land cover file.

The watersheds draining to the study lakes are highly agricultural with the most common land-uses in each watershed being pasture, corn/soybean rotations and wetlands/open water (Table 2.3, Figure 2.3). The city of Osakis mostly drains directly to Lake Osakis, with a small area (175 acres) draining to Faille Lake.

Table 2.3. Land use in each impaired lake watershed.

Land use	Osakis		Smith		Faille	
	Acres	Percent	Acres	Percent	Acres	Percent
Pasture/Hay	35,139	40%	4,883	41%	4,452	30%
Corn/Soybean	21,648	24%	2,999	25%	5,644	38%
Wetlands/Open Water	12,744	14%	1,074	9%	1,850	13%
Forested	9,517	11%	1,500	13%	584	4%
Transportation	5,286	6%	747	6%	966	7%
Alfalfa/Wheat/Rye	3,862	4%	662	6%	1,029	7%
Low Density Urban	413	<1%	52	<1%	175	1%
Medium Density Urban	61	<1%	10	<1%	29	<1%
General Agriculture	38	<1%	3	<1%	8	<1%
High Density Urban	15	<1%	1	<1%	5	<1%
Total	88,723	100%	11,931	100%	14,742	100%

Note: Land use was calculated using a combination of the 2009 and 2008 NASS and the US Fish and Wildlife NWI GIS files

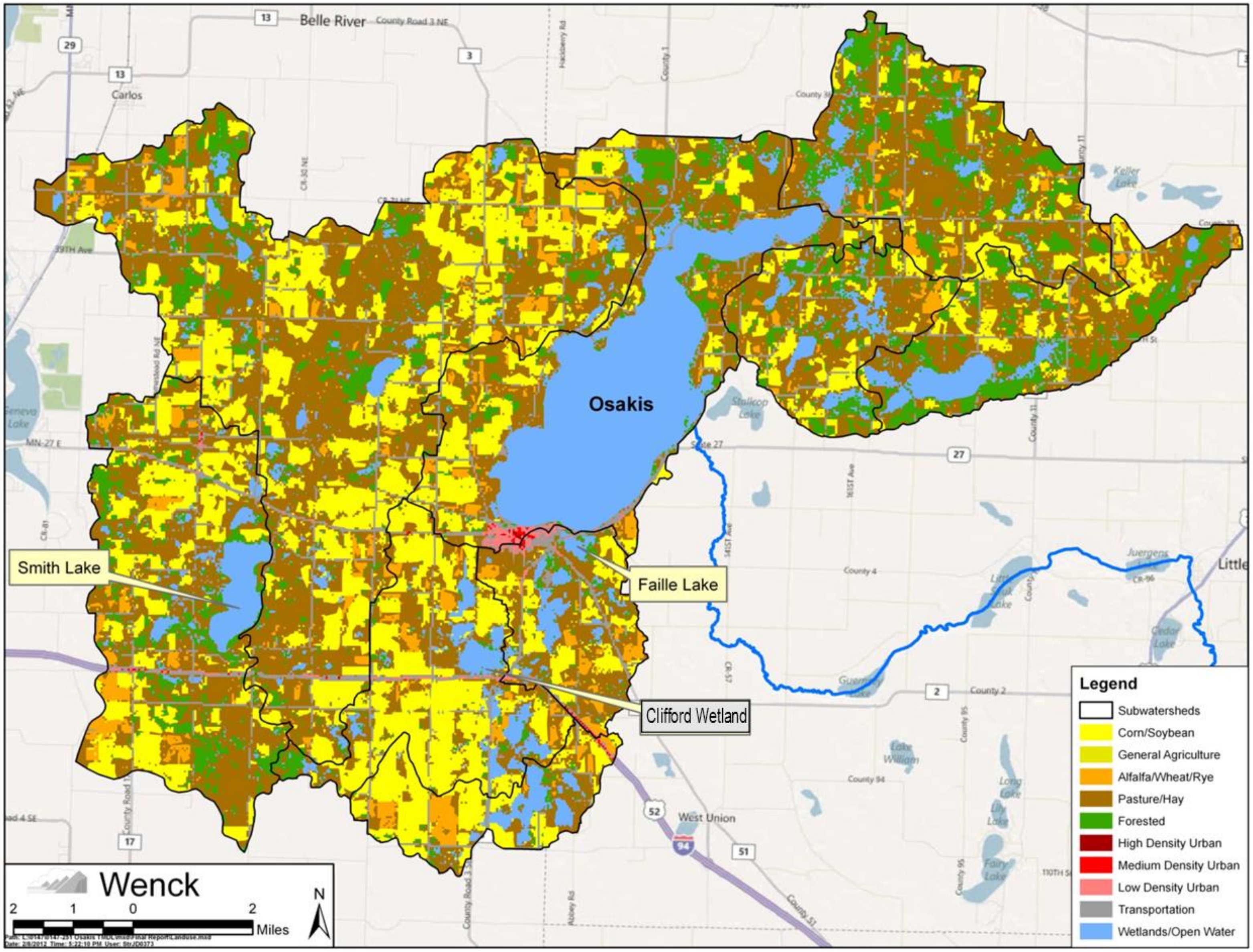

Figure 2.3. Land use in the Lake Osakis Watershed.

2.4 LAKE WATER QUALITY

2.4.1 Introduction

Water quality in Minnesota lakes is often evaluated using three associated parameters: TP, chlorophyll-a, and Secchi depth. TP is typically the limiting nutrient in Minnesota's lakes, meaning that algal growth will increase with increases in P. However, there are cases where P is widely abundant and the lake becomes limited by nitrogen or light availability. Chlorophyll-a is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Since chlorophyll-a is a simple measurement, it is often used to evaluate algal abundance rather than expensive cell counts. Secchi depth is a physical measurement of water clarity, measured by lowering a disk into the waterbody until it can no longer be seen from the surface. Higher Secchi depths indicate less light refracting particulates in the water column and better water quality. Conversely, high TP and chlorophyll-a concentrations point to poorer water quality and thus lower water clarity. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

2.4.2 Lake Monitoring Efforts

Water quality monitoring has been conducted at several locations on each of the three impaired lakes in the Osakis Watershed under a variety of efforts. Figure 2.4 shows the primary water quality monitoring locations for each lake. Lake Osakis is a large, deep lake that has three main sampling stations situated near the deep hole of each of the three major basins/sections of the lake. All three stations were sampled regularly (four or more times) in 2000, 2005, 2006, 2007 and 2009. Station 102 was the only site sampled in 2004. Smith Lake is also considered a deep lake and has two sampling locations that are located near the lake's deep hole. Faille Lake has three monitoring locations that have been sampled periodically since 2000. Smith Lake station 202 is the primary sampling site and was sampled regularly in 2004, 2005, 2008 and 2010. Smith Lake stations 102 and 203 were also sampled in 2000 and 2004, respectively. The two Faille Lake water quality monitoring sites are considered representative of the entire lake since the lake is a shallow system with little depth variability. Site 201 was sampled in regularly in 2000, 2003, 2004 and 2007 while site 202 was sampled in 2003 and 2004. During monitoring years, sampling was typically conducted bi-weekly or once per month from April/May through September for the following lake water quality parameters: Secchi depth, TP, chlorophyll-a, ortho-phosphorus, nitrate+nitrite, total Kjeldahl nitrogen (TKN), total suspended solids (TSS), and temperature and dissolved oxygen (DO) measurements. Collection efforts were coordinated and carried out by the Sauk River Watershed District (SRWD) and the MPCA.

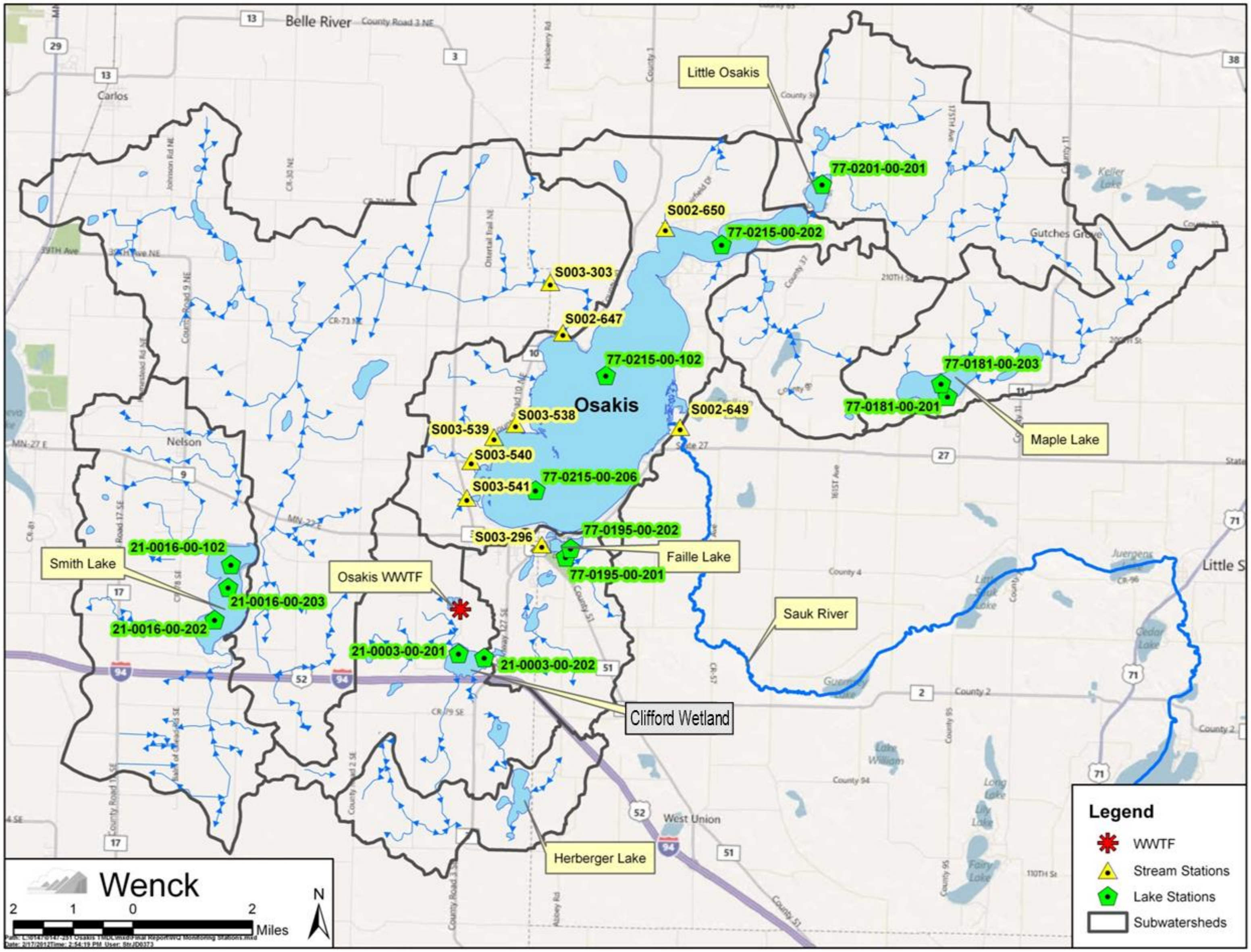

Figure 2.4. Lake and stream water quality sampling locations in the Osakis Lake Watershed.

2.4.3 Lake Monitoring Data Processing

All of the monitoring stations discussed in the previous section are considered representative of each lake's overall water quality conditions, since they are located at or near each lake's deep hole or the deepest portion of a section/basin of the lake. Thus, data from all sites were combined and consolidated (averaged) by date to represent one single value for each lake. Summer index period (June 1 through September 30) data for each year was then averaged in order to compare each lake's data to the state's numeric standards for deep and shallow lakes in the NCHF ecoregion. Results from this analysis are presented in sections 2.4.4 through 2.4.8. Appendix A provides summary tables of historic water quality data collected in Osakis, Smith and Faille Lakes.

2.4.4 Temperature and Dissolved Oxygen

The DO profiles for Smith Lake were collected monthly in 2000 from June through August. The DO and temperature profiles were collected in Faille Lake four times in 1999 (May through September), five times in 2000 (May through September), three times in 2001 (June through August), two times in 2002 (August and September) and five times in 2004 (May through July). Profiles for Lake Osakis were collected from three separate sites (77-0215-00-202, 102 and 206) from 1998-2007 and in 2009. The 2005 through 2007 and 2009 profiles represent the most complete profile dataset as at least six profiles were collected throughout the summer. Data prior to 2005 are not as reliable since they may not have been deep enough to determine the thermocline and complete oxygen profile at each Lake Osakis monitoring site (Appendix B).

The Smith Lake profiles collected in 2000 demonstrate anoxia (DO ≤ 2 mg/L) occasionally occurred in the bottom 1-2 meters of the water column during the summer months (June to late August), which suggests the potential for some internal loading of P (Appendix C). Smith Lake internal loading will be discussed more in section 3.3.4.

Faille Lake temperature profiles show very slight temperature gradients between surface waters during the mid-summer months while DO profiles never demonstrated anoxia (Appendix C). It should be noted that Faille Lake is a shallow system with a moderate surface area to depth ratio, which causes the lake to be more susceptible to wind-driven mixing events. Thus Faille Lake does not appear to sustain a strong thermocline or large anoxic areas for the entire summer period.

Lake Osakis is much deeper and has a significantly larger surface area compared to Smith and Faille Lakes. Profiles for site 202 suggest a strong thermocline develops between 8 meters and 12 meters throughout summer growing season and anoxia develops anywhere from 8-20 meters and has been measured as shallow as six meters (Appendix C). It should be noted this site is located in the far north basin, which is more protected from wind mixing due to its smaller fetch. Sites 102 and 206 are located in the south basin of the lake, which is a very open basin with a large fetch. As a result, anoxia occasionally develops at these sites but typically at deeper depths and for shorter periods of time compared to site 202. Internal loading estimates for Lake Osakis are discussed in section 3.3.4. However, based on these profiles it appears unlikely internal loading under anoxic conditions is an important factor in the P budget of Lake Osakis.

2.4.5 Total Phosphorus

Summer average TP concentrations in Osakis and Smith Lake consistently exceeded the deep lake TP water quality standard of 40 µg/L (Figures 2.5 and 2.6). The highest summer average TP concentration for Osakis Lake was 84 µg/L in 2000. Smith Lake's highest measured average summer TP concentration was 61 µg/L in 2010. Since 2000, Faille Lake has also consistently exceeded the 60 µg/L NCHF ecoregion shallow lake TP standard (Figure 2.7). The highest average summer TP concentration for Faille Lake was 238 µg/L in 2007.

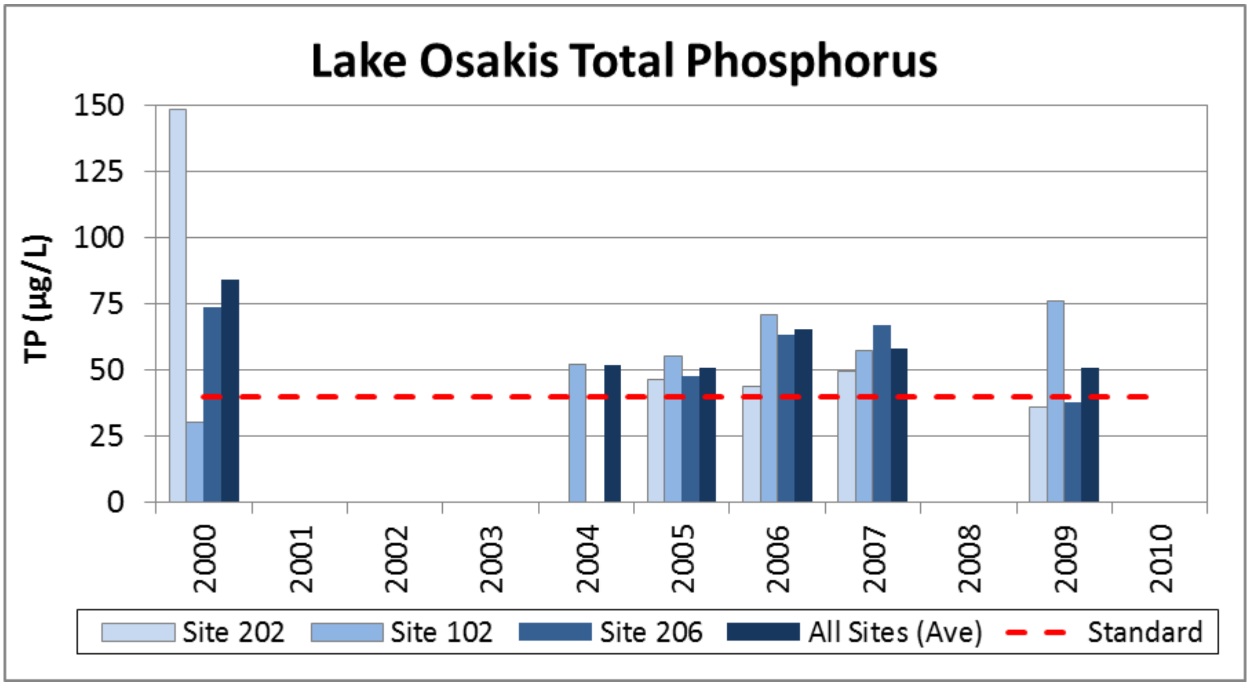

Figure 2.5. Summer mean TP at the three Lake Osakis monitoring stations since 2000.

Note for Figures 2.5-2.7: Summer index period is from June 1 through September 30. The dashed red lines indicate the current deep (Osakis and Smith) and shallow (Faille) lake state standards for the NCHF ecoregion. Only sampling seasons with four or more measurements/observations are displayed.

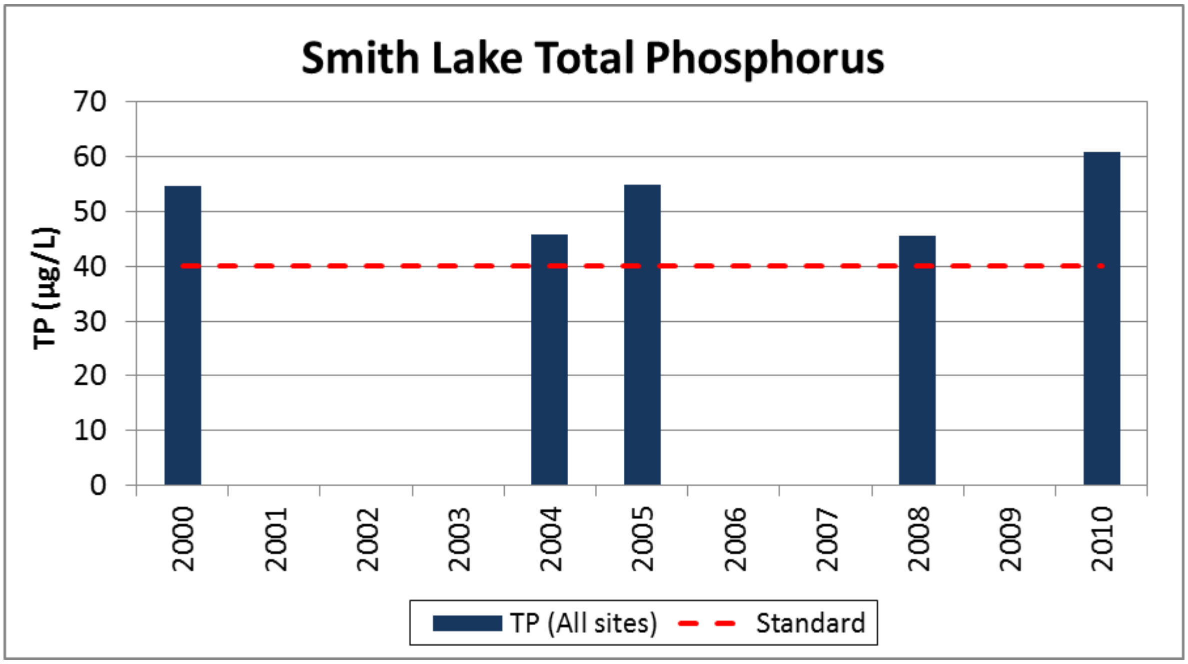

Figure 2.6. Summer mean TP for Smith Lake since 2000.

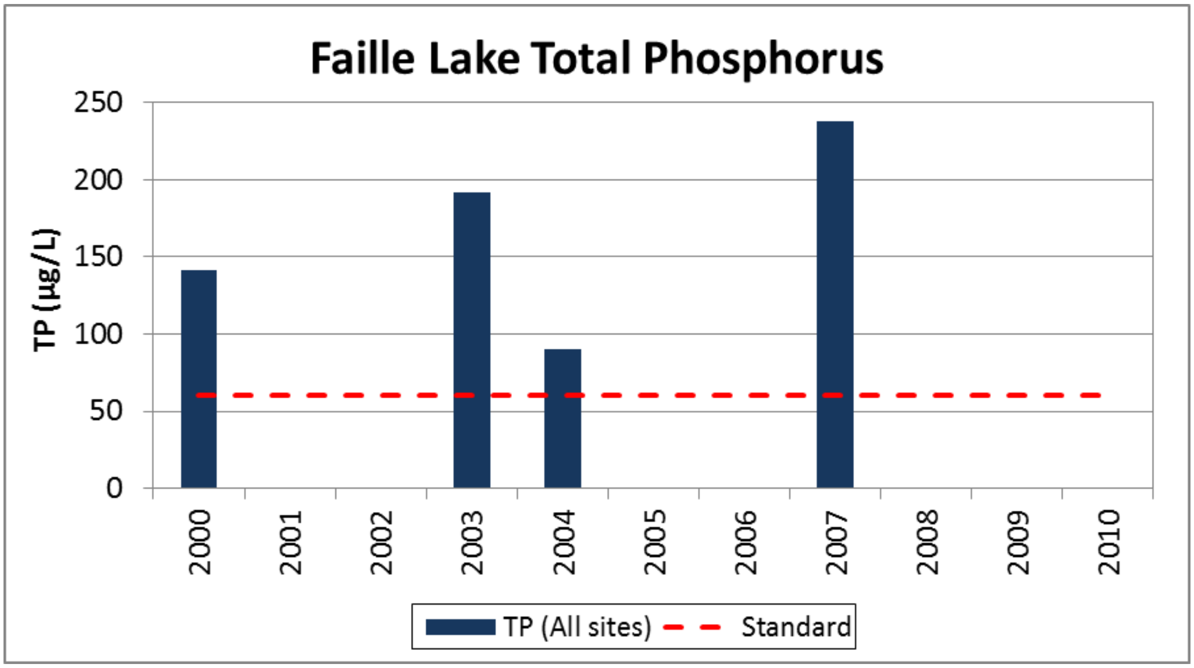

Figure 2.7. Summer mean TP for Faille Lake since 2000.

2.4.6 Chlorophyll-a

Since 2000, average chlorophyll-a concentrations in Lake Osakis have ranged from 9 µg/L to as high as 52 µg/L in years with four samples or more during the summer season (Figure 2.8). Smith Lake average summer chlorophyll-a concentrations have ranged from 21 µg/L to 43 µg/L (Figure 2.9). Chlorophyll-a concentrations over 14 µg/L exceed state water quality standards for deep lakes and indicate a high incidence of nuisance algae blooms. Mean summer chlorophyll-a concentrations have exceeded the state standard in four of six years for Lake Osakis and all five years for Smith Lake.

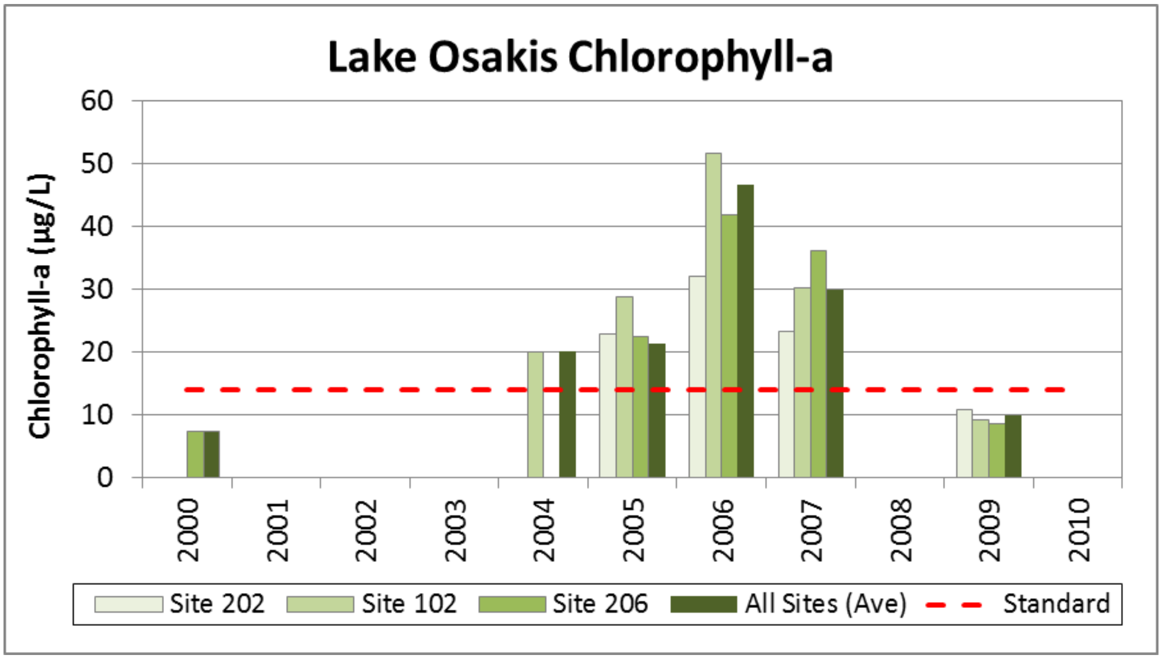

Figure 2.8. Summer mean chlorophyll-a at the three Lake Osakis monitoring stations since 2000.

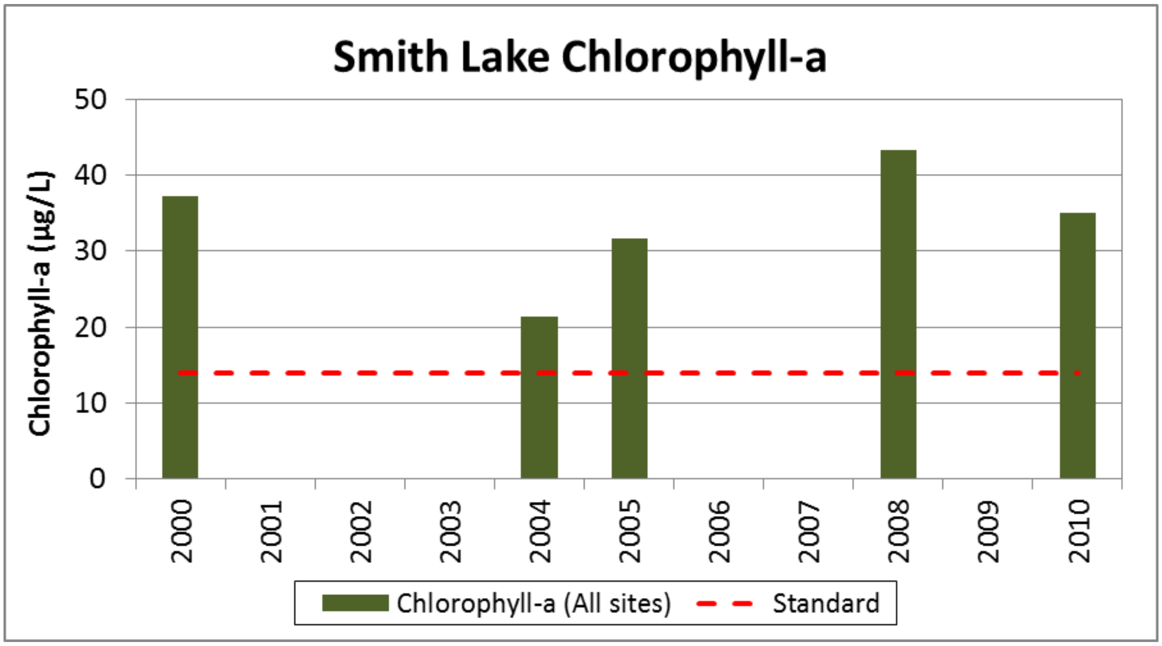

Figure 2.9. Summer mean chlorophyll-a for Smith Lake since 2000.

Faille Lake mean summer chlorophyll-a ranged from 12 µg/L to 51 µg/L in the four seasons since 2000 with adequate measurements (Figure 2.10). Summer average chlorophyll-a concentrations have exceeded this standard in two of the four seasons for Faille Lake.

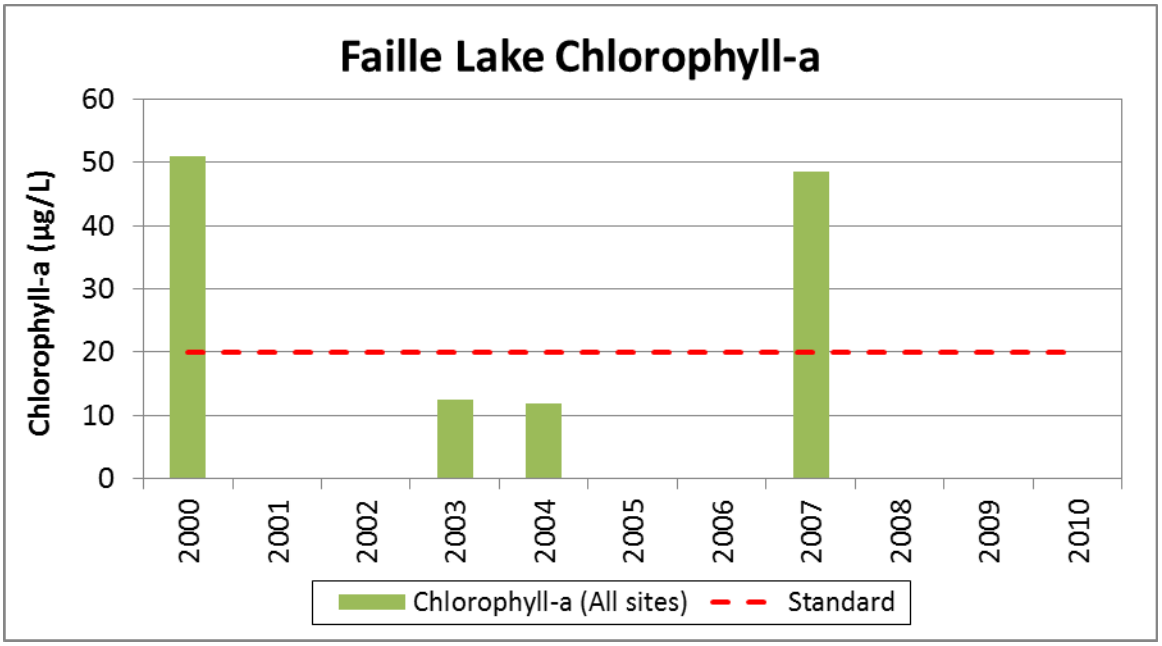

Figure 2.10. Summer mean chlorophyll-a for Faille Lake since 2000.

2.4.7 Secchi Depth

Water clarity (Secchi depth) in general follows the same trend as TP and chlorophyll-a. Since 2000, mean summer Secchi depth in Osakis Lake has met or been better than the 1.4 meters (4.6 ft) deep lake standard for all 10 years with adequate monitoring data (Figure 2.11). Smith Lake has met the deep lake Secchi depth standard in only 5 of the 10 monitored years since 2000 (Figure 2.12). Faille Lake has met the shallow lake Secchi standard in two of three monitored years since 2000 (Figure 2.13).

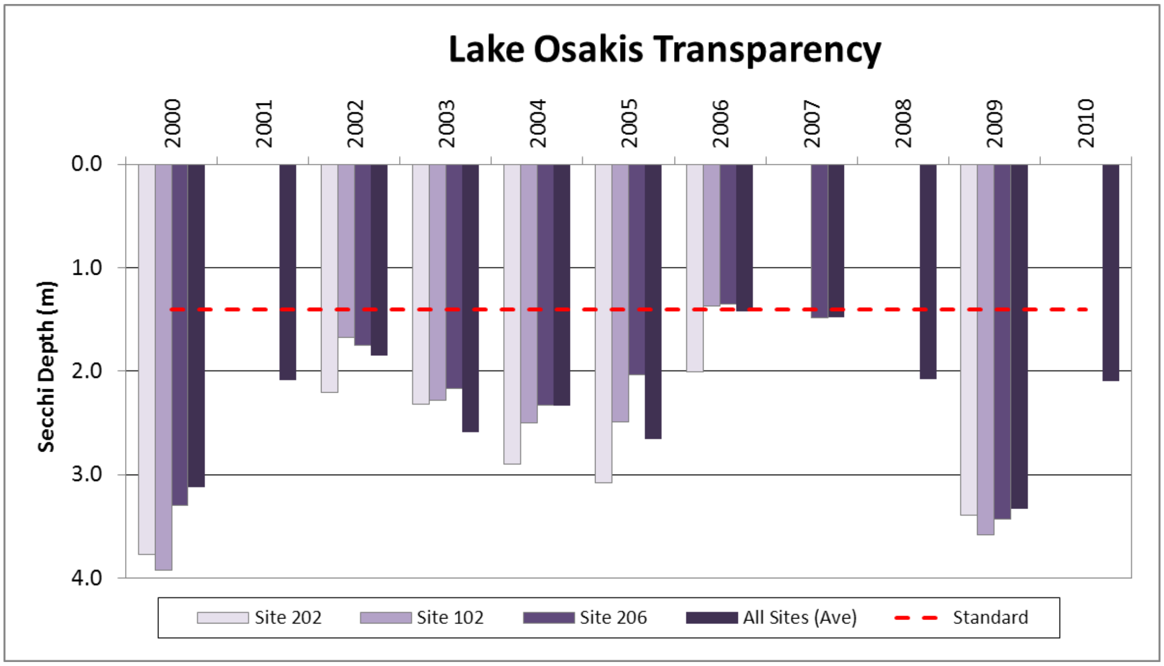

Figure 2.11. Summer mean Secchi depth at the three Lake Osakis monitoring sites since 2000.

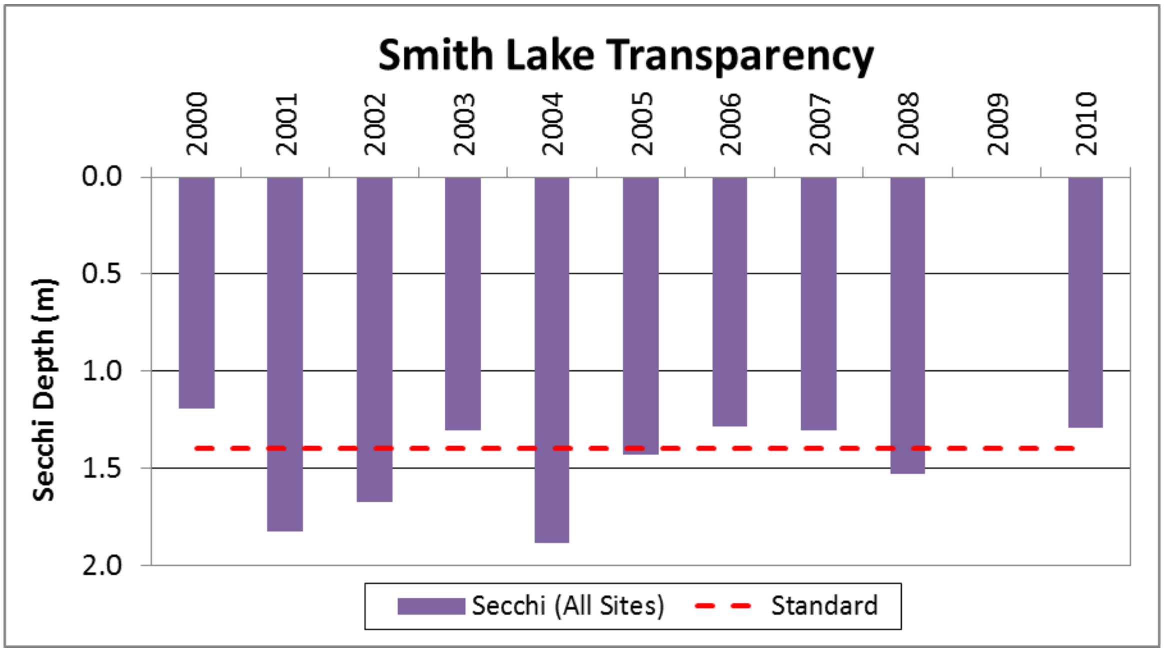

Figure 2.12. Summer mean Secchi depth for Smith Lake since 2000.

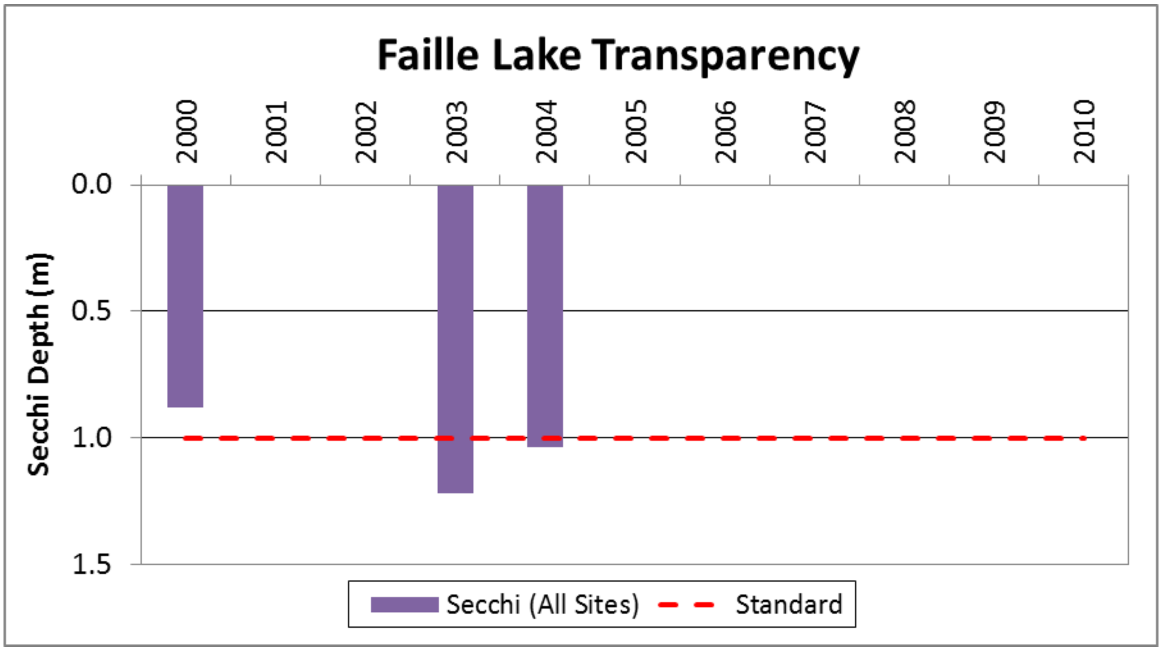

Figure 2.13. Summer mean Secchi depth for Faille Lake since 2000.

2.4.8 Conclusions

Overall, Osakis, Smith and Faille Lake have not met current state standards since 2000 (as of the writing of the original 2013 TMDL). While there is some variability in the monitoring data from year to year, trends over the past 10 years show that the water quality is relatively stable in its current state. There does not appear to be a significant decline or improvement in the water quality of these lakes over this period.

2.5 LAKE ECOLOGY

2.5.1 Fish Populations

Fish survey reports for Lake Osakis and Smith Lake were provided by the Department of Natural Resources (DNR) Area Fisheries Office in Glenwood, Minnesota. To date, there have been no DNR fish surveys conducted on Faille Lake. The first DNR fish surveys for Osakis and Smith Lake were conducted in 1950 and 1951, respectively. Standard survey methods used by the DNR include gill net and trap nets. These sampling methods do have some sampling bias, including focusing on game management species (i.e., northern pike and walleye), under representing small minnow and darter species presence/abundance, and under representing certain management species such as largemouth bass. The current methods also likely under represent carp populations in the lakes. However, when carp are present in the lakes, the sampling methods do capture some of the population. So, although carp density is likely under represented, the methods do provide a reasonable year to year comparison.

There have been 18 species collected during the Osakis and Smith Lake DNR surveys:

- black bullhead
- black crappie
- bluegill
- bowfin
- brown bullhead
- common carp
- hybrid sunfish
- largemouth bass
- northern pike
- pumpkinseed sunfish
- rock bass (Osakis only)
- shorthead redhorse (Osakis only)
- smallmouth bass (Osakis only)
- tulibee cisco (Osakis only)
- walleye
- white sucker
- yellow bullhead
- yellow perch

Lake Osakis supports a diverse fish community and offers a wide range of fishing opportunities. It is well known for its walleye fishery and its ability to produce large panfish. Other species commonly targeted by anglers include bluegill, black crappie, northern pike, and largemouth bass. Typical of most large walleye fisheries, natural reproduction contributes greatly to population abundance. The DNR stocks fry on an annual basis and fingerling stockings are prescribed following documentation of two consecutive years of limited contributions from natural reproduction and fry stocking.

The fish community in Smith Lake is diverse and supports good fishing opportunities. Habitat attributes are typical of a "bass-panfish" lake. Primary gamefishes include walleye, northern pike, largemouth bass, bluegill, and black crappie. Walleye are stocked every other year (odd numbered years) to sustain a viable fishery.

Fish community data for each lake was summarized by trophic groups (Figures 2.14 through 2.17). Species within a trophic group serve the same ecological process in the lake (i.e., panfish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community then analyzing individual species trends. The following conclusions can be drawn from the fish data:

- Lake Osakis represents the headwaters of the Sauk River and this large river system undoubtedly has an impact on the lake's fish population. Shorthead redhorse is a common river species that was captured and documented in numerous Lake Osakis fish surveys. Other species, such as smallmouth bass, tulibee cisco and white suckers can live and survive in both lake and stream environments. The Sauk River may also aid in the migration and movement of carp and other rough fish in and out of the system.
- Rough fish (primarily black and yellow bullhead) have typically been the most abundant species for a majority of the Osakis Lake surveys since 1950.
- At least one common carp was captured in 11 of the 14 Osakis Lake surveys and 3 of the 10 Smith Lake surveys. No common carp were captured during the Osakis surveys from 1950 through 1986; however, each survey since 1989 have netted at least one carp. 2001, 2006 and 2010 are the only sampling years where common carp were netted in Smith Lake. It should be noted that common carp abundance might not be accurately assessed using DNR surveys. However, the current methods allow reasonable year-to-year comparisons. Carp specific surveys would ultimately assess actual carp abundance in each lake.
- Top predators have comprised the largest percentage of the total biomass catch during 7 of the 14 Osakis surveys and 8 of the 10 Smith Lake DNR surveys. In both lakes, northern pike, walleye and bowfin make up a majority of the predator biomass. While top predator biomass in Smith Lake is high, overall abundance is relatively low, suggesting a few large individuals. The low abundance may not be able to adequately control the panfish population.

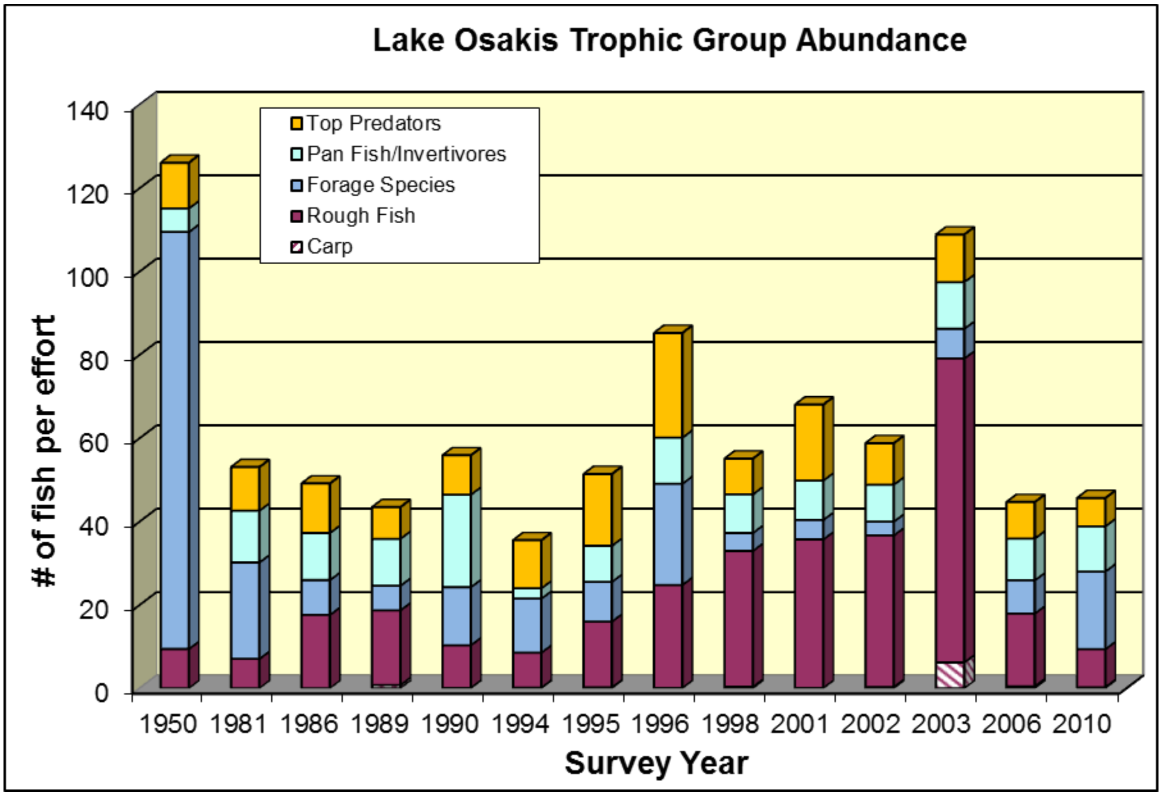

Figure 2.14. Trophic group abundance in Lake Osakis based on historic MN-DNR fish survey results.

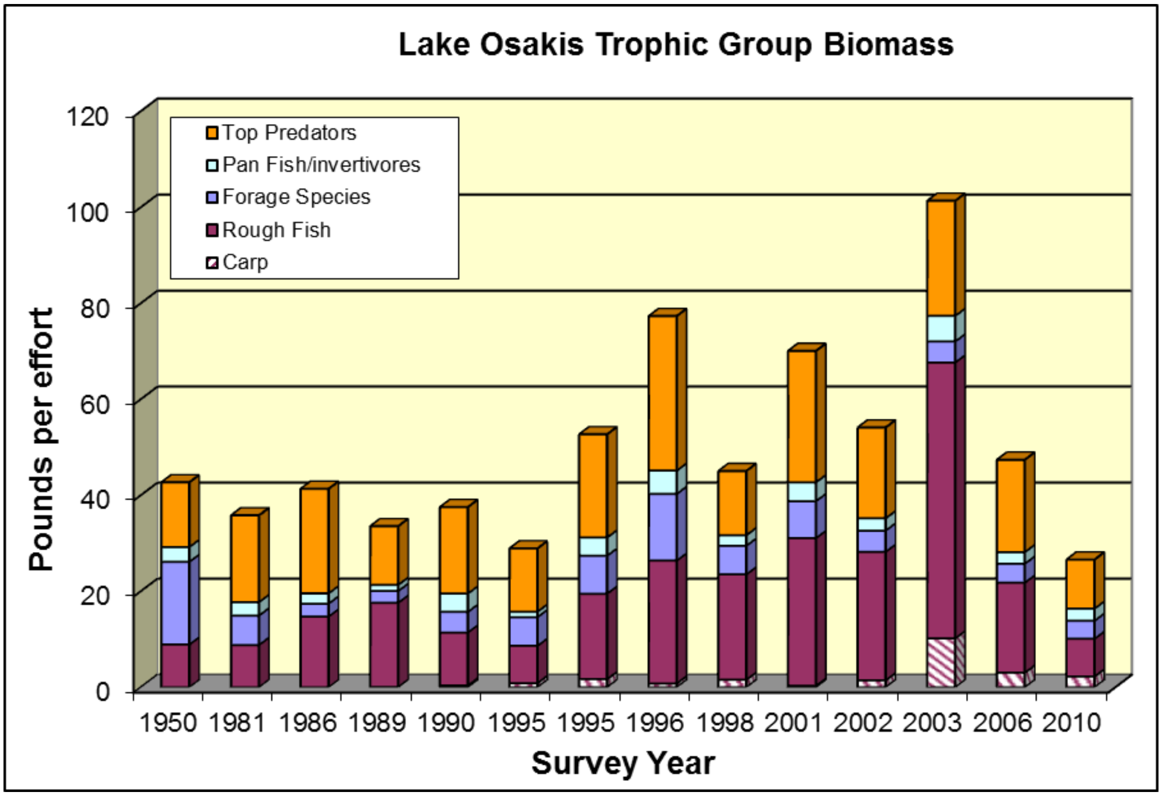

Figure 2.15. Trophic group biomass in Lake Osakis based on historic MN-DNR fish survey results.

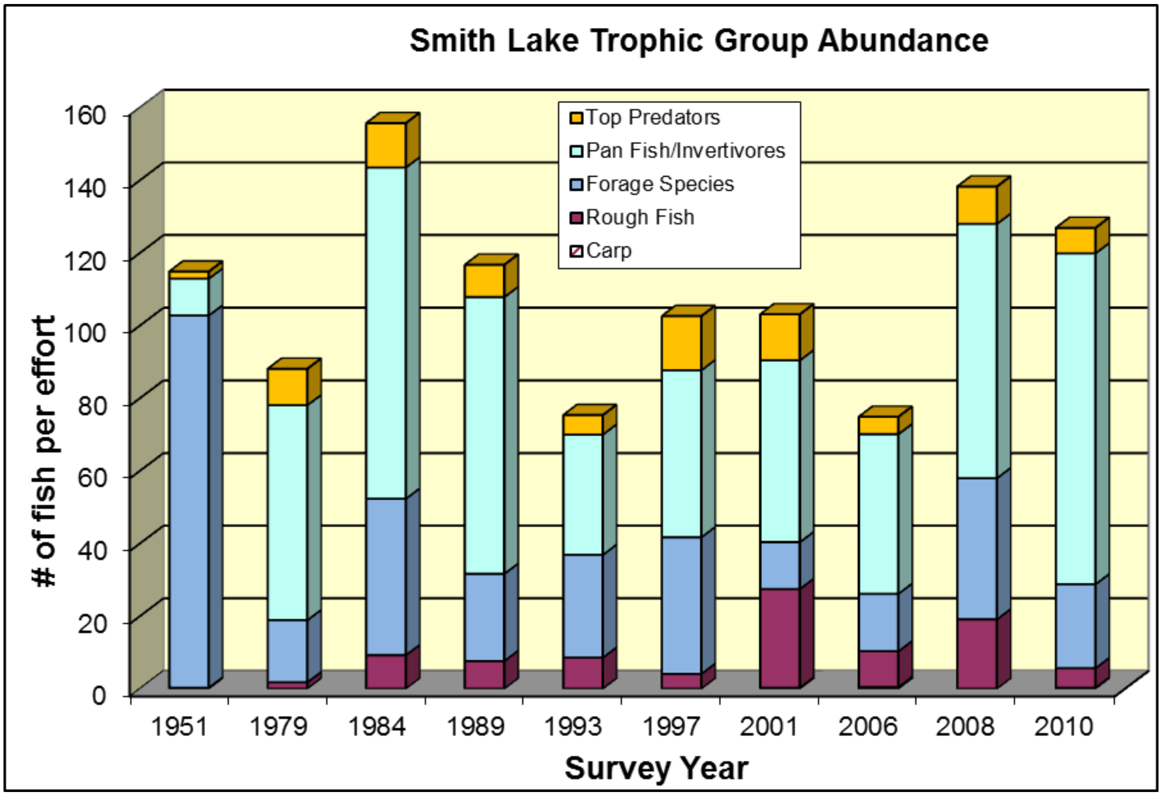

Figure 2.16. Trophic group abundance in Smith Lake based on historic MN-DNR fish survey results.

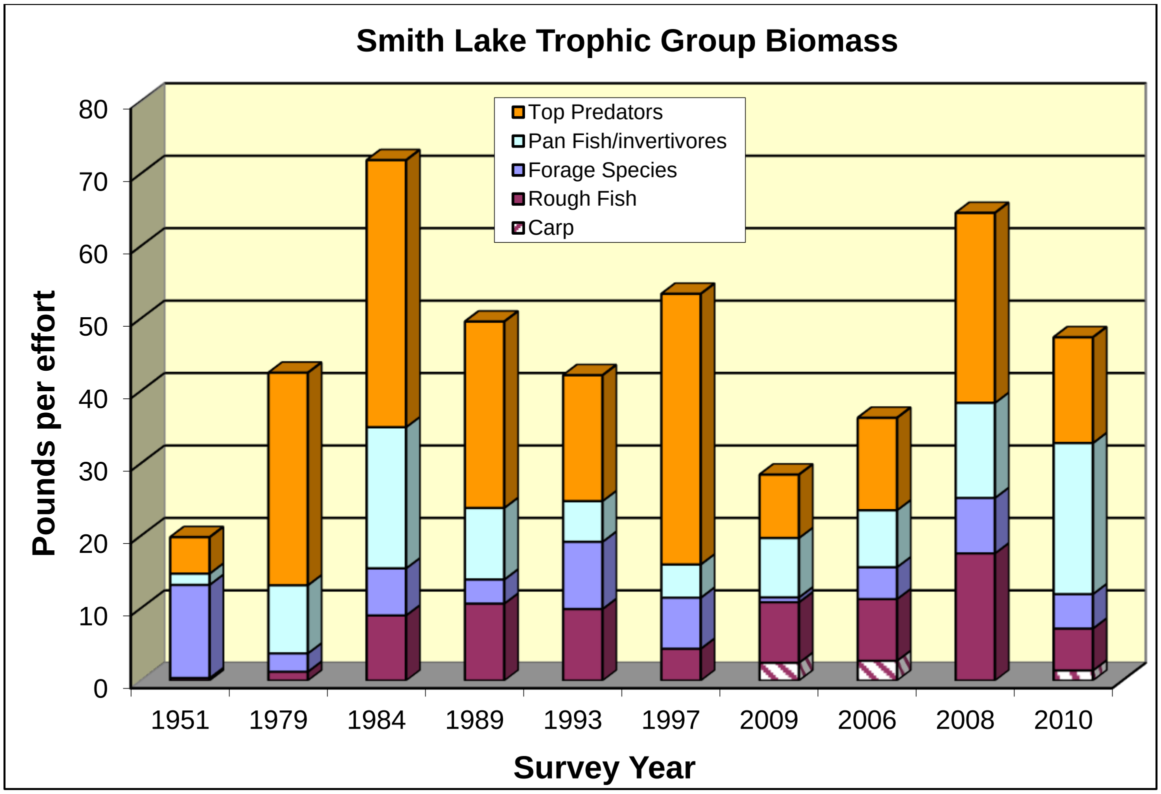

Figure 2.17. Trophic group biomass in Smith Lake based on historic MN-DNR fish survey results.

2.5.2 Carp

Common carp have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. Carp and other rough fish are present in Osakis and Smith Lakes, but their size and composition is currently unclear. Although no data is available, carp are also likely to exist in Faille Lake since it is hydrologically connected to Lake Osakis. Standard DNR methods are not particularly effective at capturing carp. However, when carp populations are quite large, the DNR methods often do catch some. Common carp have been captured in all Osakis surveys since 1989 and three out of the last four Smith Lake DNR surveys. Further analysis may be needed to better characterize the carp population for both lakes. However, based on year to year comparisons from DNR surveys, current carp populations appear to be relatively small and likely are having little impact on lake water quality.

2.5.3 Aquatic Plants

Aquatic plants are beneficial to lake ecosystems, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. However, in high abundance and density they limit recreation activities, such as boating and swimming, and may reduce aesthetic value. Excess nutrients in lakes can lead to non-native, invasive aquatic plants taking over a lake. Some exotics can lead to special problems in lakes. For example, under the right conditions, Eurasian watermilfoil can reduce plant biodiversity in a lake because it grows in great densities and out-competes all the other plants. Ultimately, this can lead to a shift in the fish community because these high densities favor panfish over larger game fish. Species such as curly-leaf pondweed can cause very specific problems by changing the dynamics of internal P loading. Overall, there is a delicate balance within the aquatic plant community in any lake ecosystem.

The littoral zone is defined as that portion of the lake that is less than 15 feet in depth and is where the majority of the aquatic plants are found. The littoral zone of the lake also provides the essential spawning habitat for most warm water fishes (e.g. bass, walleye, and panfish). Faille Lake is predominantly littoral and should support a healthy rooted aquatic plant community. The key is fostering a diverse population of rooted aquatic plants that is dominated by native (non-invasive) species.

To date, there have been no fish or vegetation surveys performed on Faille Lake. The DNR conducted qualitative plant surveys during the August 1949, September 1981 and August 1994 Lake Osakis surveys. In May through June of 2006, the DNR conducted a quantitative point-intercept plant survey to assess the spring plant community of Osakis Lake (Perleberg 2006; Appendix D). Lake Osakis possesses a moderately diverse aquatic plant community with 43 different species observed across the various surveys, with a mix of emergent, floating leaf and submerged plant species. There were 19 different submerged species observed during the four aquatic plant surveys from 1949 through 2006 (Figure 2.18). There was a relatively high abundance of native submergent vegetation species such as water celery, sago pondweed, clasping-leaf pondweed, flat-stem pondweed and coontail. There was also less desirable aquatic vegetation species present in high occurrence and abundance including curly-leaf pondweed and muskgrass. Curly-leaf pondweed was first noted in the lake during the 1994 lake survey by the DNR. Osakis Lake is not on the 2011 Minnesota DNR Designated Infested Waters list for Eurasian water milfoil or the other nuisance species included in this list.

Vegetation surveys for Smith Lake were performed by the DNR in conjunction with the September 1969, June 1979 and July 1997 fish surveys. Survey results indicate Smith Lake has a moderately diverse aquatic plant community with 14 different submerged species observed across the three surveys (Figure 2.19). The two most common native submerged plant species observed during the most recent survey were coontail and narrowleaf pondweed. Muskgrass, water milfoil and white-stem pondweed are the other native submerged plant species commonly observed in Smith Lake over the three survey years.

One of the submerged species noted in both Osakis and Smith, curly-leaf pondweed, is invasive and has been one of the more dominant species in Smith Lake dating all the way back to 1969 and in Osakis Lake since 1994. Curly-leaf pondweed is an invasive species that can easily take over a lake’s aquatic macrophyte community. Curly-leaf pondweed presents a unique problem in that it is believed to significantly affect the in-lake availability of P, contributing to the eutrophication problem. Curly-leaf pondweed begins growing in late-fall, continues growing under the ice, and dies back relatively early in summer, releasing nutrients into the water column as it decomposes, possibly contributing to algal blooms. Curly-leaf pondweed can also out-compete more desirable native plant species.

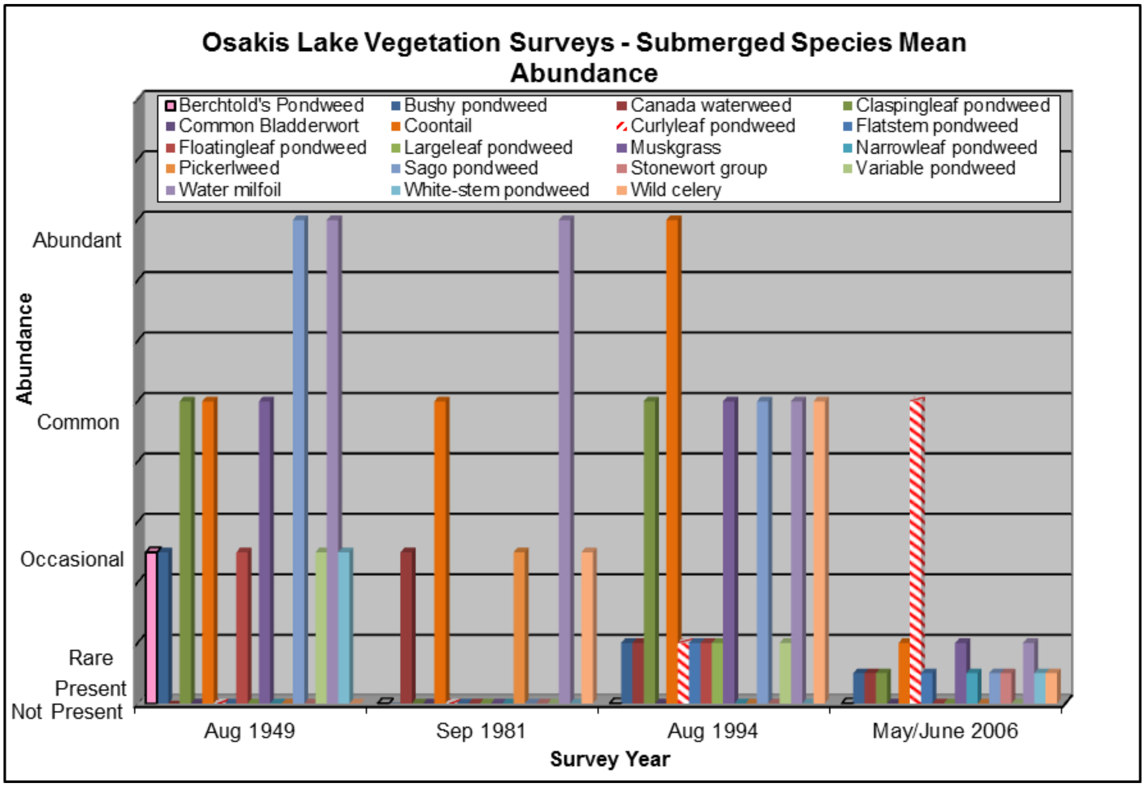

Figure 2.18. Submerged aquatic plant species in Lake Osakis.

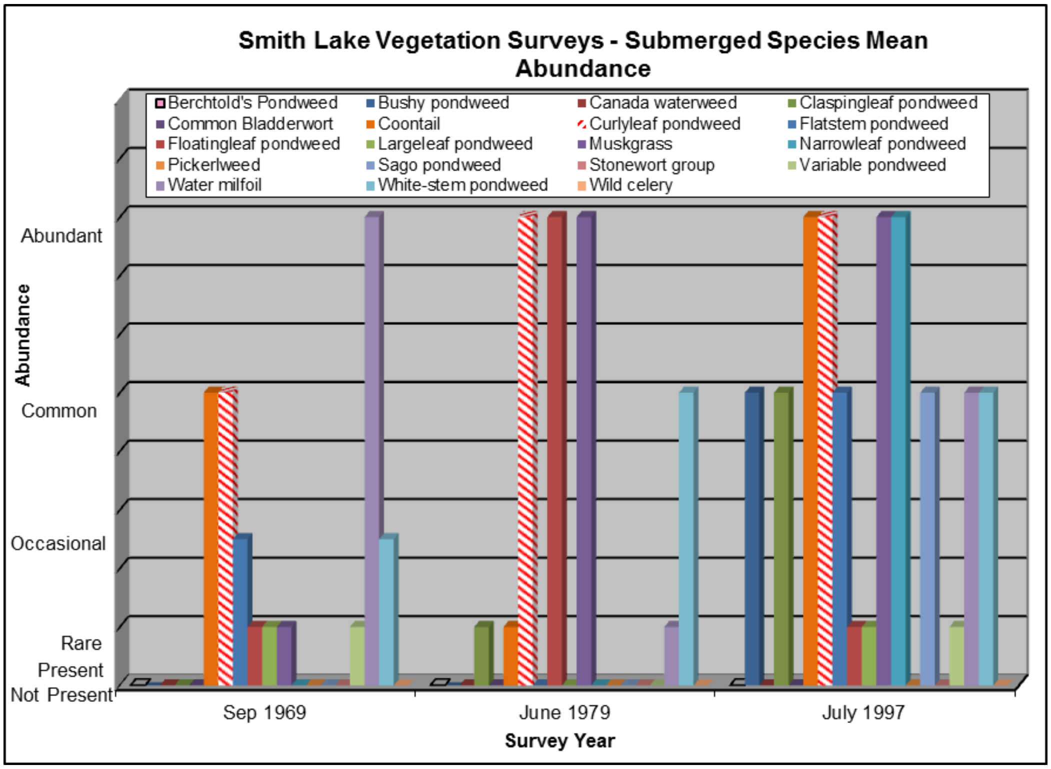

Figure 2.19. Submerged aquatic plant species in Smith Lake.

2.5.4 Shoreline Habitat and Conditions

The shoreline areas are defined as the areas adjacent to the lake's edge, with hydrophytic vegetation and water up to 1.5 feet deep or a water table within 1.5 feet from the surface. Natural shorelines provide water quality treatment, wildlife habitat, and increased biodiversity of plants and aquatic organisms. Natural shoreline areas also provide important habitat to fisheries including spawning areas and refugia as well as aesthetic values. In addition to the ecological benefits, natural shorelines can stabilize sediments, and protect lake edges from wave-induced erosion. Natural shoreland exists around Smith, Faille and Osakis; however, no quantitative data have been collected to date.

2.6 STREAM MONITORING

The SRWD and the MPCA staff have monitored continuous flow on JD #2 at sites S003-303 and S002-647 from 2006 through 2010. Both of these stations are located close to the outlet of JD #2 to Osakis Lake (Figure 2.4). Periodic TP, ortho-phosphorus and TSS grab samples were also collected at S003-303 from 1995-2010 and at S002-647 from 2004-2010. The TP data from the most downstream JD #2 monitoring station, S002-647, shows concentrations are high and often exceed the proposed state stream TP standard of 100 µg/L (Figure 2.20). Ortho-phosphorus concentrations are also high and suggest a large portion of the P load from JD #2 is in dissolved form. Pollutant loads to Osakis Lake were estimated and are discussed in the source assessment section (3.3.2) of this report.

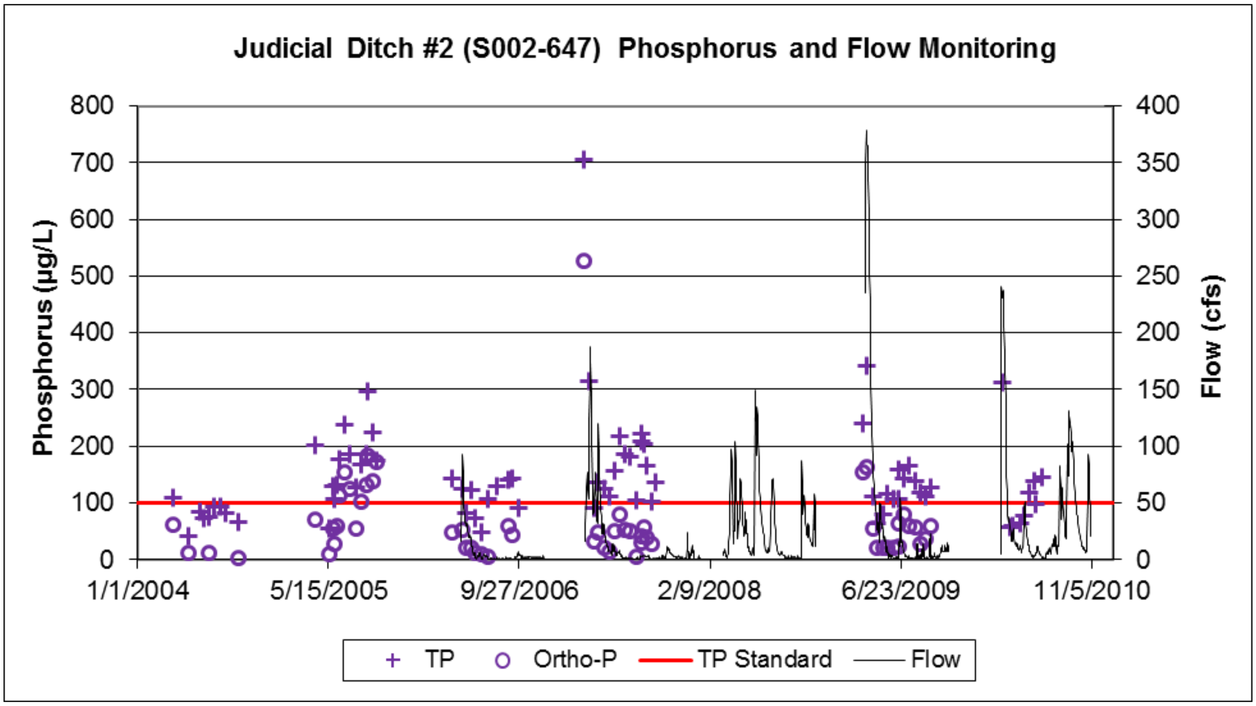

Figure 2.20. Total phosphorus, ortho-phosphorus and flow monitoring at S002-647 since 2004.

In addition to the aforementioned monitoring stations, there are 21 stream, ditch and tributary monitoring sites throughout the Osakis Lake Watershed where at least one P grab has been collected since 1990 (Figure 2.4). It should be pointed out, however that most of these have less than 20 measurements and do not have any continuous flow records and very few gaged flow measurements. Watershed TP sampling for each stream station is summarized in Appendix E.

3.0 Nutrient Sources and Lake Response

3.1 INTRODUCTION

Understanding the sources of nutrients to a lake is a key component in developing an excess nutrient TMDL for lakes. To that end, a P budget that sets forth the current P load contributions from each potential source was developed using the modeling and collected data described below. Additionally, lake response models can be developed to understand how different lake variables respond to changes in nutrient loads.

3.2 MODELING APPROACH

Several models were used to develop the nutrient budget necessary to establish load and WLAs. See USEPA (1997) for general information about watershed and receiving water body modeling.

3.2.1 Watershed Models

A unit-area load (UAL) and runoff coefficient approach was used to develop watershed runoff and P loading totals to each of the lakes. The watershed was broken into Hydrologic Response Units (HRU), which are unique combinations of land cover, soils, and slope. Each HRU is treated independently to estimate runoff and TP loading.

To estimate annual water volumes, a runoff coefficient approach was applied for each HRU for the monitored years (McCuen 2004). Then, a unique calibration factor was universally applied to the land use runoff coefficients to match each year to the monitored volumes (Table 3.1). This runoff coefficient was applied to the unmonitored areas to estimate runoff from those areas. For years where no monitoring data were available, an average runoff coefficient calibration factor (0.72) was applied. Runoff coefficients for each HRU are presented in Appendix F.

Table 3.1. Runoff data and model results for Judicial Ditch #2

Year	Precipitation (in)	Observed flow (acre-ft)	Observed runoff (in)	Model Flow (acre-feet)	Calibration Factor for Runoff Coefficient
2001	24.7	--	--	11,609	0.72
2002	25.1	--	--	15,565	0.72
2003	33.7	--	--	13,453	0.72
2004	29.1	--	--	11,840	0.72
2005	25.7	--	--	18,398	0.72
2006	22.30	3,412	1.06	10,306	0.24
2007	25.18	8,786	2.73	8,889	0.55
2008	29.66	13,572	4.22	13,480	0.71
2009	26.28	15,876	4.93	15,785	0.75
2010	32.79	18,340	5.70	18,311	0.87
Average	27.24	11,997	3.73	13,354	0.62
2007-2010 Average					0.72

To estimate potential source areas, a runoff TP concentration was applied to each HRU (MPCA 2008; Appendix F). These results are used to identify potential loading areas for TP from varied land uses. Model agreement is presented in Figure 3.1. However, these results are only used to assess potential TP sources in the watershed. Estimation of actual TP loading was developed by using available P monitoring data, which is further described in Section 3.3.2.

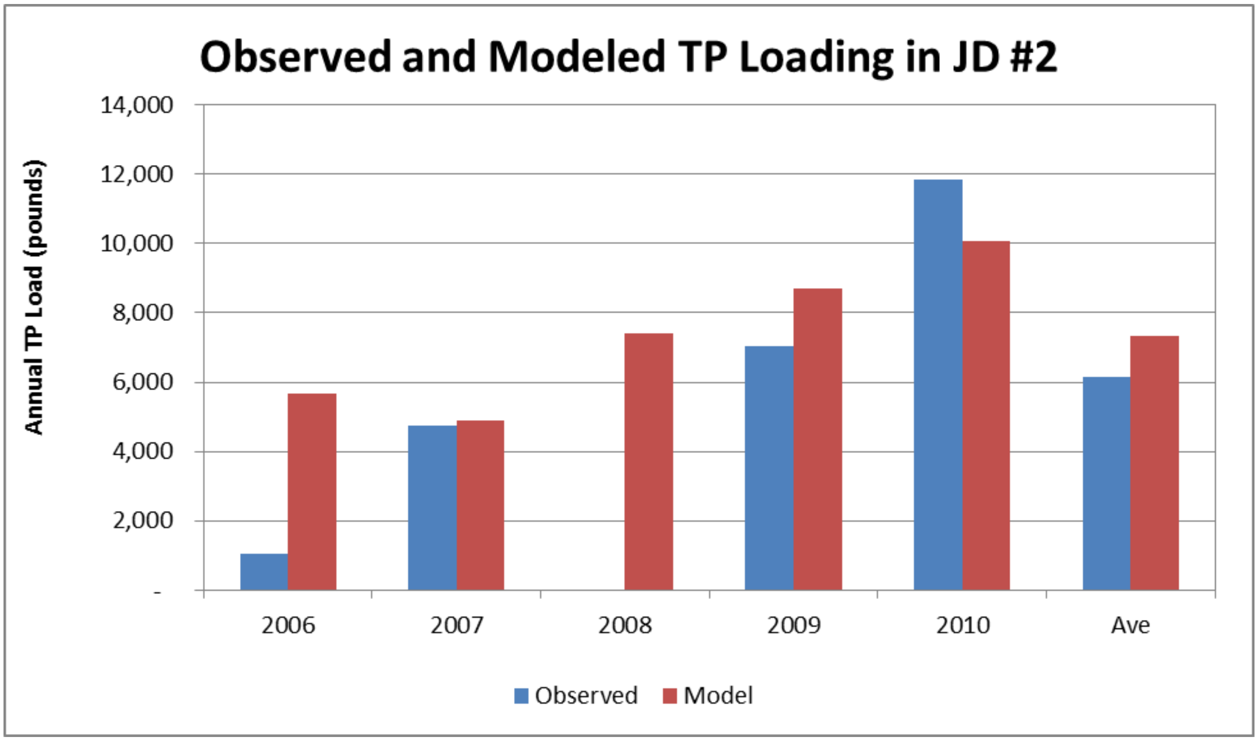

Figure 3.1. Observed and modeled TP loading in JD #2.

3.2.2 Internal Loading

The next step in developing an understanding of nutrient loading to the lakes is to estimate internal nutrient loads. Internal P loading from lake sediments has been demonstrated to be an important aspect of the P budgets of lakes. However, measuring or estimating internal loads can be difficult, especially in shallow lakes that may mix many times throughout the year.

To estimate internal loading, an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, is estimated from the DO profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor is then used along with a sediment release rate to estimate the TP load from the sediments. P release rates were estimated from sediment P concentrations and release rates provided in a previous study (Barr Engineering 2006; Appendix G).

3.2.3 Atmospheric Load

The atmospheric load refers to the load applied directly to the surface of the lake through atmospheric deposition. Atmospheric inputs of P from wet and dry deposition are estimated using rates set forth in Barr Engineering (2007), and are based on annual precipitation. The values used for dry (less than 25 inches), average, and wet precipitation years (greater than 38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km^2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre-year for dry, average, and wet years in English units, respectively.

3.2.4 BATHTUB Model (Lake Response)

Once the nutrient budget for a lake has been developed, the response of the lake to those nutrient loads must be established. The focus of the lake response modeling is on TP, chlorophyll-a and Secchi depth. For this TMDL, the BATHTUB model was selected to link P loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). BATHTUB has been used successfully in many lake studies in Minnesota and throughout the United States.

BATHTUB is a steady-state annual or seasonal model that predicts a lake's summer (June through September) mean surface water quality. BATHTUB's time-scales are appropriate because watershed P loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. The heart of BATHTUB is a mass-balance P model that accounts for water and P inputs from watershed runoff, the atmosphere. BATHTUB also computes P losses from the lake through the lake outlet, water loss via evaporation, and P sedimentation and retention in the lake sediments. P inputs that were deemed important to the P budget of the lakes in this TMDL include tributary loading, direct watershed runoff (near-lake), upstream lakes, failing septic systems, atmospheric deposition, and P release from sediment under anoxic conditions. All inputs were calculated outside of BATHTUB and then entered into the BATHTUB model interface. Section 3.3 provides detailed descriptions of how each input were calculated. Appendix H provides a final summary of the BATHTUB inputs and outputs for the Smith Lake and Lake Osakis TMDLs; Section 9.2 in the Faille Lake 2023 Addendum provides a BATHTUB summary for the Faille Lake TMDL.

BATHTUB allows choice among several different mass-balance P models. For deep lakes in Minnesota, the option of the Canfield-Bachmann Lake formulation has proven to be appropriate in most cases. For shallow Minnesota lakes, other options such as a second order decay model have often been more useful. BATHTUB's in-lake water quality predictions include two response variables, chlorophyll-*a* concentration and Secchi depth, in addition to TP concentration. Empirical relationships between in-lake TP, chlorophyll-*a*, and Secchi depth form the basis for predicting the two response variables. Among the key empirical model parameters is the ratio of the inverse of Secchi depth (the inverse being proportional to the light extinction coefficient) to the chlorophyll-*a* concentration. The ratio's default value in the model is 0.025 meters squared per milligram (m^2/mg); however, the experience of the MPCA staff supports a lower value, as low as 0.015 m^2/mg, as typical of Minnesota lakes in general.

A BATHTUB lake response model was constructed using the nutrient budget developed using the methods previously described in this section. As many years as possible out of the last 10 years were modeled to validate the assumptions of the model. Several models (subroutines) are available for use within the BATHTUB model. The selection of the subroutines is based on past experience in modeling lakes in Minnesota and is focused on subroutines that were developed based on data from natural lakes. The Canfield-Bachmann natural lake model was chosen for the P model as it performs well for lakes with limited data inputs and is widely accepted by the MPCA. For more information on these model equations, see the BATHTUB model documentation (Walker 1999) or the MPCA report (MPCA 2005). Model coefficients are also available in the model for calibration or adjustment based on known cycling characteristics. Any applied calibration coefficients are discussed in Section 3.4.

3.3 ESTIMATION OF SOURCE LOADS

3.3.1 Atmospheric Load

The atmospheric loads (pounds/year) for the lakes were calculated by multiplying the lake area (acres) by typical atmospheric deposition rates for wet (0.259 lbs/acre/year) average (0.239 lbs/acre/year) and dry (0.222 lbs/acre/year) precipitation years (Barr Engineering 2007). For example, in an average precipitation year the atmospheric load to Lake Osakis would be 0.24 pounds/acre-year times the lake surface area (6,361 acres), which is 1,520 pounds/year. Atmospheric loads were calculated for each year modeled in BATHTUB (Table 3.2; Appendix H).

3.3.2 Watershed Phosphorus Loading

Watershed runoff and P loads to Osakis and Faille Lake were calculated using the runoff coefficient model and TP monitoring data. The UAL P model was used to predict watershed P loads to Smith Lake since there was no stream TP monitoring data available. Runoff and P loads were calculated for each year modeled in BATHTUB (Table 3.2).

Table 3.2. Runoff and phosphorus loading by subwatershed. Watershed runoff and phosphorus load estimates for Maple Lake Downstream, JD #2 and Faille Lake Direct Subwatersheds do not include estimated outflow and loads from upstream lakes.

Subwatershed	Years Modeled	Average Runoff[1] (acre-ft/year)	Average TP (µg/L)	Average TP Load (lbs/year)
Smith Lake Direct[2]	04, 05, 08, 10	4,412	190	2,282
Faille Lake Direct[3]	03, 04, 07	109	199	59
Judicial Ditch #2[4]	04-07, 09	9,846	141	3,784
Maple Lake Downstream[5]	04-07, 09	1,673	455	2,070
Osakis Lake Direct	04-07, 09	3,351	455	4,146

[1] Runoff calculated using runoff coefficient model

[2] Phosphorus load calculated using UAL phosphorus model

[3] Average phosphorus runoff concentration calculated using monitored data from S003-296. Calculations were modified from the original 2013 TMDL to reflect just the direct drainage area downstream of the intermediate wetlands. See Figure 9.1 in Section 9.0: *Faille Lake 2019 Addendum* for more information.

[4] Average phosphorus runoff concentration for JD #2 calculated using monitored data from S002-647

[5] Downstream and Osakis Lake Direct subwatershed runoff concentration calculated using monitored data from S003-537, S003-538, S003-539, S003-540 and S003-541.

3.3.2.1 Upstream Lakes

Lake outflow volumes and P loads from Smith, the intermediate wetlands, Faille, Little Osakis and Maple Lakes were calculated using the runoff coefficient model and average monitored in-lake TP concentrations (Table 3.3).

Table 3.3. Lake outflow volumes and phosphorus loads.

Lake	Downstream Lake	Years Modeled	Average Outflow[1] (acre-ft/year)	Average TP[2] (µg/L)	Average TP Outflow (lbs/year)
Smith	Osakis	04-07, 09	3,747	52	531
Intermediate wetlands[3]	Faille	03, 04, 07	4,522	244	2,989
Faille	Osakis	04-07, 09	4,983	161	2,180
Little Osakis	Osakis	04-07, 09	2,654	34	246
Maple Lake	Osakis	04-07, 09	1,943	81	427

[1] Runoff calculated using runoff coefficient model

[2] Average phosphorus concentrations calculated using summer monitored values

[3] Calculations were modified from the original 2013 TMDL to reflect the outflow from the intermediate wetlands in the Faille Lake watershed. See Section 9.0: *Faille Lake 2023 Addendum* for more information

3.3.2.2 Loading by Land use

Figure 3.2 shows average annual P loading throughout the Osakis Lake Watershed calculated using the UAL model. Table 3.4 summarizes average (2000 through 2010) annual P loading model results by land use for the entire watershed. Results indicate agricultural land practices, primarily pasture/hay and corn/soybean rotations, are the biggest contributors of watershed P loading in the Osakis Lake Watershed. Runoff from roads/highways and urban areas throughout the watershed also contribute a relatively large amount of P.

Table 3.4. Unit area load model average annual phosphorus load by land use in the Osakis Lake watershed.

Land use	Phosphorus Loading (Percent of total)
Pasture land	48%
Corn/Soybean	25%
Urban/Roads	22%
Alfalfa/Wheat/Rye	4%
Forested	1%
Other Agriculture	<1%

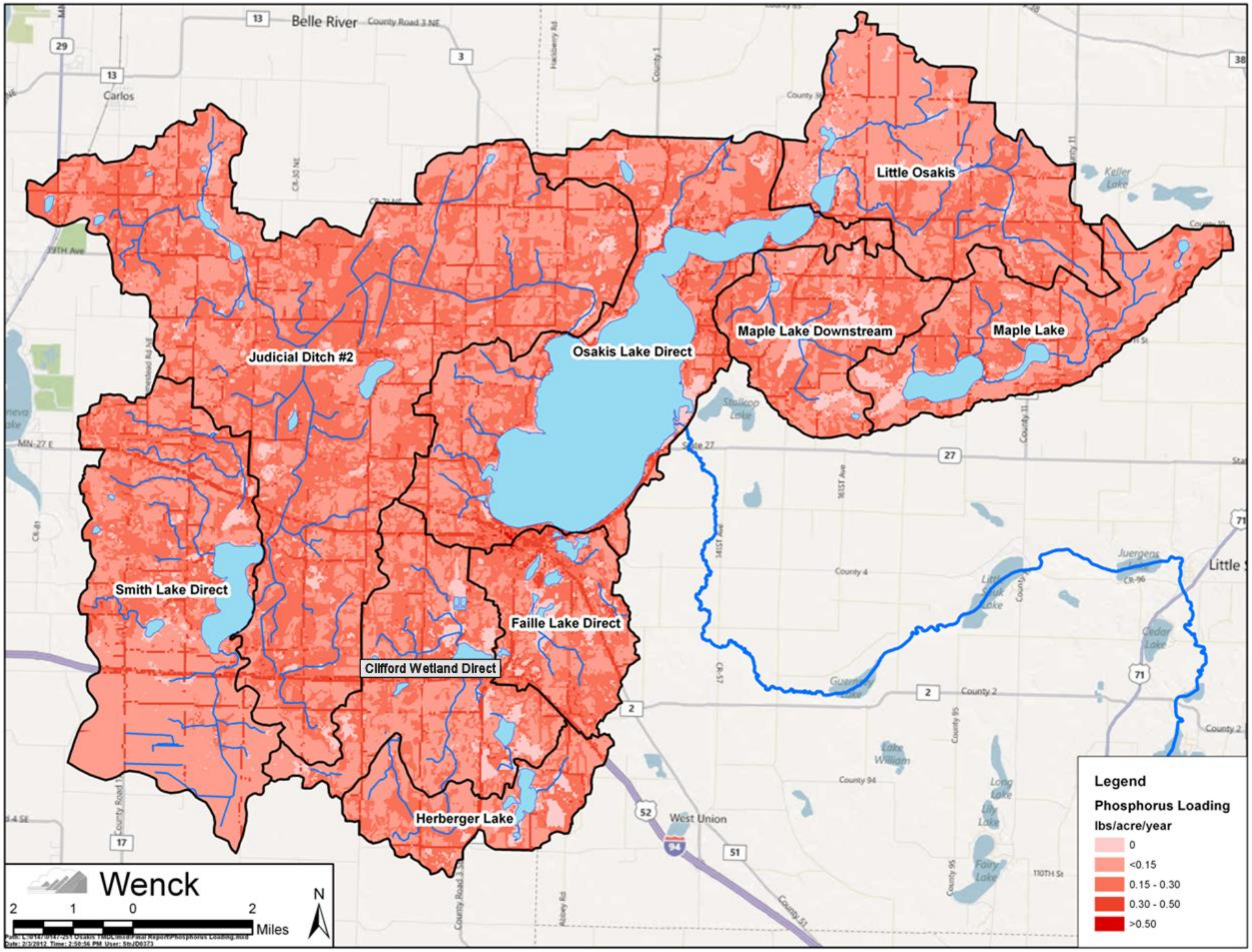

Figure 3.2. Average annual phosphorus loading in the Osakis Lake Watershed.

3.3.2.3 Animal Agriculture

To assess the role of manure management on surface water nutrient concentrations and loads, an inventory of all registered agricultural animals in the watershed was conducted. The MPCA maintains a statewide GIS database of registered feedlots throughout the state of Minnesota. The MPCA categorizes feedlots based on the number of registered AUs. AUs are the standardized measurement of animals for various agricultural purposes. AUs are calculated by multiplying the number of animals by their average weight in pounds and dividing by 1,000.

Owners with fewer than 300 AUs are not required to have a permit for the construction of a new facility or expansion of an existing facility as long as construction is in accordance with technical standards. For owners with 300 AUs or more, and less than 1,000 AUs, a streamlined short-form permit is required for construction/expansion activities. Any feedlot that meets one of the criteria below is considered a large concentrated animal feeding operation (CAFO) by Minnesota state rules:

- 700 mature dairy cows, whether milked or dry
- 1,000 veal calves
- 1,000 cattle other than mature dairy cows or veal calves. Cattle includes but is not limited to heifers, steers, bulls and cow/calf pairs
- 2,500 swine each weighing 55 pounds or more
- 10,000 swine each weighing less than 55 pounds
- 500 horses
- 10,000 sheep or lambs
- 55,000 turkeys
- 30,000 laying hens or broilers, if the AFO uses a liquid manure handling system
- 125,000 chickens (other than laying hens), if the AFO uses other than a liquid manure handling system
- 82,000 laying hens, if the AFO uses other than a liquid manure handling system
- 30,000 ducks (if the AFO uses other than a liquid manure handling system)
- 5,000 ducks (if the AFO uses a liquid manure handling system)

CAFOs are required by state rules to apply for a National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) Permit (Permit). These operations, by law, are not allowed to discharge to waters of the state (Minn. R. 7020.2003). There are currently two turkey feedlots located in the Osakis Lake Direct Subwatershed and one turkey feedlot in the Smith Lake Direct Subwatershed that are permitted as CAFOs (feedlot ID # 041-98420, 041-66945 and 041-50001).

Animal agriculture is a prominent use throughout the Lake Osakis Watershed. Manure produced by the animals in the watershed is applied to fields and pastures for fertilizer as well as general manure management. Manure that is applied beyond the nutrient uptake ability of the fields moves easily into surface waters adding to eutrophication and nutrient loads.

There are 129 separate animal operations and more than 13,000 total AUs throughout the Osakis Lake Watershed (Table 3.5). Dairy and beef cattle operations together account for well over 50% of the AUs throughout the watershed. Owners of an animal feedlot or manure storage area with 50 or more AUs (10 AUs in shoreland areas) are required to register with the MPCA.

Table 3.5. Total AUs by animal type throughout the Osakis Lake Watershed.

Watershed	Dairy Cows	Beef Cows	Swine	Horses	Sheep	Chickens	Turkeys	Other	Total
Herberger Lake	174	17	0	1	0	0	0	0	192
Clifford Wetland Direct	824	60	0	0	0	0	425	0	1,309
Faille Lake Direct	478	233	0	12	5	0	0	0	728
Smith Lake Direct	271	357	69	3	20	1	612	0	1,334
Judicial Ditch #2	1,619	2,832	177	55	7	1	0	135	4,827
Little Osakis	975	1,040	62	8	0	0	0	0	2,085
Maple Lake	395	555	5	46	7	0	0	14	1,022
Maple Lake Downstream	367	106	0	5	0	0	0	20	498
Osakis Lake Direct	498	313	0	28	0	0	989	1	1,830
Watershed total	5,601	5,513	313	158	39	3	2,026	170	13,823

The total mass of P produced by each AU category can be estimated using literature values (Evans et al. 2002). Based on these estimates, over 1.1 million pounds of P are potentially applied to land in the form of manure throughout the Osakis Lake Watershed (Table 3.6). To put this in perspective, total loading to Osakis Lake is typically around 15,171 pounds or approximately 1% of the P applied to the land throughout the entire watershed. Only a small proportion of this P need make its way into each lake to cause serious eutrophication issues.

Table 3.6. Agricultural animal phosphorus production in the Osakis Lake watershed.

Watershed	[1]Agricultural Land (Acres)	Total P (lbs/day)	Total P (lbs/year)	[2]Total P (lbs/year/acre)
Herberger Lake	2,253	30	10,793	4.8
Clifford Wetland Direct	5,253	323	117,833	22.4
Faille Lake Direct	2,597	121	44,176	17.0
Smith Lake Direct	7,885	410	149,653	19.0
Judicial Ditch #2	20,568	918	335,451	16.3
Little Osakis	5,542	376	137,239	24.8
Maple Lake	3,796	184	67,127	17.7
Maple Lake Downstream	3,236	83	30,305	9.4
Osaki Lake Direct	5,695	577	210,609	37.0
Watershed total	56,825	3,020	1,103,185	19.4

[1] Only includes land where manure is potentially spread (corn/soybeans and other row crops) or directly deposited (pasture)
[2] Calculated by dividing total agricultural animal phosphorus production by agricultural land in each watershed

The Osakis Watershed UAL model does not explicitly model P contributions from manure spreading. The model does, however, implicitly account for animal contributions by calibrating to the Judicial Ditch #2 Watershed, which has 44 feedlot operations, 4,827 total AUs and a wide range of agricultural animal types. Judicial Ditch #2 is the largest tributary inflow to Lake Osakis and has been extensively monitored for water quality and flow in recent years (Figure 2.20). This subwatershed should be representative of the surrounding subwatersheds assuming manure practices are similar and spreading occurs close to where the animals are contained.

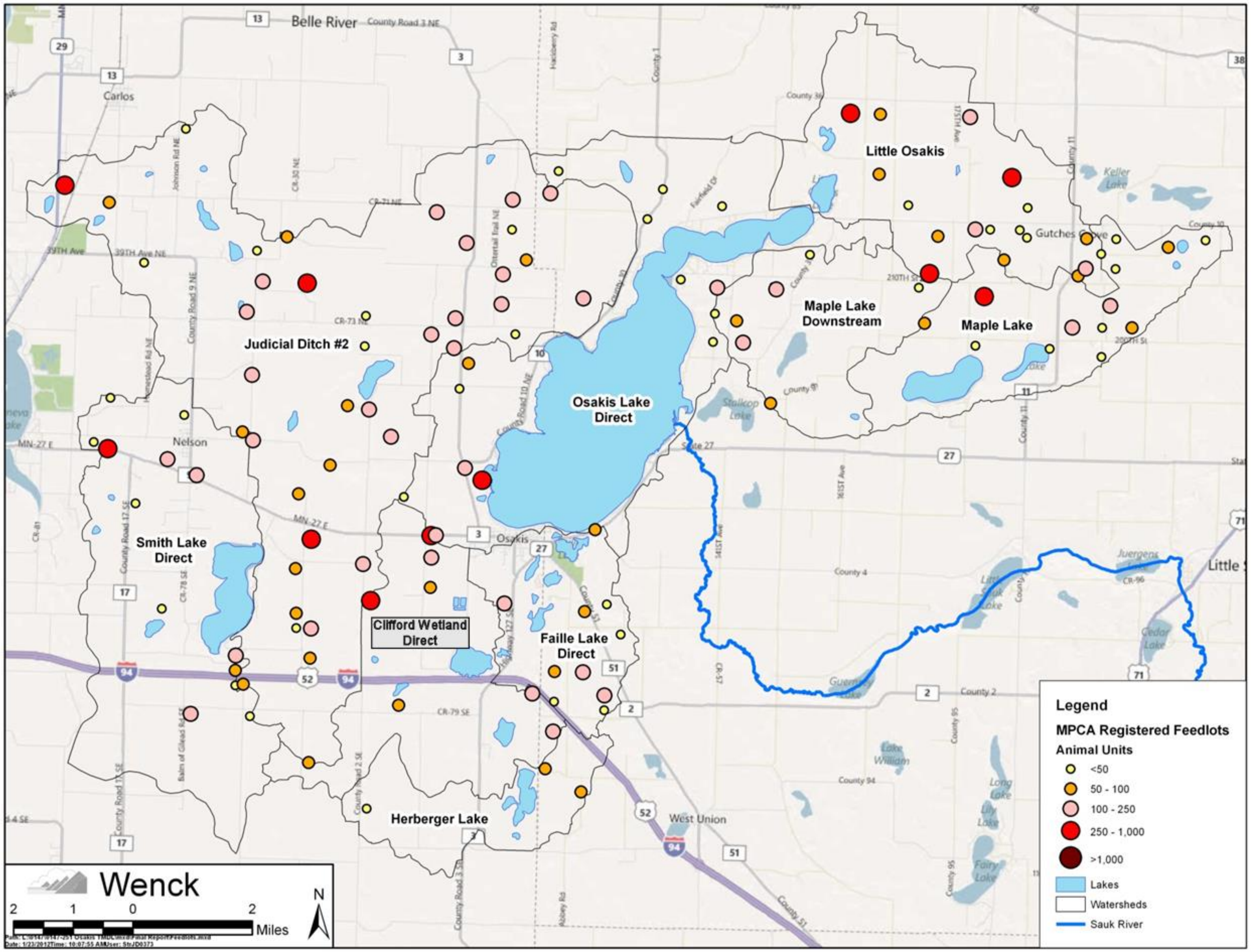

Figure 3.3. Feedlots in the Osakis Lake Watershed.

3.3.3 Septic Systems

Failing or nonconforming subsurface sewage treatment systems (SSTS) can be an important source of P to surface waters. In 2011, Todd County Planning and Zoning inspected over 200 SSTSs within 1,000 feet of Lake Osakis to determine which systems are in compliance or may be failing. Inspection results show that approximately 33% of the SSTSs surveyed were out of compliance or considered imminent environmental threats (Table 3.7). Wastewater from failing septic systems may include many types of contaminants such as P, nitrates, harmful bacteria and viruses, and other toxic substances, which can be hazardous to both groundwater and surface water.

Table 3.7. Todd County Planning and Zoning 2011 SSTS inspection results.

Status	Number	Percent of Total SSTS Inspected
Compliant	44	21%
Partial Compliance	96	46%
Failing	59	29%
Imminent Threat	8	4%
Total Inspections	207	100%

Douglas County recently applied for funds to inspect SSTSs in the watershed. However, to date, there have been no SSTS inspections in the Douglas County portion of the Osakis Watershed or in the rural areas of Todd County greater than 1,000 feet from Lake Osakis. Year 2000 census data was used to determine the population in these areas and the total number of SSTSs were estimated assuming there are, on average, 2.7 people per household. Failing SSTSs in Douglas County and rural Todd County were then estimated using the 33% failure rate discussed previously (Table 3.7). Finally, P loading to ground or surface water discharge from failing SSTS throughout the entire (inspected and non-inspected) Osakis Lake Watershed was estimated assuming an average P production rate of 2.7 grams/person/day (EPA 2002). Estimated SSTS P loads by subwatershed are presented in Table 3.8. These estimates are included as a separate P input load in each of the BATHTUB lake response models (Appendix H).

Table 3.8. Failing SSTS phosphorus loading estimates by watershed.

Subwatershed	Total SSTS	Failing SSTS	TP Load (lbs/year)
Clifford Wetland Direct	35	11	67
Faille Lake Direct	23	8	45
Herberger Lake	13	4	26
Smith Lake Direct	111	36	211
Judicial Ditch #2	235	76	447
Little Osakis	109	35	206
Maple Lake	68	22	129
Maple Lake Downstream	54	17	102
Osakis Lake Direct	816	261	1,531
Watershed Totals	1,464	470	2,764

3.3.4 Internal Phosphorus Loading

All of the lakes were assessed for anoxia and sediment P release rates to determine the mass of P released during the summer growing season. Anoxic conditions in lakes are often expressed as the number of days anoxia occurs over the entire lake or basin; this term is referred to as the anoxic factor. Once anoxia is quantified, the next step is to identify the rate at which sediments release P under anoxic conditions. This rate can then be used to estimate the gross internal loading based on the anoxic factor for the lake (Nürnburg 2004). Thus, all internal load calculations for Smith, Faille and Osakis Lakes were calculated outside of the BATHTUB model framework and then incorporated into the model as an individual P load.

Only very limited DO data are available for Smith Lake, with the most recent data collected in 2000. Smith Lake is considered a deep lake and demonstrated very little anoxia, suggesting that internal P loading is not an important source of P to the lake. A P release rate was not determined for Smith Lake.

For Faille Lake, DO data were collected monthly in 1999 through 2002 and in 2004. However, no anoxia was measured during any of these events. It is important to note that shallow lakes, such as Faille Lake can often demonstrate short periods of anoxia due to instability of stratification, which is often missed by monthly monitoring programs. So, for Faille Lake, an equation was used (Nürnberg 2005) to estimate the anoxic factor (65 days). A recent study estimated the internal P release rate to be 0.7 mg/m^2/day, which is quite low for a shallow lake (Barr 2006). The low release rate is not surprising because the lake received an alum treatment in spring of 2002. The total internal load for Faille Lake was estimated by multiplying the lake's area (78 acres) by the aforementioned release rate and anoxic factor (Table 3.9).

Lake Osakis had much more DO data available, which has been previously summarized (Appendices B and G). However, due to the size and large fetch of Lake Osakis, the thermocline is very deep minimizing the anoxic area in the lake. As a result, the anoxic factors are quite small (less than 12). Lake Osakis also demonstrates a relatively low P release rate based on estimates from sediment chemistry (Barr 2006; Appendix G). Internal loading is relatively small in Lake Osakis compared to the size and volume of the lake (Table 3.9).

Table 3.9. Estimated internal phosphorus release for Smith, Faille and Osakis Lake.

Lake	Year	Release Rate (mg/m^2/day)	Anoxic Factor (days)	Phosphorus Load (kilograms)	Phosphorus Load (pounds)
Smith	Average	NA	0	0	0
Faille	Average	0.7	64.5*	14	32
Osakis	2004	0.8	8.6**	166	365
	2005	0.8	0.3	6	13
	2006	0.8	10.0	193	426
	2007	0.8	12.0	232	511
	2009	0.8	12.0	232	511
	Average	0.8	8.6	166	365

*Anoxic factor calculated using equation developed by Nurnberg, 2005

**DO data not collected for this modeled year. Anoxic factor estimated based on the average of other monitored years.

3.4 LINKING WATER QUALITY TARGETS AND SOURCES

The final step in understanding lake response to nutrient loads is to link the previously described nutrient budgets to lake water quality. This step is accomplished through the use of the BATHTUB lake response model previously described in Section 3.2.4. The lake response models were applied using the water and nutrient budgets previously described in this section. Physical lake attributes such as volume, average depth, and surface area were derived from GIS and DNR contour maps. All model inputs are detailed in Appendix H.

Four years were modeled for Smith Lake with predicted values within 10% of monitored values (Figure 3.4). Modeled years were selected based on available water quality data over the past 10 years. A calibration factor of 1.31 was applied to the settling rate in all years to improve the model performance.

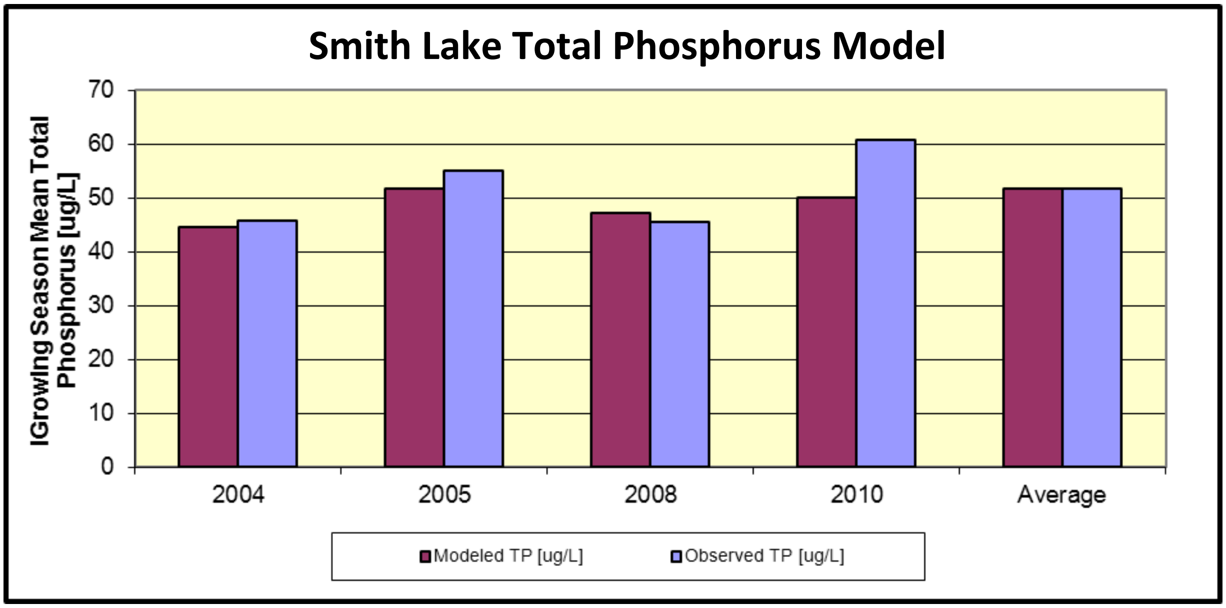

Figure 3.4. Observed versus BATHTUB model-predicted total phosphorus for Smith Lake.

Three years were modeled for Faille Lake with modeled values typically within 5% to 25% of observed values (Figure 3.5). Modeled years were selected based on available water quality data over the past 10 years. No calibration factor was needed improve the model performance.

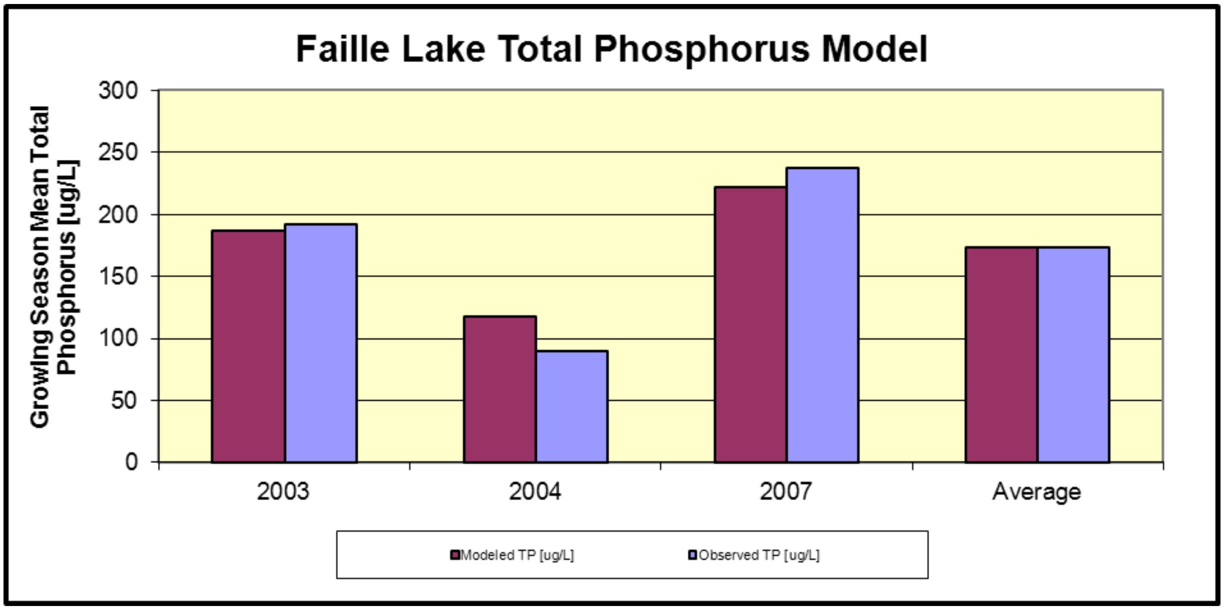

Figure 3.5. Observed versus BATHTUB model-predicted total phosphorus for Faille Lake.

Five years were modeled for Lake Osakis with modeled values typically within 5% to 25% of observed values (Figure 3.6) except for 2006. It is unclear why the model did not perform well in 2006; however, it is important to note that 2006 was a very dry year. It is likely that internal loading was underestimated for that year because of the long periods between DO profiles. Modeled years were selected based on available water quality data over the past 10 years. A calibration factor of 0.77 was applied to the settling rate in all years to improve the model performance.

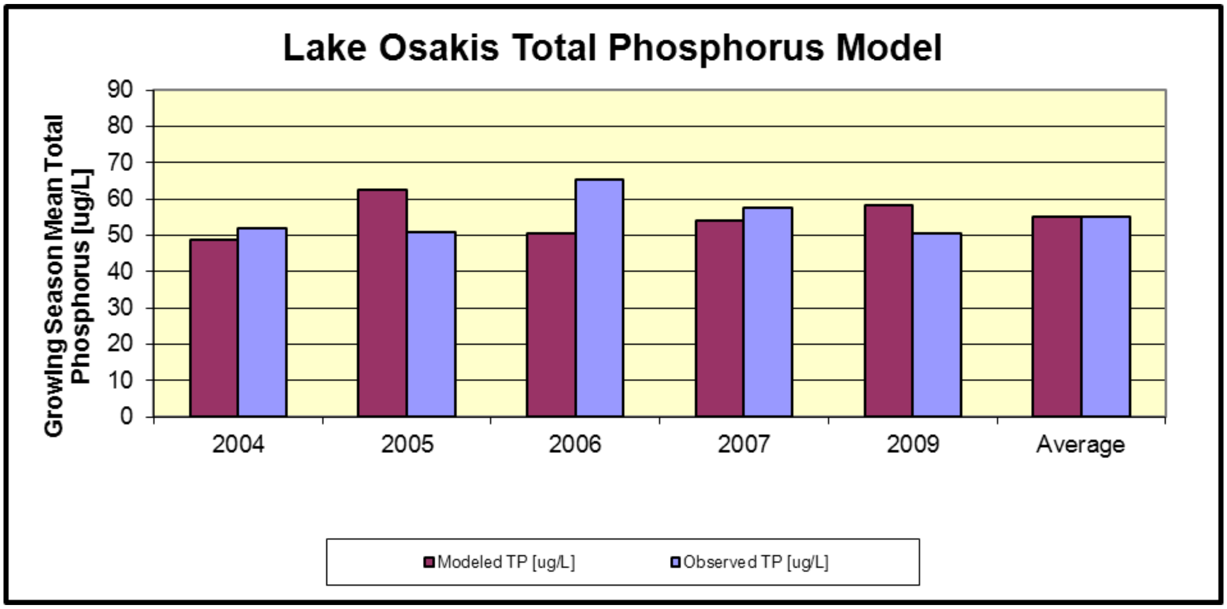

Figure 3.6. Observed versus BATHTUB model-predicted total phosphorus for Lake Osakis.

P loading to Smith Lake is dominated by watershed runoff and failing SSTS with the remaining load coming from atmospheric deposition (Figure 3.7). Based on DO profiles for Smith Lake, internal P release from sediments was assumed to be zero.

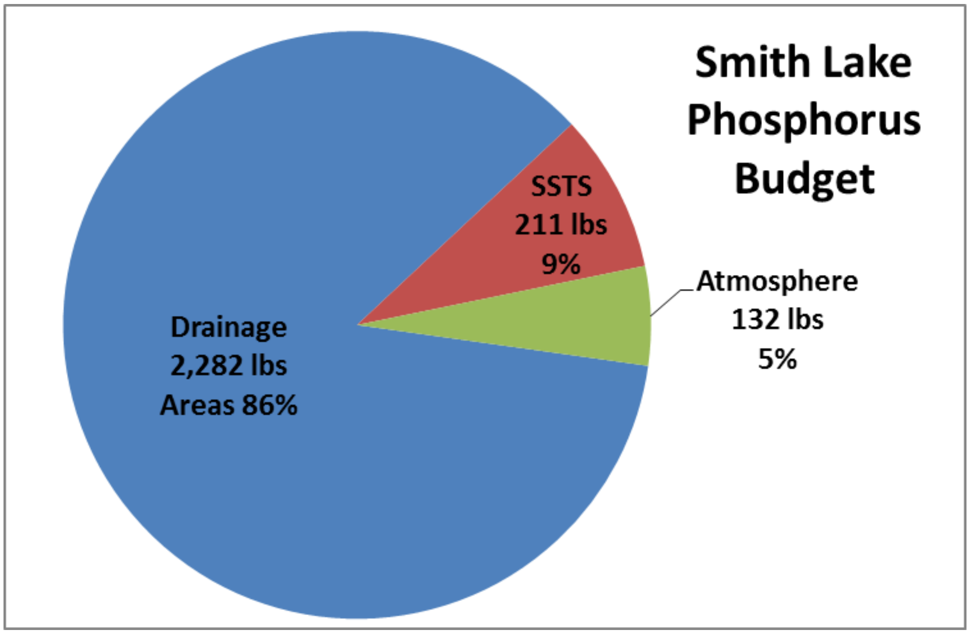

Figure 3.7. Total phosphorus loading to Smith Lake by source.

For Faille Lake, the majority of the P load is coming from upstream lakes including the intermediate wetlands, with 6% of the load coming from the Osakis WWTF (Figure 3.8). Consequently, a majority of the P load reductions will be achieved by focusing on the intermediate wetlands and the sources in their drainage area. The P load coming from internal sediment release is only 1% of the phosphorus budget, which is not surprising since an alum treatment was applied to the lake in the spring of 2002.

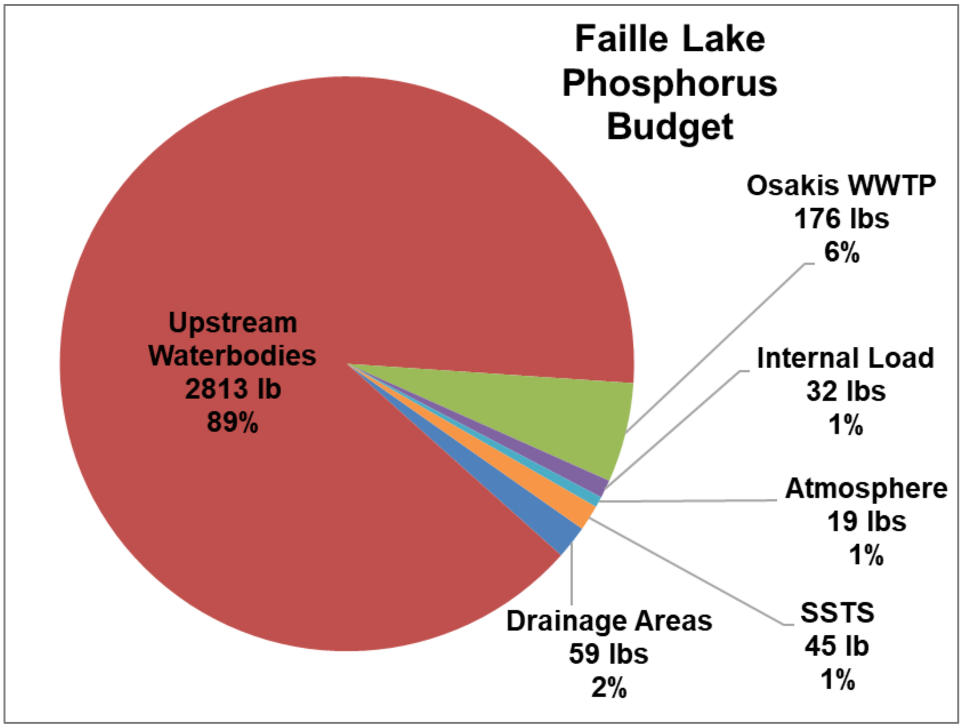

Figure 3.8. Total phosphorus loading to Faille Lake by source.

Most of the P loading to Lake Osakis comes from the watershed with the majority coming from JD #2, the drainage area below Maple Lake, the direct watershed and failing SSTS (Figure 3.9). Another 20% of the P loading comes from upstream lakes including Faille Lake, Little Osakis Lake, and Maple Lake. Internal loading was estimated to be approximately 2% of the P load to Lake Osakis. Internal loading was relatively small due to the large fetch and deep thermocline maintained in the lake.

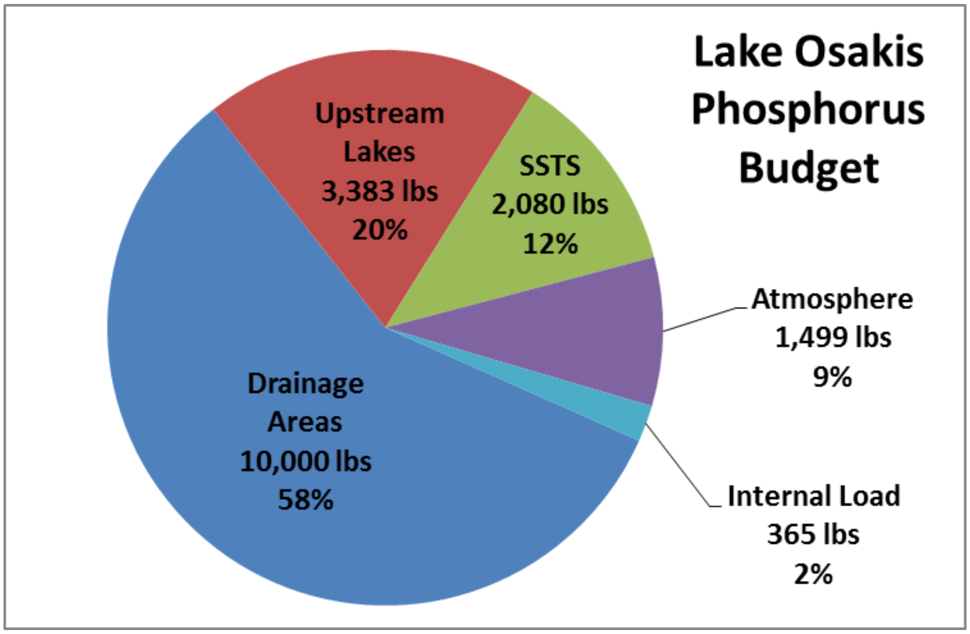

Figure 3.9. Total phosphorus loading to Lake Osakis by source.

4.0 TMDL Allocation

4.1 TOTAL MAXIMUM DAILY LOAD CALCULATIONS

The numerical TMDL for Smith Lake, Faille Lake and Lake Osakis was calculated as the sum of the WLA, LA and the Margin of Safety (MOS) expressed as P mass per unit time. Nutrient loads in this TMDL are set for P, since this is typically the limiting nutrient for nuisance aquatic algae. However, both the chlorophyll-a and Secchi response were predicted to determine if nutrient reductions would result in meeting all three state standards. This TMDL is written to solve the TMDL equation for a numeric target of 40 mg/L for Smith and Osakis Lake, and a numeric target of 60 µg/L for Faille Lake as a summer growing season average.

4.1.1 Total Loading Capacity

The first step in developing an excess nutrient TMDL for lakes is to determine the total nutrient loading capacity for the lake. To determine the total loading capacity, the current nutrient budget and the lake response modeling (average of 2004, 2005, 2008, 2010 for Smith Lake; 2003, 2004 and 2007 for Faille Lake; and 2004-2007 and 2009 for Lake Osakis) presented in Section 3 were used as the starting point. The nutrient inputs were then systematically reduced until the model predicted that the lakes met the current TP standard of 40 or 60 µg/L as a growing season mean. The reductions were applied first to the internal load and then the watershed sources. Once the TP goal is met, both the chlorophyll-a and Secchi response models are reviewed to ensure that the two response variables are predicted to meet the state standards as well. Further details of how this was applied are included in the following sections.

4.1.2 Load Allocations

The LA includes all non-permitted sources including stormwater runoff not covered by a state or federal permit, atmospheric deposition and internal loading. These sources include agricultural runoff, degraded wetlands, internal nutrient loads and atmospheric loading. No changes were expected for atmospheric deposition because this source is impossible to control.

One of the first steps in determining the allowable P loads to the lakes is setting the appropriate internal load release rate. Estimated release rates in Faille Lake and Osakis Lake (anoxic release of 0.7 and 0.8 mg/m^2/day respectively) were low, so no reductions in internal loading were assumed.

To determine the allowable watershed P load, current estimated watershed loading in the lake response models was reduced until the models predicted an in-lake P concentration of 40 or 60 µg/L.

4.1.3 Wasteload Allocations

The WLA includes permitted discharges such as WWTFs, industrial point source dischargers and regulated stormwater discharges from construction and industrial facilities and Municipal Separate Storm Sewer Systems (MS4s). Stormwater discharges are regulated under NPDES, and allocations of nutrient reductions are considered as a portion of the WLA that must be divided among permit holders. The Osakis WWTF is currently the only permitted wastewater discharger in the Lake Osakis Watershed. This facility discharges to Clifford Wetland, which is upstream of Faille Lake and Lake Osakis. Clifford Lake had been placed on the 2006 state of Minnesota's 303(d) list of impaired water for nutrients but was removed from the 303d list when it was determined to be a wetland. See the Faille Addendum at the end of this report for the changes made to the Faille Lake TMDL. There are no MS4 permit holders in the Lake Osakis Watershed, so no allocations are given for MS4 stormwater.

4.1.3.1 Construction and Industrial Stormwater

Review of NPDES Construction Permits throughout the Osakis Lake Watershed showed minimal construction activities (11 active permits and less than 1% of the watershed area). To account for future growth (reserve capacity), allocations for each lake TMDL were rounded to 1% of the load allocated to each lake's direct drainage area. The direct drainage area is the portion of the watershed that is not accounted for in the upstream waterbodies and their watershed area.

Construction and industrial stormwater WLAs were calculated as 1.5% of the load allocated to the direct drainage area of each lake. It was assumed that construction and industrial stormwater in the area upstream of the direct drainage areas is accounted for in the LAs for upstream waterbodies.

4.1.3.2 Concentrated Animal Feeding Operations (CAFOs)

There are three feedlot facilities in the Lake Osakis Watershed that are permitted as CAFOs. All three facilities operate under the same feedlot permit number (MNG440229). By rule, CAFOs are not allowed to discharge from their feedlots and are therefore assumed to not be currently discharging any P. CAFOs are assigned an allocation of zero based on these state rules. Manure from these lots is spread on nearby fields and is an important source of watershed runoff. Manure on fields is included in the watershed runoff portion of the LA.

4.1.4 Margin of Safety

The MOS accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload and monitored stream and lake water quality conditions. The purpose of the MOS is to account for uncertainty so the TMDL allocations result in attainment of water quality standards. The MOS can either be implicitly incorporated into conservative assumptions used to develop the TMDL or added as a separate explicit component of the TMDL (EPA 1991). Both an implicit and explicit MOS has been included in this TMDL. The following is the rationale for an implicit MOS.

1. Achieving runoff total P load reductions would require greater percentage reductions in soluble reactive P (likely from animal manure, or septic and wetland discharge), which has a greater impact on lake algal productivity, as compared with other forms of P that are less biologically available (Walker 1985).

2. Best Management Practices (BMPs) for reducing P loads from agriculture (Sharpley et al. 2006) and other sources could be conservatively designed in the process of implementation.

3. The 60 ppb lake standard (Faille Lake) is at the lower end of the 60 to 80 ppb range derived by Heiskary and Lindon (2005) as a TP criterion for shallow lakes. While this does not provide a MOS for achieving the lake P standard, it could be interpreted to provide a MOS for achieving the beneficial uses, upon which the lake P standard is conservatively based.

4. All P inputs to each lake were calculated as annual calendar year loads. However, the BATHTUB lake response models were calibrated to the observed annual growing season (June through September) lake water quality conditions when in-lake TP and the lake response variables are typically highest.

Thus, calibrating the models to growing season data provides an implicit MOS and ensures each lake should meet state water quality standards year around under the TMDL model scenario allocations.

As a further MOS, 5% of the TMDL load capacity has been set aside to account for uncertainties in the watershed model based on limited flow and water quality sampling data within specific subwatersheds. For each lake, the 5% MOS was applied to the final TMDL drainage area LA.

4.1.5 Summary of TMDL Allocations

A 31% reduction in overall P loading to Smith Lake is required to meet the 40 µg/L state standards (Table 4.1). A 27% reduction in watershed loading is required to meet the TMDL for Smith Lake. It was also assumed that all failing SSTSs will be made compliant, eliminating P loading from SSTSs.

Table 4.1. Smith Lake TMDL allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)	%
Wasteload Allocation	Construction & Industrial Stormwater	27	0.1	27	0.1	0	**0%**
Load Allocation	Drainage Areas	2,255	6.2	1,647	4.5	608	**27%**
	SSTS	211	0.6	0.0	0.0	211	**100%**
	Atmosphere	132	0.4	132	0.4	0	**0%**
	Internal Load	0.0	0.0	0	0.0	0	**0%**
	MOS (5%)	–	–	95	0.3	–	–
	TOTAL	**2,625**	**7.3**	**1,901**	**5.3**	**819**	**31%**

[1] Existing load is the average of 2004, 2005, 2008 and 2010.
[2] Daily load is the annual load divided by 365.

A 71% reduction in P loading to Faille Lake is required to meet the TMDL with large reductions required from non-point source watershed loads (Table 4.3). It was assumed that all SSTSs will be made compliant, eliminating P loading from SSTSs. A load reduction will be attained due to phosphorus retention when water flows through Clifford Wetland and the intermediate wetlands and into Faille Lake.

Table 4.2 Original Faille Lake TMDL allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)	%
Wasteload Allocation	Construction & Industrial Stormwater	6	<0.1	6	<0.1	0	**0%**
Load Allocation	Drainage Areas	756	2.1	330	0.9	426	**56%**
	SSTS	45	0.1	0	0.0	45	**100%**
	Atmosphere	19	0.1	19	0.1	0	**0%**
	Upstream Lakes	2,202	6.0	480	1.3	1,722	**78%**
	Internal Load	32	0.1	32	0.1	0	**0%**
	MOS	–	–	46	0.1	–	–
	TOTAL	**3,060**	**8.4**	**913**	**2.5**	**2,193**	**72%**

[1] Existing load is the average of 2003, 2004 and 2007.

[2] Daily load is the annual load divided by 365.

Table 4.3 2023 Revision Faille Lake TMDL allocations.

Load Category		Existing Load	Allowable Load	Load Reduction[1]		TMDL[4]
	Load Component	(lb/yr)	(lb/yr)	(lb/yr)	%	(lb/day)
TOTAL LOAD		**3,143**	**962**	**2,229**	**71%**	**2.63**
Wasteload Allocation	**Total WLA**	**176.4**	**150.7**	**25.7**	**15%**	**0.41**
	Osakis WWTF net load[2]	176	150.3	25.7	15%	0.41
	Construction/Industrial SW	0.4	0.4	0	0%	0.00
Load Allocation	**Total LA**	**2,967.0**	**763.3**	**2,203.7**	**74%**	**2.09**
	Direct runoff	58.5	21.8	36.7	63%	0.06
	Upstream waterbodies[3]	2,813.2	691.2	2,122.0	75%	1.89
	SSTS	45	0	45	100%	0.00
	Atmospheric deposition	18.8	18.8	0	0%	0.05
	Internal load	31.5	31.5	0	0%	0.09
Margin of Safety		**--**	**48.1**	**--**	**--**	**0.13**

[1] The TOTAL estimated load reduction equals the (Existing - Allowable) load difference, plus the Margin of Safety.

[2] The Osakis WWTF (NPDES/SDS Permit No. MN0020028) net load WLA reflects P retention in waterbodies upstream of Faille Lake. 176 lb/yr represent the average (2003, 2004, and 2008) load from the WWTF, taking into account retention in the waterbodies upstream of Faille Lake (see Figure 9.1). 150.3 lb/year represent the P loading expected to be delivered to Faille Lake if the facility were to discharge its entire 121 kg/yr (266.8 lb/yr) permitted load. The annual and daily WLAs are derived from and consistent with the permit's effluent limit.

[3] Not including Osakis WWTP net load.

[4] Daily load is the annual load divided by 365.25

Water quality monitoring in 2017 and 2018 showed that Faille Lake was no longer impaired. It still exceeds the total phosphorus standard of 60 µg/L, but is not showing an associated increase above the 20 µg/L standard for chlorophyll-*a* or less than 1 meter in Secchi disc depth. The lake was delisted and removed from the 2020 303(d) Impaired Waters List. The Faille Lake TMDL will ensure that Faille Lake continues to meet water quality standards.

For Lake Osakis, a 41% reduction in P loading will be required to meet the 40 µg/L state standard (Table 4.4). To meet the TMDL, a 34% reduction in watershed loading will be needed from the JD #2, Maple Lake Downstream and Osakis Lake Direct subwatersheds. It was also assumed that all failing SSTSs in these subwatersheds will be made compliant. Large reductions will be attained when Faille Lake (60 µg/L), Smith Lake (40 µg/L) and Maple Lake (40 µg/L), all of which contribute to Lake Osakis, meet MPCA's impairment standards for lakes.

Table 4.4. Lake Osakis TMDL allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)	%
Wasteload Allocation	Construction & Industrial Stormwater	107	0.3	107	0.3	0	**0%**
Load Allocation	Drainage Areas	9,893	27.1	6,520	17.8	3,373	**34%**
	SSTS	2,080	5.7	0	0.0	2,080	**100%**
	Upstream Lakes	3,383	9.3	1,678	4.6	1,705	**50%**
	Atmosphere	1,499	4.1	1,499	4.1	0	**0%**
	Internal Load	365	1.0	365	1.0	0	**0%**
	MOS	--	--	535	1.5	--	**--**
	TOTAL	**17,327**	**47.5**	**10,704**	**29.3**	**7,158**	**41%**

[1] Existing load is the average of 2004-2007 and 2009.

[2] Daily load is the annual load divided by 365.

4.2 LAKE RESPONSE VARIABLES

The TMDL presented here is developed to be protective of the aquatic recreation beneficial use in lakes. However, there is no loading capacity per se for nuisance algae. Consequently, to understand the impacts of the P loads to the lake, regression equations developed by the MPCA to establish Minnesota state water quality standards were used to predict Secchi depth and chlorophyll-a concentrations after load reductions are implemented (MPCA 2005).

Input P loads were reduced in the BATHTUB TMDL model run by 5% increments to predict each lake's response to changes in P loading (Figure 4.1 and Figure 4.2).

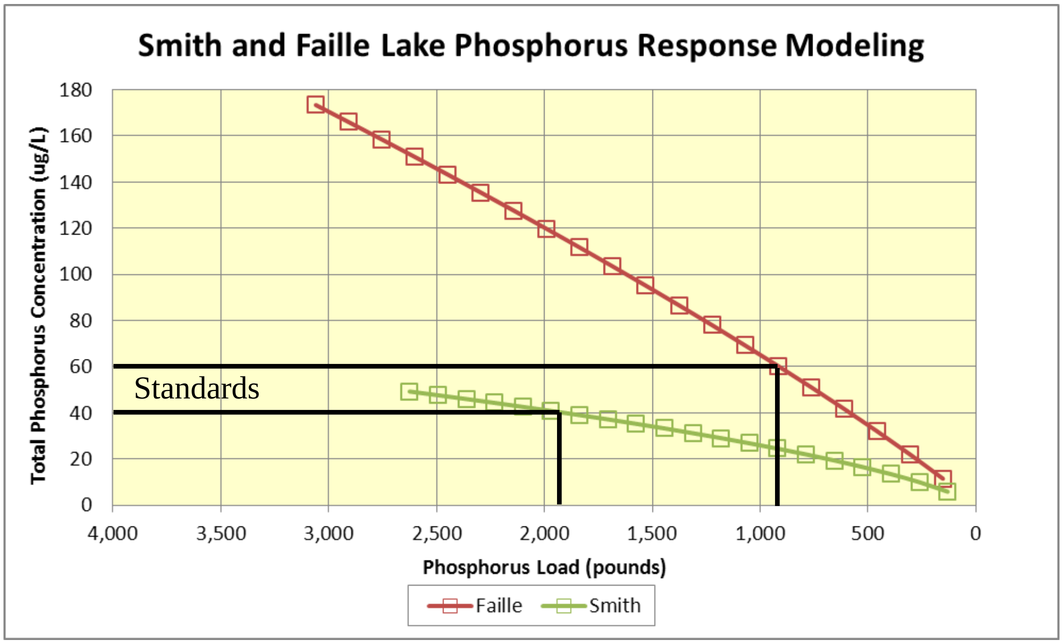

Figure 4.1. Smith and Faille Lake in-lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources.

The horizontal black line indicates state TP standards for shallow (60 µg/L) and deep (40 µg/L) lakes in the NCHF ecoregion. The vertical black line indicates the TMDL loading capacity for each lake set forth in this TMDL.

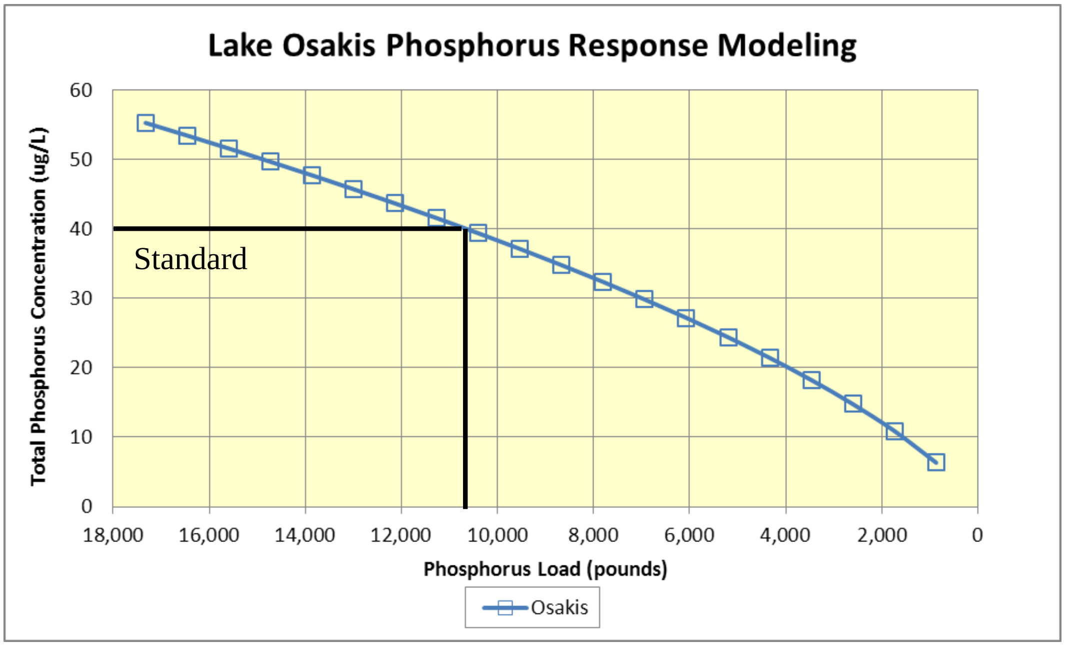

Figure 4.2. Lake Osakis in-lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources.

The horizontal black line indicates state TP standard for deep (40 µg/L) lakes in the NCHF ecoregion.
The vertical black line indicates the TMDL loading capacity for Lake Osakis set forth in this TMDL.

Using the predicted TP concentrations, chlorophyll-a concentrations were estimated using regression equations the MPCA (2005) used to develop shallow and deep lake nutrient standards (Figures 4.3 and 4.4). Using these equations, both Osakis and Smith are predicted to meet the 14 µg/L chlorophyll-a standard for deep lakes while Faille Lake should meet the 20 µg/L standard for shallow lakes in the NCHF ecoregion.

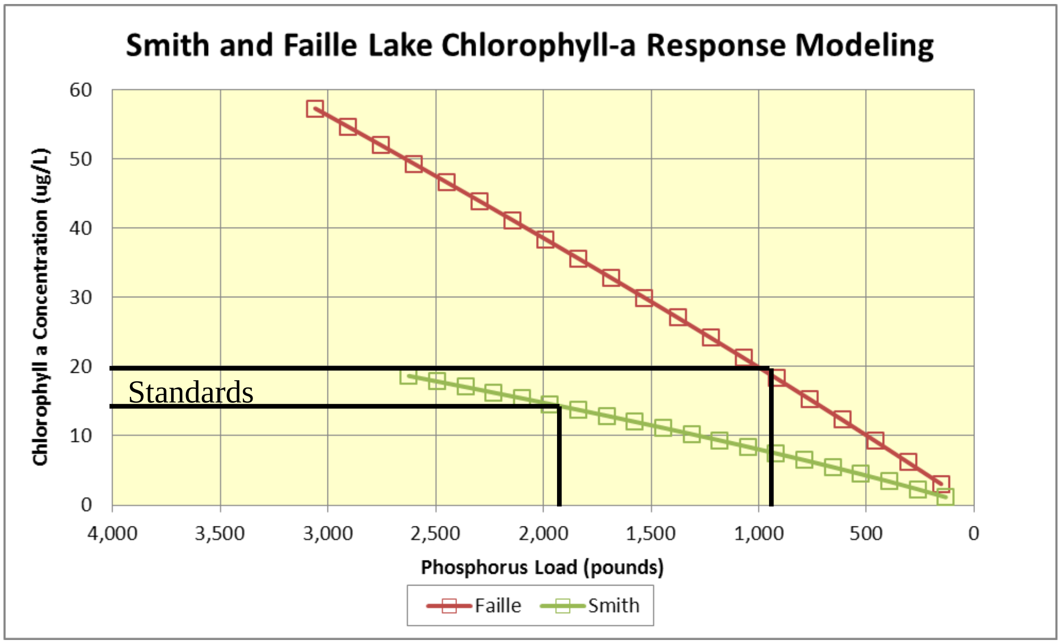

Figure 4.3. Smith and Faille Lake in-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources.

The horizontal black line indicates chlorophyll-a standards for shallow (20 µg/L) and deep (14 µg/L) lakes in the NCHF ecoregion. The vertical black line indicates the TMDL loading capacity for each lake set forth in this TMDL.

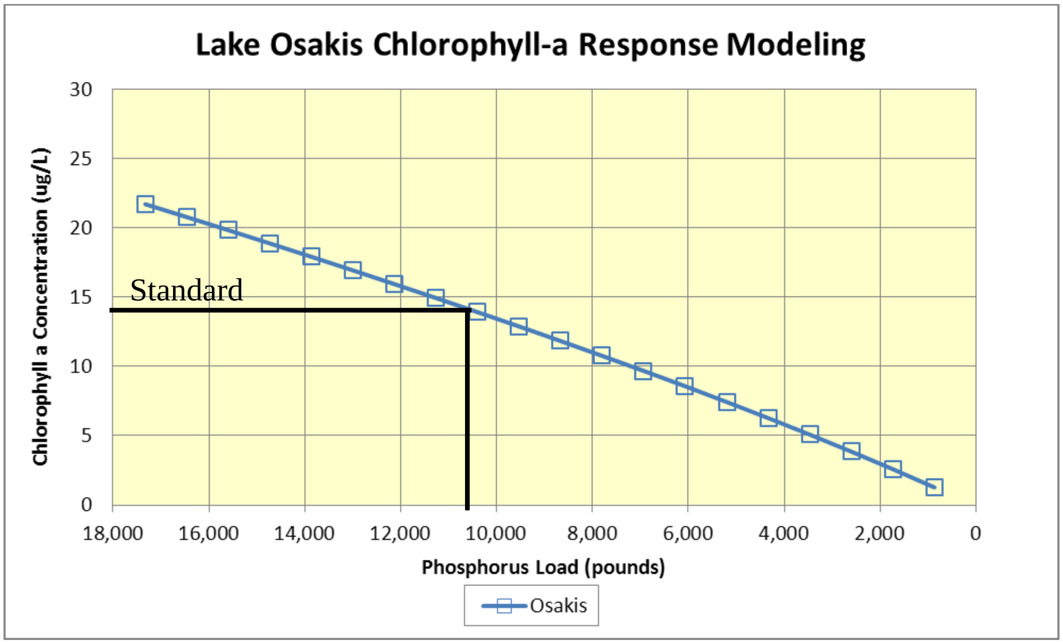

Figure 4.4. Lake Osakis in-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources.

The horizontal black line indicates the state chlorophyll standard for deep (14 µg/L) lakes in the NCHF ecoregion. The vertical black line indicates the TMDL loading capacity for Lake Osakis set forth in this TMDL.

Lake Osakis typically meets the Secchi depth standard of greater than 1.4 meter for deep lakes in the NCHF ecoregion. Smith and Faille Lake are close to meeting their Secchi depth standards of 1.4 meters and 1.0 meters, respectively. Both lakes will easily exceed these standards at the TMDL allocations (Figure 4.5 and 4.6).

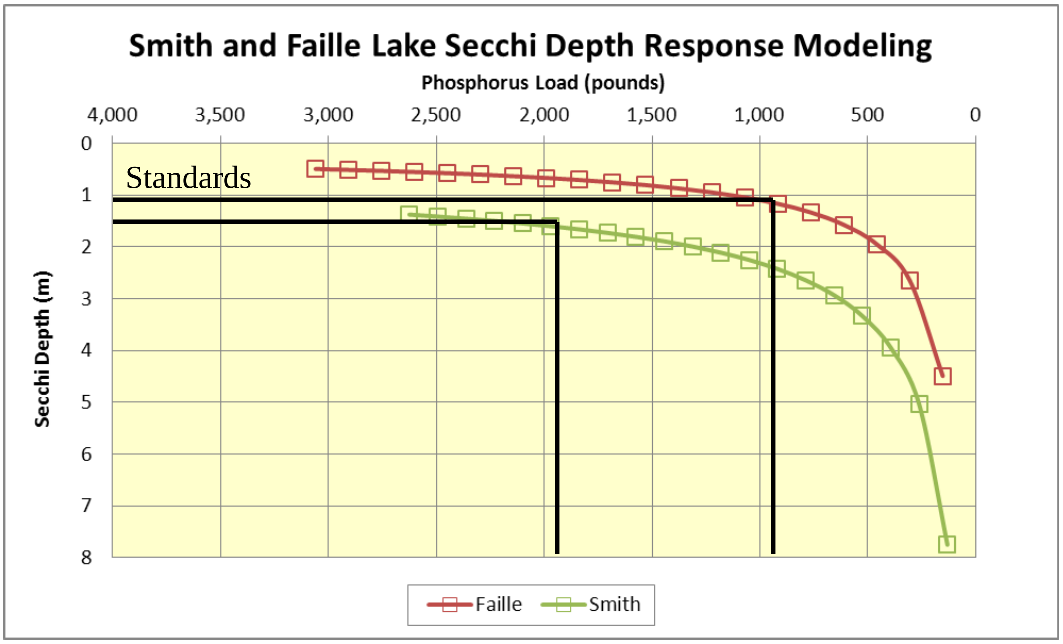

Figure 4.5. Smith and Faille Lake in-lake Secchi depth predicted for total phosphorus load reductions applied to all sources.

The horizontal black line indicates state Secchi depth standards for shallow (1.0 meters) and deep (1.4 meters) lakes in the NCHF ecoregion. The vertical black line indicates the TMDL loading capacity for each lake set forth in this TMDL.

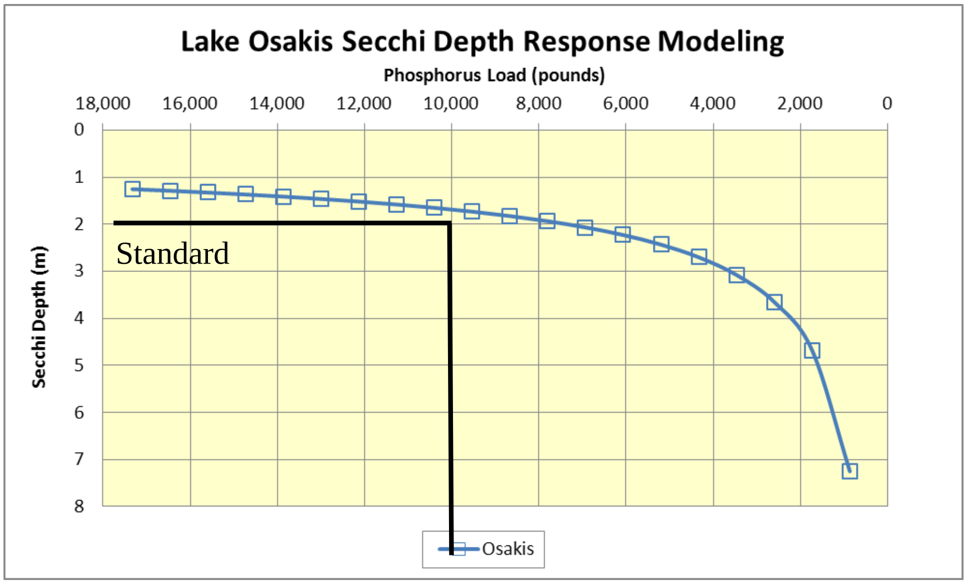

Figure 4.6. Lake Osakis in-lake Secchi depth predicted for total phosphorus load reductions applied to all sources.

The horizontal black line indicates state Secchi depth standard for deep (1.4 meters) lakes in the NCHF ecoregion. The vertical black line indicates the TMDL loading capacity for Lake Osakis set forth in this TMDL.

4.3 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current P budgets for Smith, Faille and Osakis Lake. The budget is an average of four to six years of monitoring data. BMPs designed to address excess loads to the lakes will be designed for these average conditions; however, the performance will be protective of all conditions. For example, a stormwater pond designed for average conditions may not perform at design standards for wet years; however, the assimilative capacity of the lake will increase due to increased flushing. Additionally, in dry years the watershed load will be naturally down allowing for a larger proportion of the load to come from internal loading. Consequently, averaging across several modeled years addresses annual variability in-lake loading.

Seasonal variation is accounted for through the use of annual loads and developing targets for the summer period where the frequency and severity of nuisance algal growth will be the greatest. Although the critical period is the summer, lakes are not sensitive to short term changes in water quality, rather lakes respond to long-term changes such as changes in the annual load. Therefore, seasonal variation is accounted for in the annual loads. Additionally, by setting the TMDLs to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during all the other seasons.

4.4 RESERVE CAPACITY

The amount of land in agricultural use in the Smith, Faille and Osakis Lake Watersheds is likely to remain fairly constant over the next several decades. The watershed is comprised mainly of pasture and hay and row crops (corn and soybeans). While the majority of the landscape is likely to remain in an agricultural land use, it is possible a modest shift between pasture/hay and row crops may occur. Any such shift would likely not affect the loading capacity of the lakes, since that capacity is based on long-term flow records over which time land use changes have likely occurred. Thus, slight shifts in land use should not appreciably change the magnitude of the land use runoff variability that the period of record already reflects.

5.0 Public Participation

5.1 INTRODUCTION

The TMDL development should be a stakeholder-driven process that develops an understanding of the issues and the processes driving the impairments. To that end, a detailed stakeholder process was employed that included working with a Technical Advisory Committee comprised of local stakeholders. These groups represent the stakeholders ultimately responsible for implementation of the TMDLs who need to be fully engaged in the applied science. It is our goal for this TMDL to result in a science based, implementable TMDL with a full understanding of the scientific tools developed to make informed, science based decisions.

5.2 STAKEHOLDER MEETINGS

The TMDL development included stakeholder meetings to discuss the permitting issues with the permitted parties. These meetings took place before the initial 2013 approval of this TMDL. Meetings were held on the following dates:

9/30/2008—Osakis Lake Watershed stakeholders meeting- 15 organizations represented.

12/2/2008—Osakis TMDL Technical meeting.

12/3/2008—Osakis Public Meeting.

1/6/2009—Osakis TMDL Technical Meeting.

5/5/2011—WWTF permitting meeting with technical staff, district staff and City of Osakis. Discussed the process and changes to future WWTF permit.

8/23/2011—WWTF permitting meeting with technical staff, district staff and City of Osakis. Discussed the possible limit reductions to future WWTF permit.

6/13/2012—Meeting with the Sauk River Watershed District, Wenck Assoc., MPCA and EPA staff. Discussed the EPA comments on the draft TMDL, clarify issues and tailor responses.

8/28/2012—Public meeting on the draft TMDL and the public comment period. Presenters included the Sauk River Watershed District, Wenck Assoc., and MPCA staff.

12/2012—TMDL Final Draft Public meeting; 16 people attended.

The MPCA was in communication regarding the 2016 TMDL revisions with a number of key stakeholders such as the City of Osakis and the Sauk River Watershed District. MPCA also spoke with Minnesota Center for Environmental Advocacy. Additional public meetings were not held for the revised version of this TMDL.

The MPCA and the City of Osakis had extensive discussions after the 2016 public notice of the revised TMDL report. This final, revised TMDL report reflects the agreement between the MPCA and the city regarding the City of Osakis WWTF discharge permit (MN0020028), as described in the compliance agreement (MPCA 2023).

6.0 Implementation

6.1 INTRODUCTION

The purpose of the implementation section of the TMDL is to develop an implementation strategy for meeting the LAs and WLAs set forth in this TMDL. This section is not meant to be a comprehensive implementation plan; rather it is the identification of a strategy that will be further developed in an implementation plan separate from this document.

6.2 IMPLEMENTATION FRAMEWORK

6.2.1 Watershed and Local Plans

Numerous governing units have water quality responsibilities in the watershed, including the SRWD and the Todd and Douglas County SWCDs. Each of these organizations maintain water plans aimed at improving water quality in their respective jurisdictions. These plans set the framework for implementing the TMDLs.

6.2.2 Adaptive Management

The LAs and WLAs in the TMDL represent aggressive goals for nutrient reductions. Consequently, implementation will be conducted using adaptive management principles (Figure 6.1). Adaptive management is appropriate because it is difficult to predict the lake response that will occur from implementing strategies with the paucity of information available to demonstrate expected reductions. Future technological advances may alter the course of actions detailed here. Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategies for attaining the water quality goals established in this TMDL.

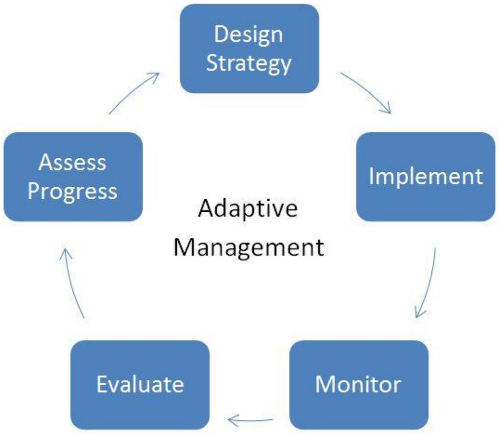

Figure 6.1. Adaptive management.

6.3 NUTRIENT REDUCTION STRATEGIES

Following is a description of potential actions for nutrient loading to Smith, Faille and Osakis Lake. These actions will be further developed in the TMDL Implementation Plan.

Smith Lake. Implementation activities for Smith Lake should focus primarily on watershed P load reductions including upgrading all noncompliant SSTSs. Remaining reductions in watershed loading will need to come from land practices including manure and livestock management. Another important factor in restoring Smith Lake will be vegetation management.

Faille Lake. Implementation activities for Faille Lake should focus on a multitude of areas including upgrading SSTSs, manure and livestock management, potentially vegetation and/or carp management, and management of the phosphorus loads discharged by the City of Osakis WWTF. Load reductions from Clifford Wetland restoration would also have a large benefit for Faille Lake.

Lake Osakis. Implementation activities for Lake Osakis should focus on upgrading SSTSs, manure and livestock management along with vegetation and carp management. Load reductions from all impaired lakes throughout the watershed including Faille Lake, Maple Lake and Smith Lake will also benefit Lake Osakis.

6.3.1 External Nutrient Load Reductions

This TMDL for Smith Lake, Faille Lake and Lake Osakis requires a 27%, 63% and 34% reduction from watershed sources respectively. To meet the required load reduction, various watershed management activities will be implemented on an opportunistic basis, including the following:

Manure Application. Minnesota feedlot rules (Minn. R. 7020) now require manure management plans for feedlots greater than 300 AUs that do not employ a certified manure applicator. These plans require manure accounting and record-keeping as well as manure application risk assessment based on method, time and place of application. The following BMPs will be considered in all manure management plans to reduce potential nutrient delivery to surface waters:

- Immediate incorporation of manure into topsoil
- Reduction of winter spreading, especially on slopes
- Eliminate spreading near open inlets and sensitive areas
- Apply at agronomic rates
- Follow setbacks in feedlot rules for spreading manure
- Erosion control through conservation tillage and vegetated buffers

Manure Stockpile Runoff Controls. There are a variety of options for controlling manure stockpile runoff that reduce nonpoint source nutrient loading, including:

- Move fences or altering layout of feedlot
- Eliminate open tile intakes and/or feedlot runoff to direct intakes
- Install clean water diversions and rain gutters
- Install grass buffers
- Maintain buffer areas
- Construct solid settling area(s)
- Prevent manure accumulations
- Manage feed storage
- Manage watering devices
- Total runoff control and storage

- Install roofs
- Runoff containment with irrigation onto cropland/grassland
- Vegetated infiltration areas or tile-drained vegetated infiltration area with secondary filter strips

Soil Phosphorus Testing. Because the amount of manure applied in the Smith, Faille and Osakis Lake Watersheds is high, soil testing would help manage where manure can be applied with little or no loss to surface waters. A soil P testing program will allow managers to make better decisions about where P from manure is needed and where it may be applied in excess.

Pasture Management. Overgrazed pastures, reduction of pastureland and direct access of livestock to streams may contribute a significant amount of nutrients to surface waters throughout all flow conditions. The following livestock grazing practices are for the most part economically feasible and are extremely effective measures in reducing nutrient runoff from feedlots:

- Livestock exclusion from public waters through setback enforcement and fencing
- Creating alternate livestock watering systems
- Rotational grazing
- Vegetated buffer strips between grazing land and surface water bodies

Increase infiltration and filtration in the watershed. One method for reducing P loading to Smith, Faille and Osakis Lakes is to increase infiltration and filtration in the watersheds. This can be accomplished through large scale infiltration areas, removing tile lines, adding buffers, or adding vegetated swales.

Urban, Road and Highway Stormwater Management. The largest municipalities in the Lake Osakis Watershed are the cities of Osakis (population 1,567) and Nelson (population 172). The watershed also contains approximately 5,286 acres of township, county and state roads and highways. While municipalities and roadways account for only 7% of watershed land use, they have the potential to contribute up to 22% of the P load to Lake Osakis. The following BMPs and activities will be considered to reduce P loading from these developed areas:

- Increase infiltration, filtration and evapotranspiration in existing developed areas through the use of rain gardens, native plantings and reforestation.
- Implement retrofit BMPs to add or increase treatment for street or highway reconstruction projects, park improvements and other road/highway projects throughout the watershed.
- Identify key areas within each municipality for street sweeping.
- Improvements/changes to WWTP and municipal stormwater ponds to ensure minimal overflow during large rain events.

Subsurface Septic Treatment Systems. Todd and Douglas County should continue to inspect and order upgrades to systems not meeting adopted septic ordinances. SSTS improvement priority should be given to lakeshore properties and other systems located near streams and waterways.

Implement construction and industrial stormwater regulation. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

Industrial stormwater activities are also considered in compliance with provisions of the TMDL if they obtain an Industrial Stormwater General Permit or General Sand and Gravel General Permit (MNG49) under the NPDES program and properly select, install, and maintain all BMPs required under the permit, or meet local industrial stormwater requirements if they are more restrictive than requirements of the State General Permit.

6.3.2 City of Osakis Wastewater Treatment Facility

As described in the compliance agreement between the MPCA and the City of Osakis regarding the City of Osakis WWTF (MPCA 2023), the city will develop an inflow and infiltration (I and I) reduction plan that establishes specific steps the city will take to further reduce I and I in the city collection system and from private lateral lines. The city will also submit a Wastewater Facility Optimization Plan and Phosphorus Management Plan (Facility Management Plan) and will provide annual updates on the I and I Reduction Plan, the Facility Management Plan, and on trading options being pursued by the city to comply with the permit limit.

This compliance agreement allows for continued operation of the city's stabilization pond facility and for long term compliance with the City of Osakis WWTF phosphorus effluent limit and TMDL WLA.

6.3.3 Studies and Biological Management Plans

Vegetation management. Curly-leaf pondweed is present in both Smith Lake and Lake Osakis at extremely high concentrations. Senescence of the curly-leaf pondweed in summer can be a significant source of internal P load that often results in a late summer nuisance algal bloom. Vegetation management, such as several successive years of chemical treatment, will be required to keep this exotic invasive species at non-nuisance levels.

Conduct periodic aquatic plant surveys, and prepare and implement vegetation management plans. As BMPs are implemented and water clarity improves, the aquatic vegetation community will change. Surveys should be updated periodically and vegetation management plans amended to take into account appropriate management activities for that changing community.

Carp Management. One activity should be to partner with the DNR to monitor and manage the fish population to maintain a beneficial community. Options to reduce rough fish populations should be evaluated, and the possibility of fish barriers explored to reduce rough fish access to spawning areas and to minimize rough fish migration between lakes.

Encourage shoreline restoration. Many property owners maintain a turfed edge to the shoreline. Property owners should be encouraged to restore their shoreline with native plants to reduce erosion and capture direct runoff. Shoreline restoration can cost $30 to $50 per linear foot, depending on the width of the buffer installed. Todd and Douglas County SWCD and the SRWD will develop some demonstration projects as well as work with all willing landowners to naturalize their shorelines.

6.3.4 Education

Provide education and outreach awareness programs. Provide educational and outreach opportunities in the subwatershed about proper fertilizer use, manure management, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to the lakes and encourage the adoption of good individual property management practices. Opportunities to better understand aquatic vegetation management practices and how they relate to beneficial biological communities and water quality should also be developed.

6.3.5 Pollutant Trading Credits

Water quality trading can help achieve compliance with WLAs or water quality based effluent limits. Water quality trading can also offset increased pollutant loads in accordance with antidegradation regulations. Water quality trading reduces pollutants (e.g., TP or TSS) in rivers and lakes by allowing a point source discharger to enter into agreements under which the point source “offsets” its pollutant load by obtaining reductions in a pollutant load discharged by another point source operation or a nonpoint source or sources in the same watershed. The MPCA must establish specific conditions governing trading in the point source discharger’s NPDES permit or in a general permit that covers the point source discharger. The MPCA implements water quality trading through permits. See MPCA’s *Water Quality Trading Guidance* (MPCA 2021) for more information.

7.0 Reasonable Assurance

7.1 INTRODUCTION

As a requirement of TMDL studies, reasonable assurance must be provided demonstrating the ability to reach and maintain water quality endpoints. The source reduction strategies detailed in Section 5 have been shown to be effective in reducing nutrients in receiving waters. It is reasonable to expect that these measures will be widely adopted by landowners and resource managers, in part because they have already been implemented in some parts of the watershed over the last 20 years.

Many of the goals outlined in this TMDL study are consistent with objectives outlined in the SRWD Watershed Management Plan and the Todd and Douglas County Comprehensive Local Water Management Plans (LWMP). These plans have the same objective of developing and implementing strategies to bring impaired waters into compliance with appropriate water quality standards, and thereby establish the basis for removing those impaired waters from the 303(d) Impaired Waters List. These plans provide the watershed management framework for addressing water quality issues. In addition, the stakeholder processes associated with both this TMDL effort, as well as the broader planning efforts mentioned previously, have generated commitment and support from the local government units affected by this TMDL and will help ensure that this TMDL project is carried successfully through implementation.

Various technical and funding sources will be used to execute measures detailed in the implementation plan that will be developed within one year of approval of this TMDL. Technical resources include the SRWD, Todd and Douglas County Soil and Water Conservation Districts (SWCDs), as well as the DNR. Funding resources include a mixture of state and federal programs, including (but not limited to) the following:

- Conservation Reserve Program and other NRCS conservation programs
- Federal Clean Water Act Section 319 program for watershed improvements
- Funds ear-marked to support TMDL implementation from the Clean Water, Land, and Legacy constitutional amendment approved by the state’s citizens in November 2008.
- SRWD program funds
- Local government cost-share funds

Finally, it is a reasonable expectation that existing regulatory programs such as those under NDPES will continue to be administered to control discharges from industrial, municipal, and construction sources, as well as large animal feedlots that meet the thresholds identified in those regulations.

Following is a discussion of the key agencies at the local level that will help assure that implementation activities proposed under this TMDL will be executed.

7.2 SAUK RIVER WATERSHED DISTRICT

The SRWD has been active in water resources management and protection since it was formed in 1986. The SRWD current watershed management plan identifies the following major roles for the District:

1. Collection of monitoring data, with an emphasis on collection of a comprehensive set of surface water quality data to support diagnostic studies.
2. Development and implementation of a regulatory program that requires a permit from the SRWD for:
    a. The development or redevelopment of properties which create greater than one acre of impervious cover
    b. Land disturbance within 500 feet of water bodies or wetlands
    c. Work in the Right of Way (ROW) of any legal drainage system
    d. Construction, installation or alteration of certain water control structures
    e. Diversion of water into a different sub-watershed or county drainage system
3. Providing technical assistance to landowners, farmers, businesses, lake associations, cities, townships, counties, state agencies, and school districts. Much of this technical assistance pertains to planning and installing BMPs for water quality protection and improvement.
4. Implementation of capital improvements.
5. Public education.

In March of 2010, the SRWD concluded the process of updating its rules, including addition of new requirements for stormwater runoff management, erosion control, drainage and water use. The SRWD has also updated its watershed management plan for the term that ends in 2023. This will provide the opportunity to link SRWD policies, programs and objects with implementation of TMDLs more closely.

7.3 TODD AND DOUGLAS COUNTY SWCDS

The Lake Osakis Watershed is located within the jurisdiction of two SWCDs, the Todd County SWCD and Douglas County SWCD. In general, the SWCDs plan and execute policies, programs, and projects that conserve soil and water resources within their jurisdictions. The SWCDs are involved in implementation of practices that reduce or prevent erosion, sedimentation, siltation, and other pollution in order to protect water and soil resources. The SWCDs frequently provide cost share for many types of projects, such as erosion control structures.

The SWCD is the first step for landowners wanting to implement BMPs or other conservation projects. The SWCD provides technical assistance through the planning, engineering, and funding process. The Area II-SWCD Technical Service Area (TSA) provides engineering and project oversight assistance. Through the SWCD, the TSA provides a licensed engineering, engineering technician, and vegetation specialist for work on BMPs. The local SWCD works with the landowner on project planning, coordination, and funding assistance.

Both the Todd County SWCD and the Douglas County SWCD have LWMPs in place to serve as a guide for water resource protection and preservation. These plans were developed and written under the legislative authority of the "Comprehensive LWMP Act" (Minn. Stat. § 103B.301 to 103b.355).

The Todd County Water Management Advisory Committee has updated the Local Water Management Plan in 2016. The plan was updated to better guide the county's efforts to protect and enhance water resources in the County, and to comply with State requirements. The purpose of the Todd County Comprehensive LWMP is as follows:

- Identify existing and potential problems and opportunities for protection, management, and development of water and related land resources.
- Develop objectives and carry out a plan of action to promote sound hydrologic management of water and related land resources, effective environmental protection and efficient management.

The Douglas County LWMP was updated in 2009. An assessment of the progress made toward the completion of the goals of the Douglas County LWMP was completed in 2014, and the implementation plan was updated at that time. The purpose of the Douglas County Comprehensive LWMP is to:

- Identify existing and potential problems and opportunities for the protection, management, and development of water and related land resources
- Identify priority concerns to be addressed during the effective time frame of the plan
- Develop goals and implement actions that improve water quality and quantity and related resource management and planning in the County

7.4 MONITORING

Two types of monitoring are necessary to track progress toward achieving the load reduction required in the TMDL and the attainment of water quality standards. The first type of monitoring is tracking implementation of BMPs and capital projects. The SRWD and the Todd and Douglas County SWCDs will track the implementation of these projects annually. The second type of monitoring is physical and chemical monitoring of the resources. The SRWD plans to monitor the affected resources routinely.

This type of effectiveness monitoring is critical in the adaptive management approach. Results of the monitoring identify progress toward benchmarks as well as shape the next course of action for implementation. Adaptive management combined with obtainable benchmark goals and monitoring is the best approach for implementing TMDLs.

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9.0 Faille Lake 2023 Addendum:

TMDL Revision 2023

Faille Lake is one of three lakes for which P TMDLs were developed in the Osakis Lake Area Excess Nutrient TMDL (Wenck 2013), approved by the EPA on June 5, 2013. A municipal WWTF, the Osakis WWTF (NPDES/SDS Permit No. MN0020028), discharges to the drainage network upstream from Faille Lake. However, the Faille Lake TMDL did not include a WLA for the facility because its discharge first enters a waterbody known as Clifford Lake, which at that time was listed as an impaired lake. Though it was known to be shallow, no depth survey had been performed on Clifford Lake, and a TMDL for it had been deferred. For the Faille Lake TMDL, Clifford Lake's target TP concentration was assumed to be 60 micrograms per liter (µg/L), Minnesota's shallow-lake standard for the NCHF ecoregion.

Following a depth survey by the MPCA staff (VanEeckhout 2012), Clifford Lake was subsequently determined to be a wetland rather than a shallow lake, for water quality assessment purposes. (In the remainder of this document, the name "Clifford wetland" will be applied to this waterbody.) The MPCA has not established numeric wetland water quality standards, and thus a TMDL is not required for Clifford wetland. Therefore, the Faille Lake TMDL needed to be revised to include a WLA for the Osakis WWTF. This memorandum is the technical documentation for the Faille Lake TMDL revision.

Background and Approach

Faille Lake (DNR # 77-0195) is located in central Minnesota in the Upper Mississippi River Basin along the border of Todd and Douglas Counties, and it is a tributary to Lake Osakis, at the headwaters of the Sauk River. The 2013 TMDL report includes further details on Faille Lake and its watershed. The TMDL revision documented herein is consistent with the 2013 TMDL, except for (1) the addition of the Osakis WWTF flow and P loading as a point source to Clifford wetland and (2) further reduction of runoff TP concentrations for meeting the TMDL. (Watershed runoff TP concentrations for *existing* conditions are the same as in the 2013 TMDL. Also, the same are watershed runoff *volumes* and the water and P loads for the atmospheric, internal and SSTS sources.) The water balance for the revised TMDL reflects direct addition of the Osakis WWTF flow. This addition increased the total flow through the lake-and-wetland system by 7.5%. The flow increase, in turn, led to a small increase in Faille Lake's loading capacity.

In revising Faille Lake's TMDL, the MPCA used the same model as in the 2013 TMDL, namely the Canfield-Bachmann (1981) lake model, as implemented in the BATHTUB model software (Walker 1999). But in the revision, the MPCA explicitly modeled two additional waterbodies upstream from Faille Lake. The more upstream of the two is Clifford wetland. The other, termed here the "Intermediate wetlands," is a wetland complex along the stream that connects Clifford wetland to Faille Lake (Figure 9.1).

Section 9.1 presents the morphometry of the added waterbodies and a detailed watershed area breakdown necessitated by their inclusion in the modeling.

Effluent flow and load from the Osakis WWTF in the baseline lake model are derived from DMR data, and the WLA in the TMDL scenario is consistent with the assumptions and requirements of the Osakis WWTF NPDES/SDS permit MN0020028 (Figure 9.1).

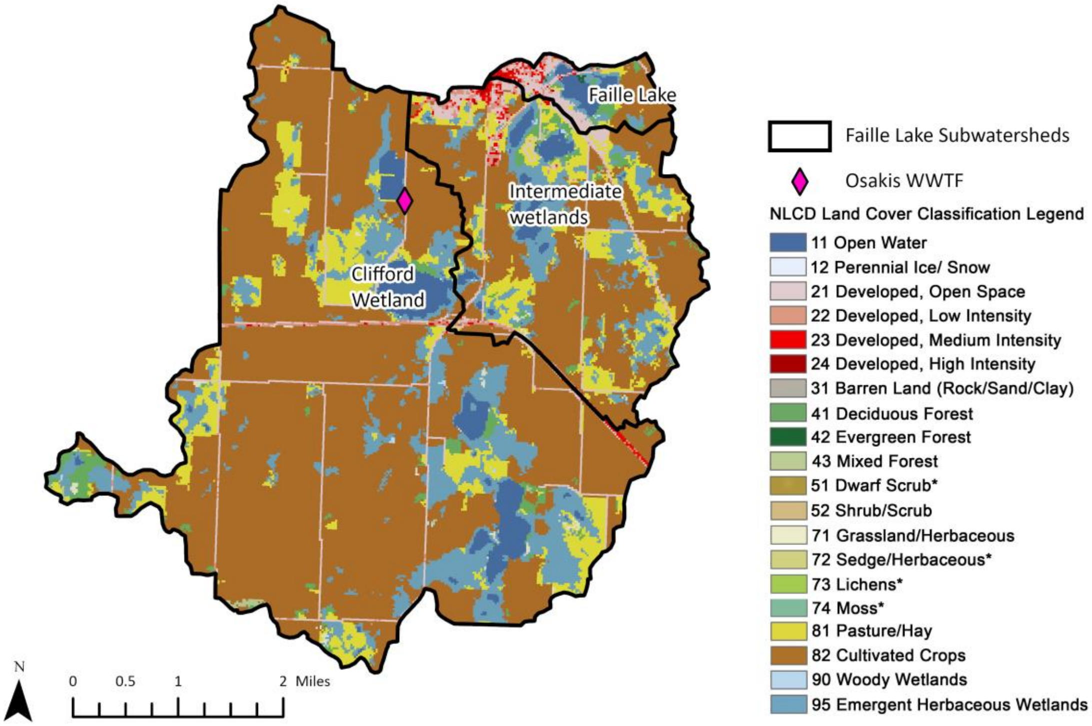

Figure 9.1. Faille Lake Subwatershed Boundaries and Land Cover (National Land Cover Database 2016)

Table 9.1 Osakis WWTF Effluent Characteristics

Parameter	Existing*	TMDL scenario **
Flow, hm^3/yr	0.2929	0.4040
TP concentration, mg/L	0.7403	0.300
P Load, kg/yr	216.8	121.2

* DMR averages for years 2003, 2004, & 2008 (concentration is flow-weighted mean).

** Per NPDES/SDS Permit No. MN0020028: average wet weather design flow = 0.293 mgd; TP <= 121 kg/yr

Section 9.2 contains the BATHTUB model outputs for existing conditions and the TMDL scenario. In calibrating to the existing conditions, it was necessary to add internal P loads to both of the upstream waterbodies. However, both waterbodies also exhibited P retention. Table 9.2 lists the BATHTUB-derived retention factor R (fraction of overall P load that is retained in the bottom sediments) for each upstream waterbody and for their combined effects. Phosphorus retention in wetlands can occur through phosphorus deposition, phosphorus uptake by plants, and phosphorus sorption ability of sediments (e.g., White et al. 2000, Verhoeven et al. 2006, Fisher and Acreman 2004, Golden et al. 2019, Land et al. 2016).

Table 9.2 Phosphorus Retention in Upstream Waterbodies

Waterbody	P Retention Factor R	
	Existing	TMDL
Clifford wetland	0.4695	0.3077
Intermediate wetlands	0.3059	0.1875
Combined upstream retention*	0.6319	0.4375

* Combined retention is calculated as follows:

(1) compute the "passing fractions" (1 - R) for each waterbody,
(2) multiply the waterbodies' passing fractions together, and
(3) subtract the result from 1.

The combined upstream P retention causes a reduced net loading to Faille Lake from the Osakis WWTF, as shown in Table 9.3.

Table 9.3 Osakis WWTF Discharged P Load and Net Load to Faille Lake

Designation	P Load (kg/yr)	
	Existing	TMDL
Osakis WWTF P load as discharged	216.8	121.2
Osakis WWTF net load to Faille Lake*	79.8	68.2

* Reflecting overall P load retention in upstream waterbodies of 63% for existing conditions and 44% for the TMDL (percent retention is larger with larger loading).

Thus, although the Osakis WWTF's permit limit is 121 kg/yr, the net load WLA, or the portion of the facility's P load that actually enters Faille Lake under the TMDL condition, is 68 kg/yr.

Revised TMDL

The revised TMDL (Table 9.4) includes the Osakis WWTF net P loads from Table 9.3. Due to phosphorus retention in upstream waterbodies, this net load WLA in the TMDL scenario is consistent with the assumptions and requirements of the Osakis WWTF permit limit of 121 kg/yr.

The MOS was set equal to 5% of the total allowable load and was taken from the upstream watershed load. The construction and industrial stormwater WLA was computed as 1.5% of the direct watershed load under the TMDL condition and was taken from the direct watershed load (same value for existing and TMDL conditions).

In the revised TMDL, the upstream waterbodies include the intermediate wetlands and all waterbodies upstream of them. Because the upstream waterbodies in the original TMDL include only Clifford Wetland, the area and resulting load from the upstream waterbodies is higher in the revised TMDL, and the direct runoff area and resulting load is lower. The construction and industrial WLAs are also lower in the revised TMDL because they are based on a percentage of the direct runoff area.

The following summarizes the revisions to the Faille Lake TMDL compared to the original 2013 Faille Lake TMDL:

- Loading capacity: Increased slightly due to a 7.5% increase in the total flow through the lake-and-wetland system from the addition of the Osakis WWTF flow.
- Osakis WWTF WLA: Omitted in original TMDL; incorporated into revised TMDL.

- Construction and industrial stormwater WLAs: Decreased due to the increase in size of the upstream waterbodies' watershed area and resulting decrease in the size of the direct drainage area.
- Direct runoff LA: Decreased due to the decrease in the size of the direct drainage area.
- Upstream waterbodies LA: Increased due to the increase in size of the upstream waterbodies' watershed area.
- SSTS, atmospheric deposition, and internal load LAs: No change.
- Margin of safety: Increased slightly due to the increase in loading capacity.

Table 9.4 Revised Faille Lake TMDL Allocation

This table is similar to Table 4.3 in Section 4.1.5, but has been converted from lb/yr to kg/yr to facilitate comparison with the WWTF permit limits.

Load Category	Load Component	Existing Load (kg/yr)	Allowable Load (kg/yr)	Load Reduction[1] (kg/yr)	Load Reduction[1] %	TMDL (kg/day)
TOTAL LOAD		**1425.7**	**436.4**	**1,011.2**	**71%**	**1.1947**
Wasteload Allocation	**Total WLA**	**80.0**	**68.3**	**11.7**	**15%**	**0.1871**
	Osakis WWTF net load[2]	79.8	68.2	11.7	15%	0.1866
	Construction/Industrial SW	0.2	0.2	0.0	0%	0.0004
Load Allocation	**Total LA**	**1345.7**	**346.2**	**999.5**	**74%**	**0.9479**
	Direct runoff	26.5	9.9	16.6	63%	0.0271
	Upstream waterbodies[3]	1276.0	313.5	962.5	75%	0.8584
	SSTS	20.4	0.0	20.4	100%	0.0000
	Atmospheric deposition	8.5	8.5	0.0	0%	0.0234
	Internal load	14.3	14.3	0.0	0%	0.0391
Margin of Safety		**--**	**21.8**	**--**	**--**	**0.0597**

[1] The TOTAL estimated load reduction equals the (Existing - Allowable) load difference, plus the Margin of Safety.

[2] Reflects P retention in upstream waterbodies; existing and allowable loads as discharged to Clifford wetland are 217 and 121 kg/yr, respectively. The net load WLA is consistent with the assumptions and requirements of the Osakis WWTF permit limit of 121 kg/yr.

[3] Not including Osakis WWTF net load.

9.1 LAKE MORPHOMETRY AND WATERSHED AREA BREAKDOWN

Table 9.5 gives the morphometry of the two waterbodies upstream from Faille Lake, the intermediate wetlands and Clifford wetland, along with that of Faille Lake (Wenck 2013) for completeness. The mean depth of Clifford wetland was derived from the depth survey conducted by the MPCA (Greg VanEeckhout) in February 2012. The depth survey included 110 gridded measuring points spanning the waterbody and made use of augered holes to measure water depth through the ice. The Intermediate wetlands' mean depth was estimated to be slightly less than Clifford's based on best field judgment. The upstream waterbodies' surface areas were determined by the MPCA staff using GIS methods. The waterbody volumes were calculated accordingly as the product of area and mean depth.

Table 9.5 Morphometry of Faille Lake and Upstream Waterbodies

Waterbody	Surface Area km^2	Mean Depth m	Volume hm^3
Clifford wetland	0.706	0.660	0.466
Intermediate wetlands	0.389	0.640	0.249
Faille Lake	0.316	1.086	0.343

A more detailed watershed area breakdown than given in the 2013 TMDL was needed for modeling the upstream waterbodies explicitly (Table 9.6). The areas were newly determined by MPCA staff using GIS methods. Faille Lake's total drainage area was determined as 14,734 acres. The 2013 TMDL reported two slightly different areas for the total drainage area (14,722 acres in Table 2.1, and 14,742 acres in Table 2.2; averaging 14,732 acres). The two earlier areas differ from one another by less than 0.15%, and the new determination virtually equals their average.

Table 9.6. Drainage Areas of within Faille Lake Watershed

Waterbody	Direct External Drainage Area[a] km^2	Upstream Drainage Area[b] km^2	Total External Drainage Area[a] km^2	Total Drainage Area[c] km^2
Clifford wetland	42.254	–	42.254	42.960
Intermediate Wetlands	14.698	42.960	57.658	58.047
Faille Lake	1.263	58.047	59.310	59.626

Notes:

[a] Excluding area of named waterbody.

[b] Including area of upstream waterbodies.

[c] Including area of named waterbody.

9.2 2023 BATHTUB MODEL RESULTS

Existing Conditions

Clifford Wetland

Clifford calibration_JBE_2016-03-15

File: C:\Users\jerdman\Desktop\01_Faille Lake TMDL 2016\Bathtub FINAL_JBE_2016-03-15\1_Faille system calibration files\btb calibration files_2016-03-15\Clifford calibration_JBE_2016-03-15.btb

Global Variables	Mean	CV	Model Options	Code	Description
Averaging Period (yrs)	1	0.0	Conservative Substance	0	NOT COMPUTED
Precipitation (m)	0.7366	0.0	Phosphorus Balance	8	CANF & BACH, LAKES
Evaporation (m)	0.7366	0.0	Nitrogen Balance	0	NOT COMPUTED
Storage Increase (m)	0	0.0	Chlorophyll-a	0	NOT COMPUTED
			Secchi Depth	0	NOT COMPUTED
Atmos. Loads (kg/km^2-yr)	**Mean**	**CV**	Dispersion	0	NONE
Conserv. Substance	0	0.00	Phosphorus Calibration	1	DECAY RATES
Total P	27	0.00	Nitrogen Calibration	0	NONE
Total N	0	0.00	Error Analysis	1	MODEL & DATA
Ortho P	0	0.00	Availability Factors	0	IGNORE
Inorganic N	0	0.00	Mass-Balance Tables	1	USE ESTIMATED CONCS
			Output Destination	2	EXCEL WORKSHEET

Segment Morphometry		Outflow		Area	Depth	Length	Mixed Depth (m)		Internal Loads (mg/m^2- Total P	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV
1	Clifford Wetland	0	1	0.706	0.66	1.23	0.66	0	4.13	0

Segment Observed Water Quality	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	272	0	0	0	0	0

Segment Calibration Factors	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0

Tributary Data				Dr Area	Flow (hm^3/yr)		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV
1	Clifford direct	1	1	42.254	3.668	0	199	0
2	Osakis WWTP	1	1	0	0.2929	0	740.3	0

Model Coefficients	Mean	CV
Total Phosphorus	1.000	0.45

Clifford Wetland

Clifford calibration_JBE_2016-03-15

Predicted & Observed Values

Segment: 1 Clifford Wetland

	Predicted Values		Observed Values	
Variable	Mean	CV	Mean	CV
TOTAL P MG/M3	272.0	0.21	272.0	
CARLSON TSI-P	85.0	0.04	85.0	

Clifford Wetland

Clifford calibration_JBE_2016-03-15

Overall Water & Nutrient Balances **Averaging Period = 1.00 years**

Name	Area km^2	Flow hm^3/yr	Conc mg/m^3	Load kg/yr	Runoff m/yr	Export kg/km^2/yr
Clifford direct	42.254	3.668	199.0	729.9	0.09	17.3
Osakis WWTP		0.2929	740.3	216.8		
PRECIPITATION	0.706	0.520	36.7	19.1	0.74	27.0
INTERNAL LOAD				1,065.0		
TRIBUTARY INFLOW	42.254	3.961	239.0	946.8	0.09	22.4
***TOTAL INFLOW	42.960	4.481	453.2	2,030.8	0.10	47.3
ADVECTIVE OUTFLOW	42.960	3.961	272.0	1,077.4	0.09	25.1
***TOTAL OUTFLOW	42.960	3.961	272.0	1,077.4	0.09	25.1
***EVAP / RETENTION		0.520		953.4		

Overflow Rate (m/yr)	5.6	Nutrient Resid. Time (yrs)	0.0624
Hydraulic Resid. Time (yrs)	0.1176	Turnover Ratio	16.0
Reservoir Conc (mg/m3)	272	Retention Coef.	0.469

Existing Conditions

Intermediate Wetlands

Intermediate wetlands calibration_JBE_2016-03-15

File: C:\Users\jerdman\Desktop\01_Faille Lake TMDL 2016\btb files_2016-03-15\Inter Wetlands calibration_JBE_2016-03-15.btb

Global Variables	Mean	CV	Model Options	Code	Description
Averaging Period (yrs)	1	0.0	Conservative Substance	0	NOT COMPUTED
Precipitation (m)	0.7366	0.0	Phosphorus Balance	8	CANF & BACH, LAKES
Evaporation (m)	0.7366	0.0	Nitrogen Balance	0	NOT COMPUTED
Storage Increase (m)	0	0.0	Chlorophyll-a	0	NOT COMPUTED
			Secchi Depth	0	NOT COMPUTED
Atmos. Loads (kg/km^2-yr)	**Mean**	**CV**	Dispersion	0	NONE
Conserv. Substance	0	0.00	Phosphorus Calibration	1	DECAY RATES
Total P	27	0.00	Nitrogen Calibration	0	NONE
Total N	0	0.00	Error Analysis	1	MODEL & DATA
Ortho P	0	0.00	Availability Factors	0	IGNORE
Inorganic N	0	0.00	Mass-Balance Tables	1	USE ESTIMATED CONCS
			Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

									Internal Loads (mg/m^2-	
		Outflow		Area	Depth	Length	Mixed Depth (m)		Total P	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV
1	Intermediate Wetlands	0	1	0.389	0.64	0.74	0.64	0	3.85	0

Segment Observed Water Quality

	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	0	0	0	0	0	0

Segment Calibration Factors

	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV
1	Intermed Wetlands direct	1	1	14.698	1.601	0	199	0
2	Clifford outflow	1	1	42.960	3.961	0	272	0

Model Coefficients	Mean	CV
Total Phosphorus	1.000	0.45

Intermediate Wetlands

Intermediate wetlands calibration_JBE_2016-03-15
Predicted & Observed Values
Segment: 1 Intermediate Wetlands

	Predicted Values		Observed Values	
Variable	**Mean**	**CV**	**Mean**	**CV**
TOTAL P MG/M3	243.8	0.14		
CARLSON TSI-P	83.4	0.02		

Intermediate Wetlands

Intermediate wetlands calibration_JBE_2016-03-15
Overall Water & Nutrient Balances **Averaging Period = 1.00 years**

Name	**Area** km^2	**Flow** hm^3/yr	**Conc** mg/m^3	**Load** kg/yr	**Runoff** m/yr	**Export** $kg/km^2/yr$
Intermed Wetlands direct	14.698	1.6010	199.0	318.6	0.11	21.7
Clifford outflow	42.960	3.9609	272.0	1,077.4	0.09	25.1
PRECIPITATION	0.389	0.2865	36.7	10.5	0.74	27.0
INTERNAL LOAD				547.0		
TRIBUTARY INFLOW	57.658	5.5619	251.0	1,396.0	0.10	24.2
***TOTAL INFLOW	58.047	5.8484	334.0	1,953.5	0.10	33.7
ADVECTIVE OUTFLOW	58.047	5.5619	243.8	1,355.9	0.10	23.4
***TOTAL OUTFLOW	58.047	5.5619	243.8	1,355.9	0.10	23.4
***EVAP / RETENTION		0.2865		597.6		

Overflow Rate (m/yr)	14.3	Nutrient Resid. Time (yrs)	0.0311
Hydraulic Resid. Time (yrs)	0.0448	Turnover Ratio	32.2
Reservoir Conc (mg/m3)	244	Retention Coef.	0.306

Existing Conditions

Faille Lake

Faille calibration_JBE_2016-03-15
File: C:\Users\jerdman\Desktop\01_Faille Lake TMDL 2016\btb files_2016-03-15\Faille calibration_JBE_2016-03-15.btb

Global Variables	**Mean**	**CV**	**Model Options**	**Code**	**Description**
Averaging Period (yrs)	1	0.0	Conservative Substance	0	NOT COMPUTED
Precipitation (m)	0.7366	0.0	Phosphorus Balance	8	CANF & BACH, LAKES
Evaporation (m)	0.7366	0.0	Nitrogen Balance	0	NOT COMPUTED
Storage Increase (m)	0	0.0	Chlorophyll-a	0	NOT COMPUTED
			Secchi Depth	0	NOT COMPUTED
Atmos. Loads (kg/km^2-yr)	**Mean**	**CV**	Dispersion	0	NONE
Conserv. Substance	0	0.00	Phosphorus Calibration	1	DECAY RATES
Total P	27	0.00	Nitrogen Calibration	0	NONE
Total N	0	0.00	Error Analysis	1	MODEL & DATA
Ortho P	0	0.00	Availability Factors	0	IGNORE
Inorganic N	0	0.00	Mass-Balance Tables	1	USE ESTIMATED CONCS
			Output Destination	2	EXCEL WORKSHEET

[Faille Lake inputs continued next page]

Faille Lake [inputs continued]

Segment Morphometry		Outflow		Area	Depth	Length	Mixed Depth (m)		Internal Loads (mg/m^2-	
									Total P	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV
1	Faille Lake	0	1	0.316	1.086	0.72	1.086	0	0.1236	0

Segment Observed Water Quality	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	173.39999	0	0	0	0	0

Segment Calibration Factors	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0

Tributary Data				Dr Area	Flow (hm^3/yr)		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV
1	Intermed wetlands outflow	1	1	58.047	5.562	0	243.8	0
2	Faille direct	1	1	1.263	0.134	0	199	0
3	Faille septics	1	1	0	0.0001	0	204,000	0

Model Coefficients	Mean	CV
Total Phosphorus	1.000	0.45

Faille Lake

Faille calibration_JBE_2016-03-15
Predicted & Observed Values
Segment: 1 Faille Lake

	Predicted Values		Observed Values	
Variable	Mean	CV	Mean	CV
TOTAL P MG/M3	173.4	0.14	173.4	
CARLSON TSI-P	78.5	0.03	78.5	

Faille Lake

Faille calibration_JBE_2016-03-15
Overall Water & Nutrient Balances **Averaging Period = 1.00 years**

Name	Area km^2	Flow hm^3/yr	Conc mg/m^3	Load kg/yr	Runoff m/yr	Export kg/km^2/yr
Intermed wetlnds outflow	58.047	5.562	243.8	1,355.9	0.10	23.4
Faille direct	1.263	0.134	199.0	26.7	0.11	21.1
Faille septics		0.0001	204,000	20.4		
PRECIPITATION	0.316	0.233	36.7	8.5	0.74	27.0
INTERNAL LOAD				14.3		
TRIBUTARY INFLOW	59.310	5.696	246.3	1,402.9	0.10	23.7
***TOTAL INFLOW	59.626	5.929	240.5	1,425.7	0.10	23.9
ADVECTIVE OUTFLOW	59.626	5.696	173.4	987.8	0.10	16.6
***TOTAL OUTFLOW	59.626	5.696	173.4	987.8	0.10	16.6
***EVAP / RETENTION		0.233		437.9		

Overflow Rate (m/yr)	18.0	Nutrient Resid. Time (yrs)	0.0417
Hydraulic Resid. Time (yrs)	0.0602	Turnover Ratio	24.0
Reservoir Conc (mg/m3)	173	Retention Coef.	0.307

TMDL Condition

Clifford Wetland

Clifford TMDL condition_JBE_2016-03-16

File: C:\Users\jerdman\Desktop\01_Faille Lake TMDL 2016\Bathtub FINAL_JBE_2016-03-15\Clifford TMDL condition_JBE_2016-03-16.btb

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7366	0.0
Evaporation (m)	0.7366	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	27	0.00
Total N	0	0.00
Ortho P	0	0.00
Inorganic N	0	0.00

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	0	NOT COMPUTED
Secchi Depth	0	NOT COMPUTED
Dispersion	0	NONE
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Internal Loads (mg/m^2- Total P	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV
1	Clifford Wetland	0	1	0.706	0.66	1.23	0.66	0	0.25	0

Segment Observed Water Quality

	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	0	0	0	0	0	0

Segment Calibration Factors

	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV
1	Clifford direct	1	1	42.254	3.668	0	75	0
2	Osakis WWTP	1	1	0	0.404	0	300	0

Model Coefficients	Mean	CV
Total Phosphorus	1.000	0.45

Clifford Wetland

Clifford TMDL condition_JBE_2016-03-16

Overall Water & Nutrient Balances **Averaging Period = 1.00 years**

Name	Area km^2	Flow hm^3/yr	Conc mg/m^3	Load kg/yr	Runoff m/yr	Export kg/km^2/yr
Clifford direct	42.254	3.668	75.0	275.1	0.09	6.5
Osakis WWTP		0.404	300.0	121.2		
PRECIPITATION	0.706	0.520	36.7	19.1	0.74	27.0
INTERNAL LOAD				64.5		
TRIBUTARY INFLOW	42.254	4.072	97.3	396.3	0.10	9.4
***TOTAL INFLOW	42.960	4.592	104.5	479.8	0.11	11.2
ADVECTIVE OUTFLOW	42.960	4.072	81.6	332.2	0.09	7.7
***TOTAL OUTFLOW	42.960	4.072	81.6	332.2	0.09	7.7
***EVAP / RETENTION		0.520		147.7		

Overflow Rate (m/yr)	5.8	Nutrient Resid. Time (yrs)	0.0792
Hydraulic Resid. Time (yrs)	0.1144	Turnover Ratio	12.6
Reservoir Conc (mg/m3)	82	Retention Coef.	0.308

TMDL Condition

Intermediate Wetlands

Intermediate wetlands TMDL condition_JBE_2016-03-16

File: C:\Users\jerdman\Desktop\01_Faille Lake TMDL 2016\New btb files\Inter Wetl TMDL condition_JBE_2016-03-16.btb

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7366	0.0
Evaporation (m)	0.7366	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	27	0.00
Total N	0	0.00
Ortho P	0	0.00
Inorganic N	0	0.00

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	0	NOT COMPUTED
Secchi Depth	0	NOT COMPUTED
Dispersion	0	NONE
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Internal Loads (mg/m^2- Total P	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV
1	Intermediate Wetlands	0	1	0.389	0.64	0.74	0.64	0	0.238	0

Segment Observed Water Quality

	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	0	0	0	0	0	0

Segment Calibration Factors

	Total P (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV
1	Intermediate Wetlands direc	1	1	14.698	1.601	0	75	0
2	Clifford outflow	1	1	42.960	4.072	0	81.6	0

Model Coefficients	Mean	CV
Total Phosphorus	1.000	0.45

Intermediate Wetlands

Intermediate wetlands TMDL condition_JBE_2016-03-16

Overall Water & Nutrient Balances **Averaging Period = 1.00 years**

Name	Area km^2	Flow hm^3/yr	Conc mg/m^3	Load kg/yr	Runoff m/yr	Export kg/km^2/yr
Interm Wetlands direct	14.698	1.601	75.0	120.1	0.11	8.2
Clifford outflow	42.960	4.072	81.6	332.3	0.09	7.7
PRECIPITATION	0.389	0.287	36.7	10.5	0.74	27.0
INTERNAL LOAD				33.8		
TRIBUTARY INFLOW	57.658	5.673	79.7	452.4	0.10	7.8
***TOTAL INFLOW	58.047	5.960	83.3	496.7	0.10	8.6
ADVECTIVE OUTFLOW	58.047	5.673	71.1	403.5	0.10	7.0
***TOTAL OUTFLOW	58.047	5.673	71.1	403.5	0.10	7.0
***EVAPORATION		0.287		93.1		

Overflow Rate (m/yr)	14.6	Nutrient Resid. Time (yrs)	0.0357
Hydraulic Resid. Time (yrs)	0.0439	Turnover Ratio	28.0
Reservoir Conc (mg/m3)	71	Retention Coef.	0.188

TMDL Condition

Faille Lake

Faille TMDL condition_JBE_2016-03-16

File: C:\Users\jerdman\Desktop\01_Faille Lake TMDL 2016\New btb files\Faille Lake TMDL_JBE_2016-03-16.btb

Global Variables	**Mean**	**CV**
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7366	0.0
Evaporation (m)	0.7366	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	**Mean**	**CV**
Conserv. Substance	0	0.00
Total P	27	0.00
Total N	0	0.00
Ortho P	0	0.00
Inorganic N	0	0.00

Model Options	**Code**	**Description**
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	0	NOT COMPUTED
Secchi Depth	0	NOT COMPUTED
Dispersion	0	NONE
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		**Area**	**Depth**	**Length**	**Mixed Depth (m)**		**Internal Loads (mg/m^2-** **Total P**	
Seg	**Name**	**Segment**	**Group**	**km^2**	**m**	**km**	**Mean**	**CV**	**Mean**	**CV**
1	Faille Lake	0	1	0.316	1.086	0.72	1.086	0	0.1236	0

Segment Observed Water Quality

	Total P (ppb)		**Chl-a (ppb)**		**Secchi (m)**	
Seg	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1	60	0	0	0	0	0

Segment Calibration Factors

	Total P (ppb)		**Chl-a (ppb)**		**Secchi (m)**	
Seg	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1	1	0	1	0	1	0

Tributary Data

				Dr Area	**Flow (hm^3/yr)**		**Total P (ppb)**	
Trib	**Trib Name**	**Segment**	**Type**	**km^2**	**Mean**	**CV**	**Mean**	**CV**
1	Intermed wetlands outflow	1	1	58.047	5.673	0	71.1	0
2	Faille direct	1	1	1.263	0.134	0	75	0
3	Faille septics	1	1	0	0.0001	0	0.001	0

Model Coefficients	**Mean**	**CV**
Total Phosphorus	1.000	0.45

Faille Lake

Faille TMDL condition_JBE_2016-03-16

Predicted & Observed Values

Segment: 1 Faille Lake

	Predicted Values		**Observed Values**		
Variable	**Mean**	**CV**	**Mean**	**CV**	
TOTAL P MG/M3	60.0	0.09	60.0	…………………	**Water Quality Standard**
CARLSON TSI-P	63.2	0.02	63.2		

Faille Lake

Faille TMDL condition_JBE_2016-03-16

Overall Water & Nutrient Balances		**Averaging Period =**		**1.00**	**years**	
	Area	**Flow**	**Conc**	**Load**	**Runoff**	**Export**
Name	**km^2**	**hm^3/yr**	**mg/m^3**	**kg/yr**	**m/yr**	**kg/km^2/yr**
Intermediate wetlands outflc	58.047	5.673	71.1	403.5	0.10	7.0
Faille direct	1.263	0.134	75.0	10.1	0.11	8.0
Faille septics		0.0001	0.001	0.0		
PRECIPITATION	0.316	0.233	36.7	8.5	0.74	27.0
INTERNAL LOAD				14.3		
TRIBUTARY INFLOW	59.310	5.807	71.2	413.6	0.10	7.0
***TOTAL INFLOW	59.626	6.040	72.2	436.4	0.10	7.3
ADVECTIVE OUTFLOW	59.626	5.807	60.0	348.3	0.10	5.8
***TOTAL OUTFLOW	59.626	5.807	60.0	348.3	0.10	5.8
***EVAP / RETENTION		0.233		88.1		

Overflow Rate (m/yr)	18.4	Nutrient Resid. Time (yrs)	0.0472
Hydraulic Resid. Time (yrs)	0.0591	Turnover Ratio	21.2
Reservoir Conc (mg/m3)	60	Retention Coef.	0.202

9.3 COMPARISON OF REVISED AND ORIGINAL (2013) FAILLE LAKE TMDL

In the comparison below (Tables 9.7 through 9.9), some components of the TMDL had to be combined because of differences in component definitions. In particular, the 2013 TMDL did not include the Osakis WWTF as a loading component; and the 2013 TMDL divided Faille Lake's Watershed only at the Clifford wetland outlet, whereas the revised TMDL also divided the watershed at the upstream waterbodies' point of inflow to Faille Lake.

Table 9.7. Summary of Revised Faille Lake TMDL

Load Component	Existing Load (kg/yr)	Allowable Load (kg/yr)
TOTAL LOAD	**1,426**	**436**
Runoff and wastewater combined	1,383	392
SSTS	20	0
Atmospheric deposition	9	9
Internal load	14	14
Margin of Safety	**--**	**22**

Table 9.8. Summary of Original (2013) Faille Lake TMDL

Source	Existing Load (kg/yr)	Allowable Load (kg/yr)
TOTAL LOAD	**1,388**	**414**
Runoff and wastewater combined	1,344	370
SSTS	20	0
Atmosphere	9	9
Internal Load	15	15
Margin of Safety	**--**	**21**

* Loads have been converted to kg/yr.

Table 9.9. Differences, Revised Minus Original

Source	Existing Load (kg/yr)	Allowable Load (kg/yr)
TOTAL LOAD	**38**	**22**
Runoff and wastewater combined	39	22
SSTS	0	0
Atmosphere	0	0
Internal Load	-1 *	-1
Margin of Safety	**--**	**1**

* The internal load estimate did not change between the two reports; the difference shown here is due to rounding.

9.4 REFERENCES (FAILLE LAKE 2023 ADDENDUM ONLY)

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Appendix A

Historic Lake Water Quality Sampling

Smith Lake

Year	Secchi (All Sites)		Chl a (All Sites)		TP (All Sites)		TKN (All Sites)		TSS (All Sites)	
	Count	Ave (m)	Count	Ave (ug/L)	Count	Ave (ug/L)	Count	Ave (mg/L)	Count	Ave (mg/)
1990	--	--	--	--	--	--	--	--	--	--
1991	--	--	--	--	--	--	--	--	--	--
1992	--	--	--	--	--	--	--	--	--	--
1993	--	--	--	--	--	--	--	--	--	--
1994	--	--	--	--	--	--	--	--	--	--
1995	--	--	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--	--	--
1998	--	--	--	--	--	--	--	--	--	--
1999	16	1.77	--	--	--	--	--	--	--	--
2000	16	1.19	5	37	5	55	5	1.26	5	8
2001	12	1.83	--	--	--	--	--	--	--	--
2002	12	1.67	3	34	3	52	--	--	--	--
2003	12	1.30	--	--	--	--	--	--	--	--
2004	15	1.89	8	21	8	46	4	1.09	4	5
2005	13	1.43	4	32	4	55	--	--	--	--
2006	13	1.29	3	43	3	51	--	--	--	--
2007	12	1.31	3	30	3	56	--	--	--	--
2008	4	1.53	4	43	4	46	--	--	--	--
2009	2	3.15	2	11	2	29	--	--	--	--
2010	4	1.30	4	35	4	61	--	--	--	--
2011	--	--	--	--	--	--	--	--	--	--

Faille Lake

Year	Secchi (All sites)		Chl a (All sites)		TP (All Sites)		TKN (All Sites)		TSS (All Sites)	
	Count	Ave (m)	Count	Ave (chl-a)	Count	Ave (ug/L)	Count	Ave (mg/L)	Count	Ave (mg/L)
1990	--	--	--	--	--	--	--	--	--	--
1991	--	--	--	--	--	--	--	--	--	--
1992	--	--	--	--	--	--	--	--	--	--
1993	--	--	--	--	--	--	--	--	--	--
1994	--	--	--	--	--	--	--	--	--	--
1995	--	--	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--	--	--
1998	2	0.71	2	24	2	123	1	1.90	1	31
1999	4	1.04	4	17	4	115	4	1.68	4	39
2000	4	0.88	4	51	4	141	4	3.40	4	39
2001	3	1.27	3	13	3	158	3	1.80	3	37
2002	3	1.22	3	28	3	236	3	1.43	3	24
2003	8	1.22	8	13	8	192	8	1.30	8	4
2004	5	1.04	5	12	5	90	5	1.60	5	2
2005	--	--	--	--	--	--	--	--	--	--
2006	--	--	--	--	--	--	--	--	--	--
2007	--	--	4	49	4	238	4	2.63	4	10
2008	--	--	--	--	--	--	--	--	--	--
2009	--	--	--	--	--	--	--	--	--	--
2010	--	--	--	--	--	--	--	--	--	--
2011	--	--	--	--	--	--	--	--	--	--

Lake Osakis

	Secchi (All Sites)		Chl-a (All Sites)		TP (All Sites)		TKN (All Sites)		TSS (All Sites)	
Year	Count	Ave (m)	Count	Ave (m)	Count	Ave (ug/L)	Count	Ave (mg/L)	Count	Ave (mg/L)
1990	35	1.98	--	--	7	63	2	1.05	7	5
1991	32	1.92	--	--	--	--	--	--	--	--
1992	25	2.87	--	--	--	--	--	--	--	--
1993	12	2.35	--	--	--	--	--	--	--	--
1994	53	1.47	--	--	--	--	--	--	--	--
1995	55	2.15	1	8	1	40	1	1.60	--	--
1996	45	2.00	1	7	1	30	1	1.01	--	--
1997	44	2.58	1	15	1	20	1	0.88	--	--
1998	27	2.17	2	23	2	28	2	0.99	--	--
1999	27	1.44	3	29	3	67	3	1.38	3	31
2000	29	3.13	4	9	4	84	4	1.02	3	30
2001	25	2.08	--	--	--	--	--	--	--	--
2002	29	1.85	2	11	2	64	2	1.20	1	28
2003	19	2.59	1	11	1	87	1	0.69	1	2
2004	23	2.33	7	18	7	52	3	1.28	3	6
2005	17	2.66	8	26	8	51	8	1.10	8	7
2006	13	1.42	8	52	8	65	7	1.05	7	11
2007	7	1.48	9	30	9	58	9	1.13	9	7
2008	6	2.08	--	--	--	--	--	--	--	--
2009	12	3.33	8	9	8	50	8	1.05	8	3
2010	1	2.10	--	--	--	--	--	--	--	--
2011	--	--	--	--	--	--	--	--	--	--

Maple Lake

Year	Secchi (All Sites)		Chl a (All Sites)		TP (All Sites)		TKN (All Sites)		TSS (All Sites)	
	Count	Ave (m)	Count	Ave (ug/L)	Count	Ave (ug/L)	Count	Ave (mg/L)	Count	Ave (mg/L)
1990	--	--	--	--	--	--	--	--	--	--
1991	--	--	--	--	--	--	--	--	--	--
1992	--	--	--	--	--	--	--	--	--	--
1993	--	--	--	--	--	--	--	--	--	--
1994	--	--	--	--	--	--	--	--	--	--
1995	--	--	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--	--	--
1998	--	--	--	--	--	--	--	--	--	--
1999	--	--	--	--	--	--	--	--	--	--
2000	--	--	--	--	--	--	--	--	--	--
2001	--	--	--	--	--	--	--	--	--	--
2002	--	--	--	--	--	--	--	--	--	--
2003	--	--	--	--	--	--	--	--	--	--
2004	--	--	--	--	--	--	--	--	--	--
2005	--	--	--	--	--	--	--	--	--	--
2006	11	1.55	4	32	4	55	--	--	--	--
2007	13	1.22	9	58	9	92	4	2.00	4	9
2008	11	2.90	5	34	5	72	--	--	--	--
2009	12	1.60	5	46	5	92	--	--	--	--
2010	19	1.65	5	42	5	93	--	--	--	--
2011	--	--	--	--	--	--	--	--	--	--

Little Osakis Lake

Year	Secchi (All sites)		Chl a (All Sites)		TP (All sites)		TKN (All Sites)		TSS (All Sites)	
	Count	Ave (m)	Count	Ave (ug/L)	Count	Ave (ug/L)	Count	Ave (mg/L)	Count	Ave (mg/L)
1990	--	--	--	--	--	--	--	--	--	--
1991	--	--	--	--	--	--	--	--	--	--
1992	--	--	--	--	--	--	--	--	--	--
1993	--	--	--	--	--	--	--	--	--	--
1994	--	--	--	--	--	--	--	--	--	--
1995	--	--	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--	--	--
1998	--	--	--	--	--	--	--	--	--	--
1999	--	--	--	--	--	--	--	--	--	--
2000	--	--	--	--	--	--	--	--	--	--
2001	--	--	--	--	--	--	--	--	--	--
2002	--	--	--	--	--	--	--	--	--	--
2003	--	--	--	--	--	--	--	--	--	--
2004	--	--	--	--	--	--	--	--	--	--
2005	--	--	--	--	--	--	--	--	--	--
2006	--	--	--	--	--	--	--	--	--	--
2007	2	2.52	--	--	--	--	--	--	--	--
2008	2	4.57	--	--	--	--	--	--	--	--
2009	2	1.83	--	--	--	--	--	--	--	--
2010	9	2.11	5	10	5	34	--	--	--	--
2011	--	--	--	--	--	--	--	--	--	--

Clifford Lake

	Secchi (All Sites)		Chl a (All Sites)		TP (All Sites)		TKN (All Sites)		TSS	
Year	Count	Ave (m)	Count	Ave (m)	Count	Ave (ug/L)	Count	Ave (mg/L)	Count	Ave (mg/L)
1990	--	--	--	--	--	--	--	--	--	--
1991	--	--	--	--	--	--	--	--	--	--
1992	--	--	--	--	--	--	--	--	--	--
1993	--	--	--	--	--	--	--	--	--	--
1994	--	--	--	--	--	--	--	--	--	--
1995	--	--	--	--	5	201	--	--	--	--
1996	--	--	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--	--	--
1998	1	1			3	232			1	53
1999	4	4	4	134	6	464	4	4.49	4	135
2000	4	4	4	134	5	331	4	4.58	4	117
2001	3	3			3	369			3	53
2002	3	3			4	121			3	20
2003	8	8	8	13	9	266	8	1.74	8	11
2004	3	3	4	22	6	154	4	2.07	4	8
2005	--	--	--	--	--	--	--	--	--	--
2006	--	--	--	--	--	--	--	--	--	--
2007	--	--			4	450			3	55
2008	--	--	--	--	--	--	--	--	--	--
2009	--	--	--	--	--	--	--	--	--	--
2010	--	--	--	--	--	--	--	--	--	--
2011	--	--	--	--	--	--	--	--	--	--

Appendix B

Internal Loading Analysis for Lake Osakis

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TECHNICAL MEMORANDUM

TO: Julie Klocker
Lynn Nelson

FROM: Joe Bischoff

DATE: February 21, 2006

SUBJECT: Internal Loading Analysis for Lake Osakis

The purpose of this memo is to outline the results of the internal loading analysis for Lake Osakis.

Dissolved Oxygen and Temperature Profiles

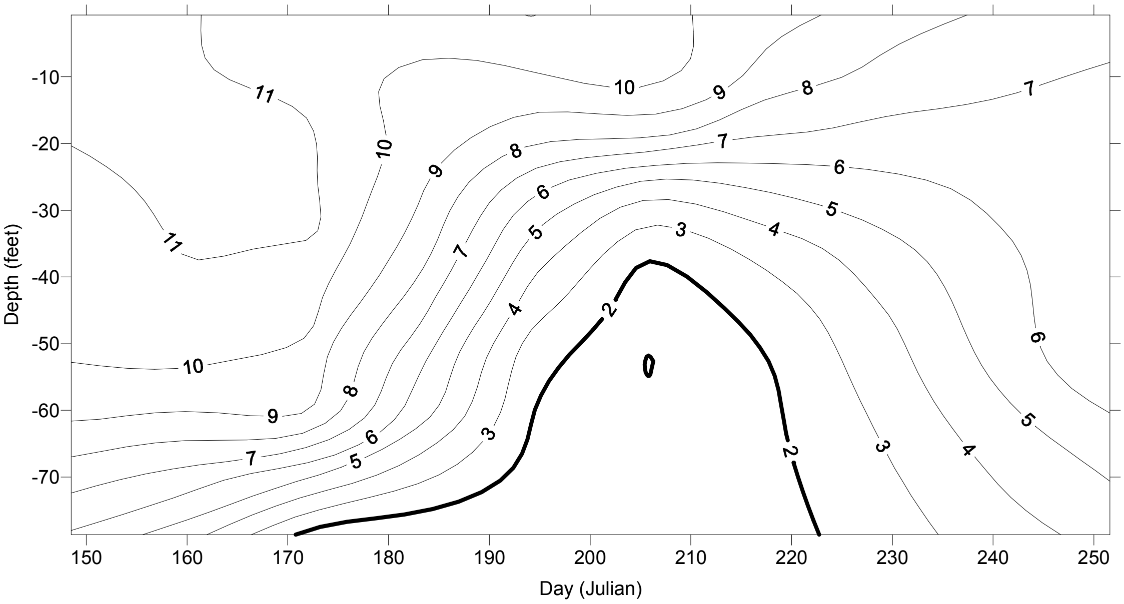
Isoplots were developed for both the OL6202 and OL6201 sites. These two sites were chosen since they represent the deepest areas. Isoplots were not developed for site OL6203 since the maximum depth was less than 15 feet, which is much less then the expected depth to the thermocline of 40 feet. The isoplots are provided below to this memo. Raw data used for the isoplots are attached for reference. On the dissolved oxygen plots, values below 2 mg/L are presented with bold lines since these represent anoxia. The days in the year are presented in Julian days. The following table will help interpret the dates.

Table 1. Dates and corresponding Julian days.

Date	Julian Day
1/1	0
2/1	31
3/1	59
4/1	90
5/1	120
6/1	151
7/1	181
8/1	212
9/1	243
10/1	273
11/1	304
12/1	334

Figure 1 & 2: Dissolved Oxygen and Temperature Isoplots for SRWD Monitoring Station OL6202 - 2004

SRWD 6202 2004 Dissolved Oxygen (mg/L)



SRWD 6202 2004 Temperature (F)

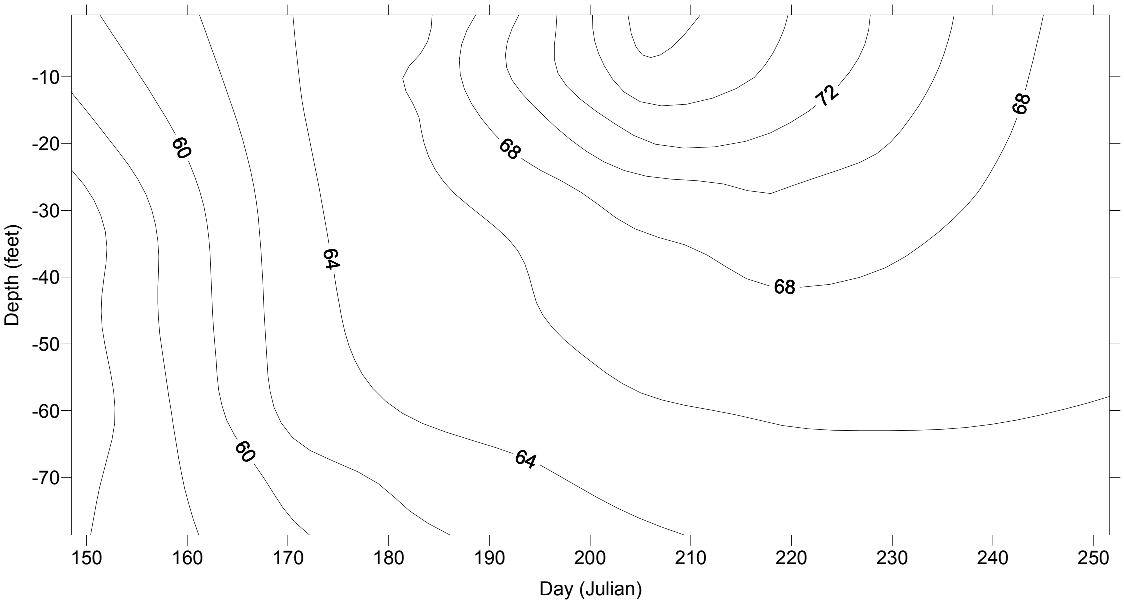
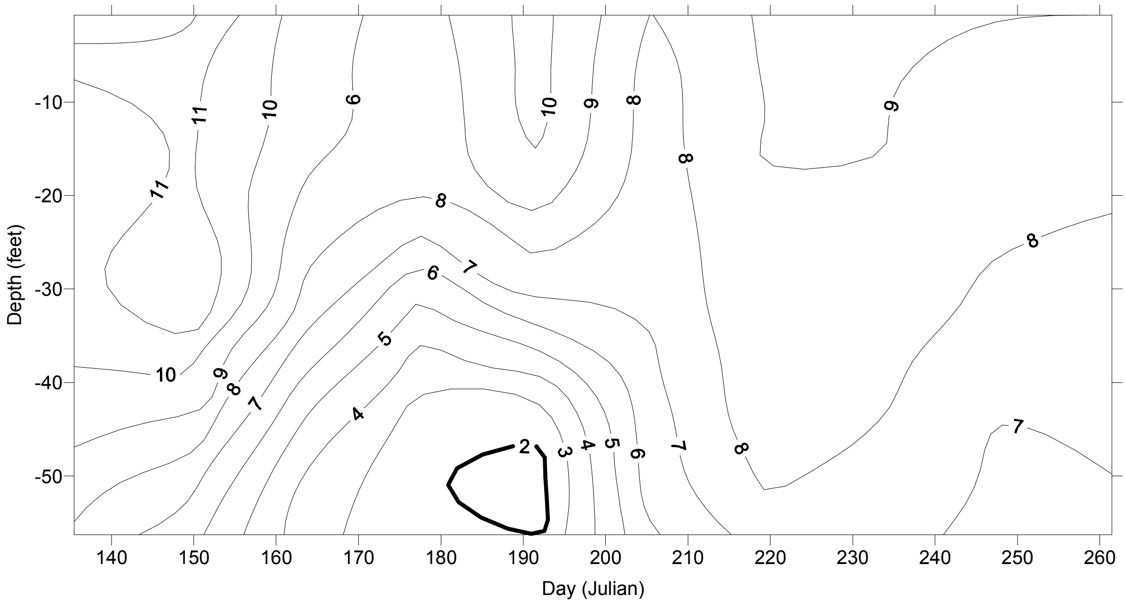


Figure 3 & 4: **Dissolved Oxygen and Temperature Isoplots for SRWD Monitoring Station OL6202 - 2005**


SRWD 6202 1005 Dissolved Oxygen (mg/L)

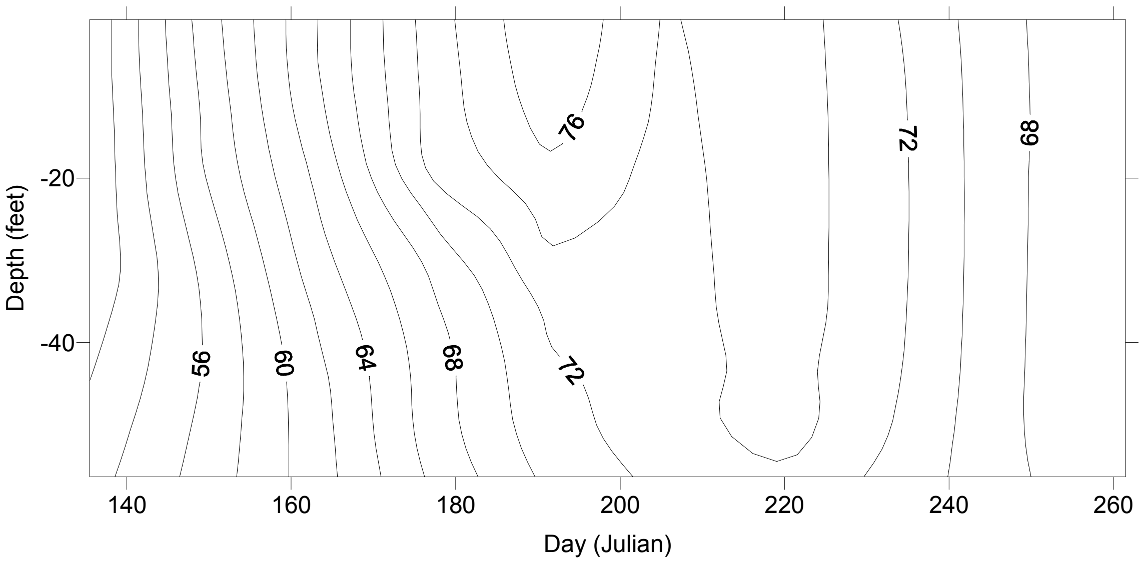
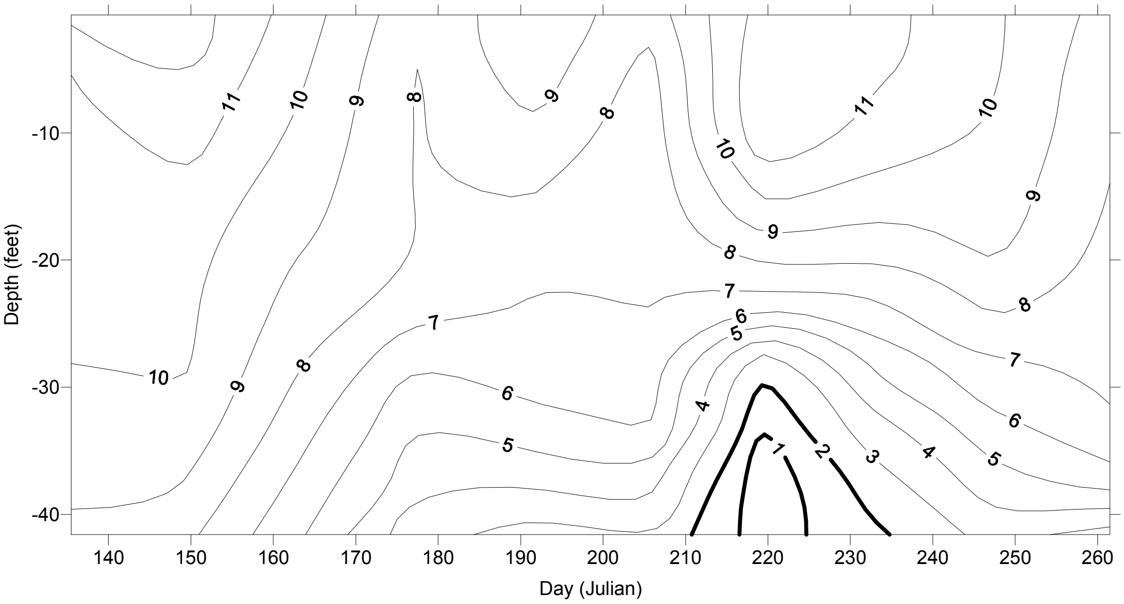

SRWD 6202 2005 Temperature (F)

Figure 5 & 6: **Dissolved Oxygen and Temperature Isoplots for SRWD Monitoring Station OL6201 - 2005**


SRWD 6201 2005 Dissolved Oxygen (mg/L)

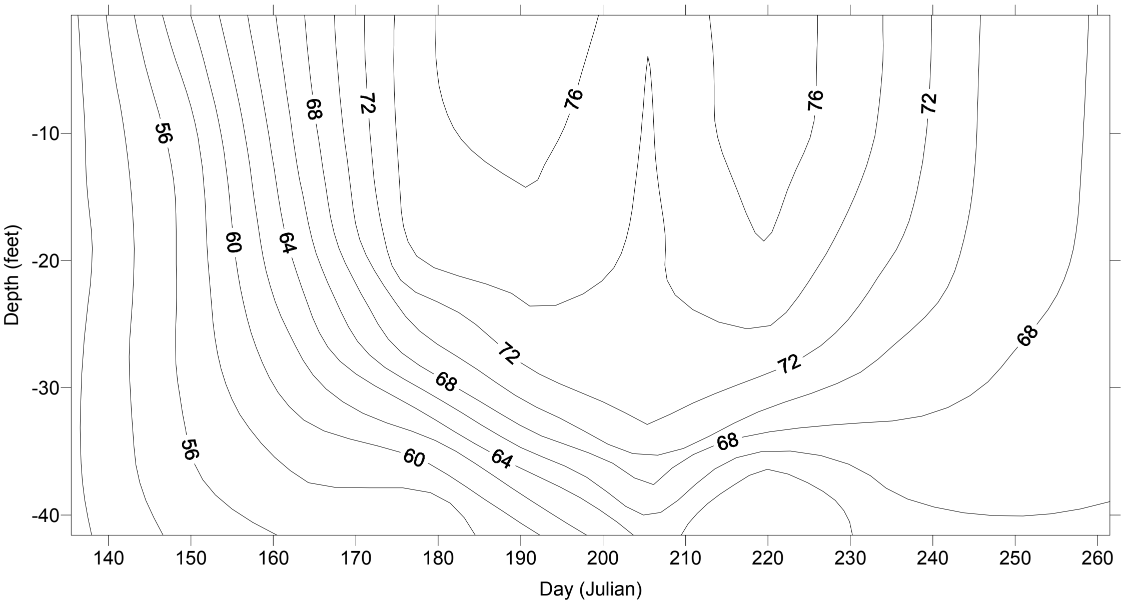
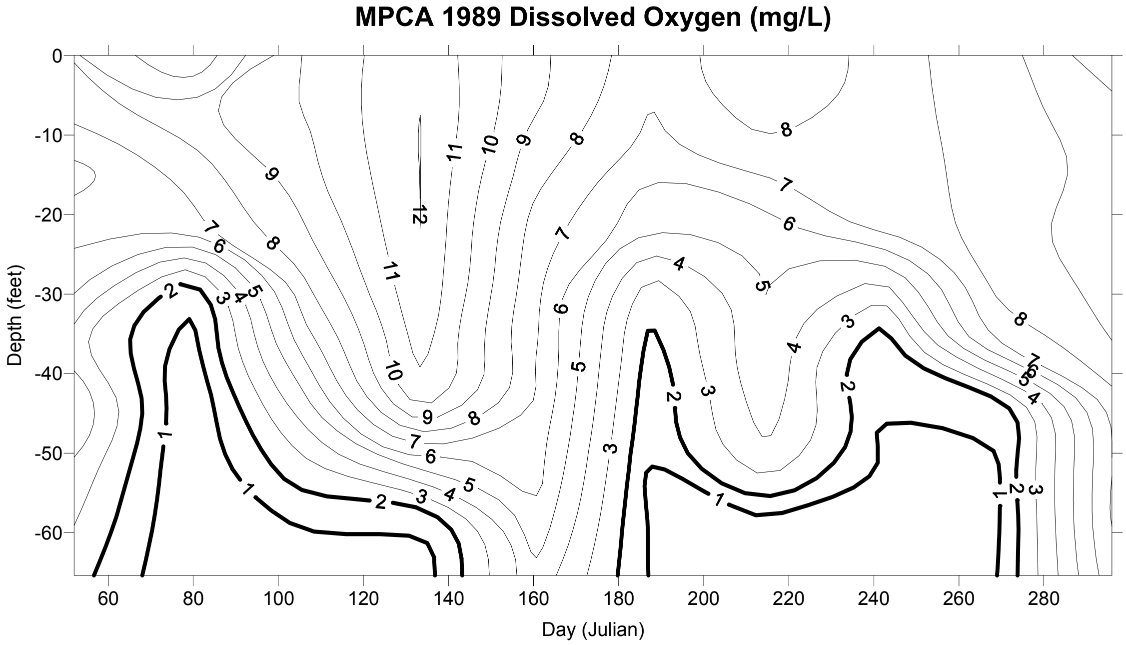

SRWD 6201 2005 Temperature (F)

Figure 7 & 8: Dissolved Oxygen and Temperature Isoplots for MPCA Monitoring Data - 1989



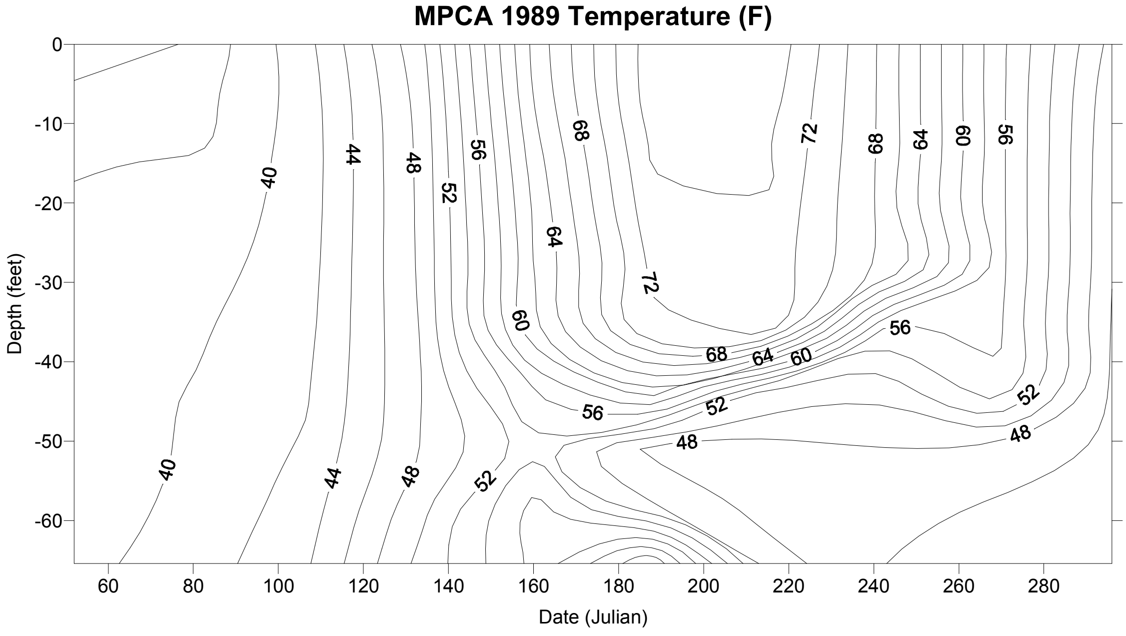
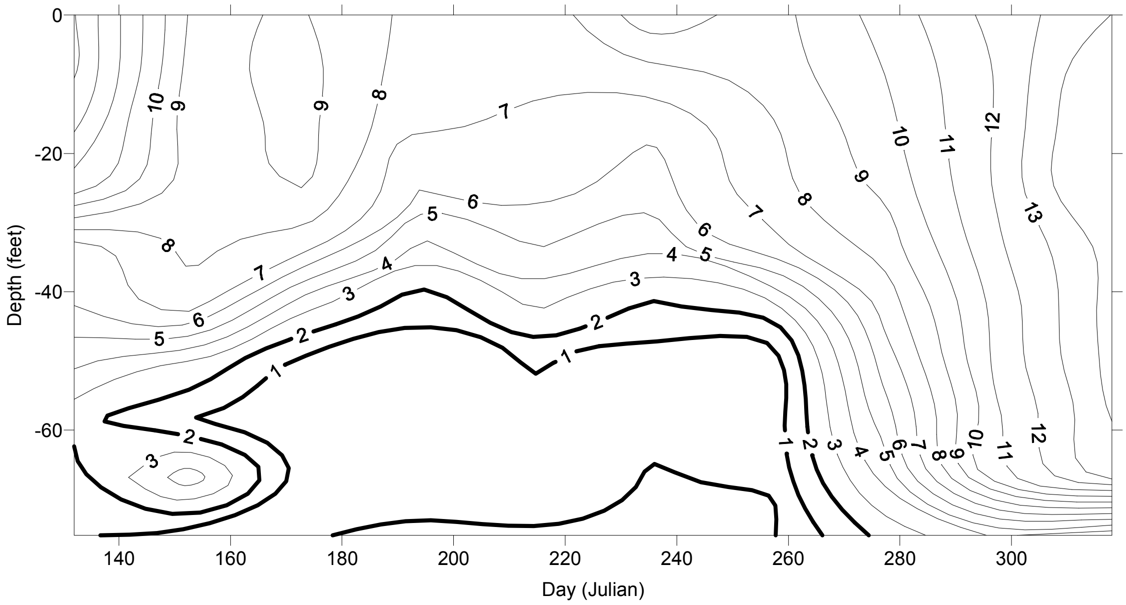
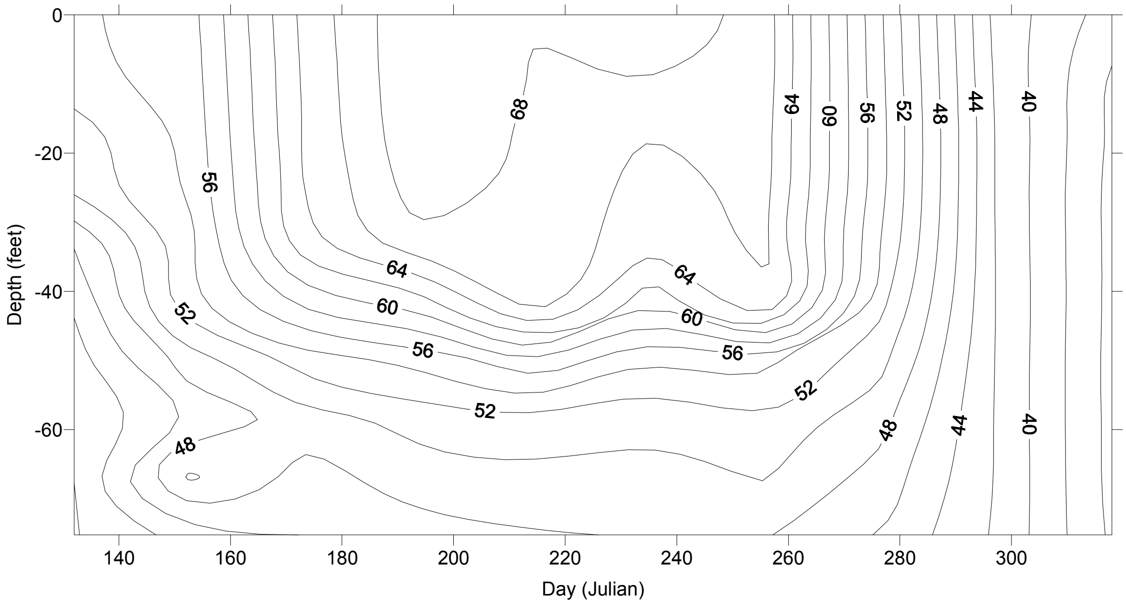


Figure 9 & 10: **Dissolved Oxygen and Temperature Isoplots for MPCA Monitoring Data - 1990**


MPCA 6202 1990 Dissolved Oxygen (mg/L)


MPCA 6202 1990 Temperature (F)

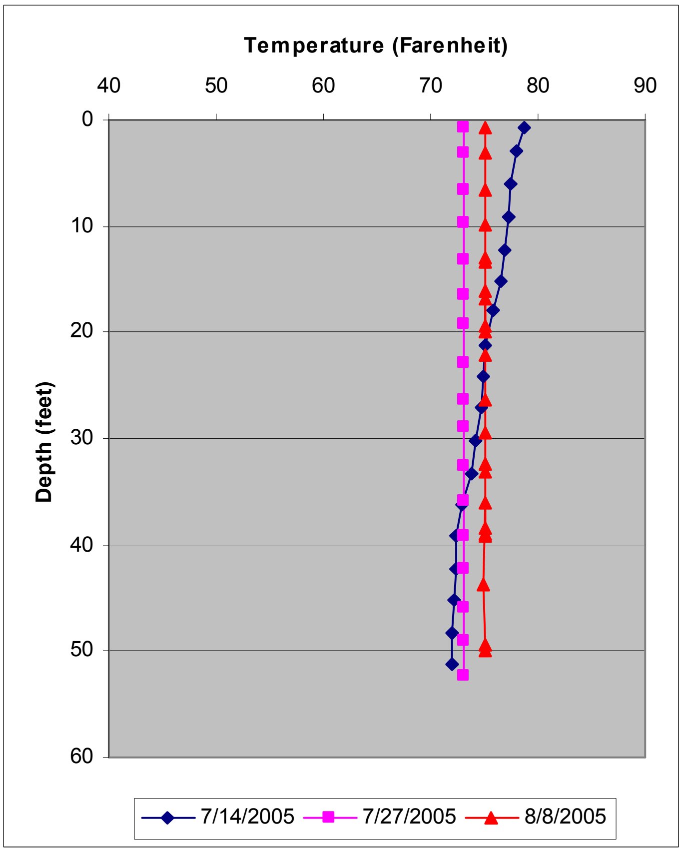
Depth to Thermocline

To assess the expected depth to the thermocline, an equation developed by Ragotzie (1978) was used:

$D_{thermocline}$=4*Square Root of the Fetch (kilometers)

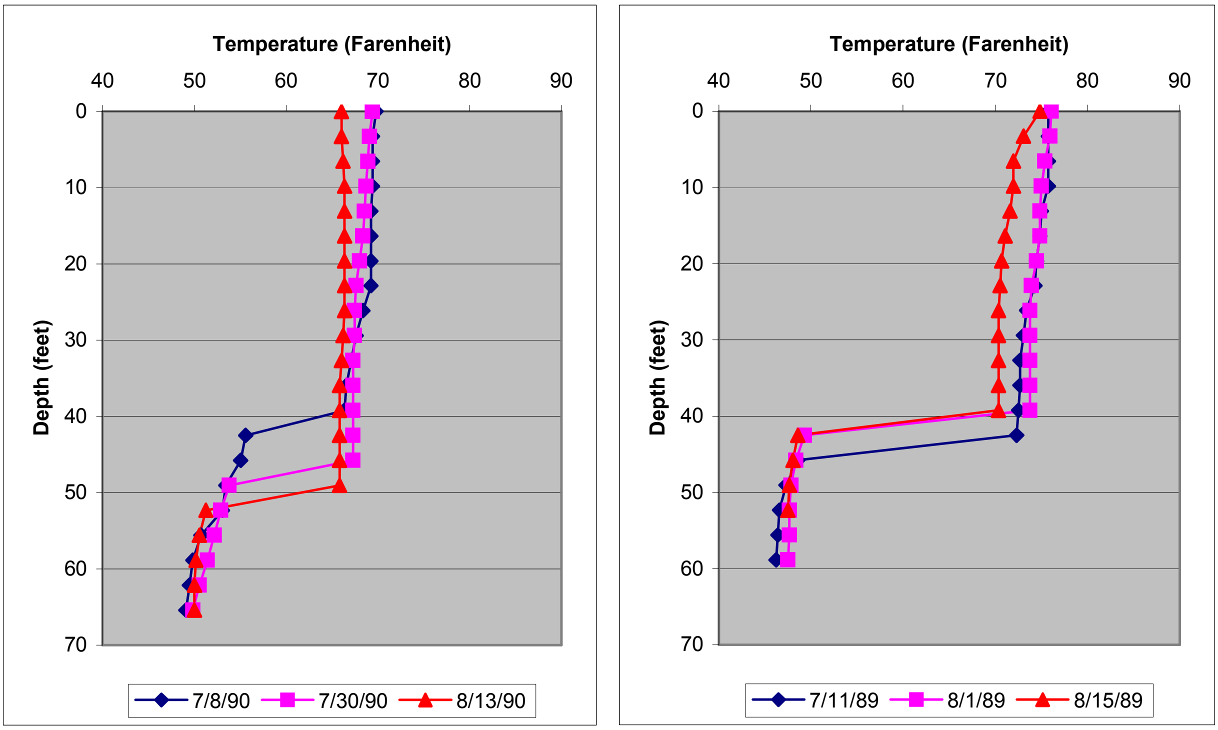
The fetch for Lake Osakis was estimated at approximately 9 kilometers resulting in a thermocline depth of 40 feet. However, monitoring data did not demonstrate a thermocline at site OL6202 (Figure 11).

Figure 11. Selected 2005 data points collected by SRWD for Monitoring Site OL6202



To further evaluate the expected depth to the thermocline, temperature data was gathered from the MPCA website for 1989 and 1990 (Figure 12 & 13). Midsummer profiles in both 1989 and 1990 demonstrated a thermocline starting at a depth of 40 to 50 feet. SRWD data was collected to a maximum of 50 feet and may have missed the thermocline.

Figure 12 & 13. Selected 1989 and 1990 data points retrieved from the MPCA data server.



Calculation of the Anoxic Factor

An anoxic factor (expressed in days) is used to estimate the time and area where sediments experience anoxia and release phosphorus. This number is then divided by the whole lake area to express the term over the area of the lake. For example, if a lake experiences 30 days of anoxia over 50% of the area, the anoxic factor would be 15 days (30 days x 0.5 = 15 days) to express the term over the entire lake. To calculate the anoxic factor for deep stratified lakes, both dissolved oxygen profiles and a depth to area curve are needed. Wenck developed two depth to area curves for Lake Osakis due to deep hole on the north end of the lake (Table 2).

Table 2. Areas and volumes for depths in Lake Osakis.

Depth	Area (acres)	Volume (ac-ft)
Lake Osakis		
0	5,247	
5	4,282	23,783
10	3,269	18,821
15	2,235	13,679
20	1,852	10,205
30	724	12,448
40	88	3,547
50	46	657
60	7	236
Upper Lake Osakis (North End)		
0	819	
5	710	3,819
10	612	3,301
15	545	2,890
20	464	2,519
30	292	3,746
40	169	2,276
50	77	1,202
60	21	463

The anoxic factors for the OL6202 site are presented in Table 3. Anoxic factors were not developed for OL6201 since very few of the data points demonstrated anoxia and those that did were in years where only one or two days were analyzed.

Table 3. Anoxic factor for Lake Osakis.

Year	Anoxic Factor (days)
1989	10
1990	4
2001	1
2003	<1
2004	<1
2005	<1

There is one important consideration in these anoxic factors. Data was collected at a maximum depth of 50 feet. However, the deepest areas of the lake are over 60 feet in depth. Since anoxia tends to begin development in the deepest areas and move outward, there may be some time where smaller areas of the lake are anoxic and releasing phosphorus. Future profiles at the deepest portions of the lake for the full depth would be useful for improving the precision of the internal load estimates.

However, based on the dissolved oxygen profiles, it appears unlikely that internal loading is an important factor in Lake Osakis. Lake Osakis has a rather large fetch resulting in a large amount of mixing energy from wind. Consequently, the lake mixes fairly deep (40 feet) with only small areas of the lake going anoxic.

Conclusions

Data suggests that recent profiles may not be deep enough to determine the thermocline in Lake Osakis. However, based on previous years data retrieved from the MPCA website, it appears unlikely that internal loading is an important factor in the phosphorus budget of Lake Osakis. Water quality monitoring efforts should be focused on the external phosphorus loads.

Recommendations

1. Future collection of profiles should occur at the deepest area of the lake. Depth to thermocline should be approximately 40 feet.

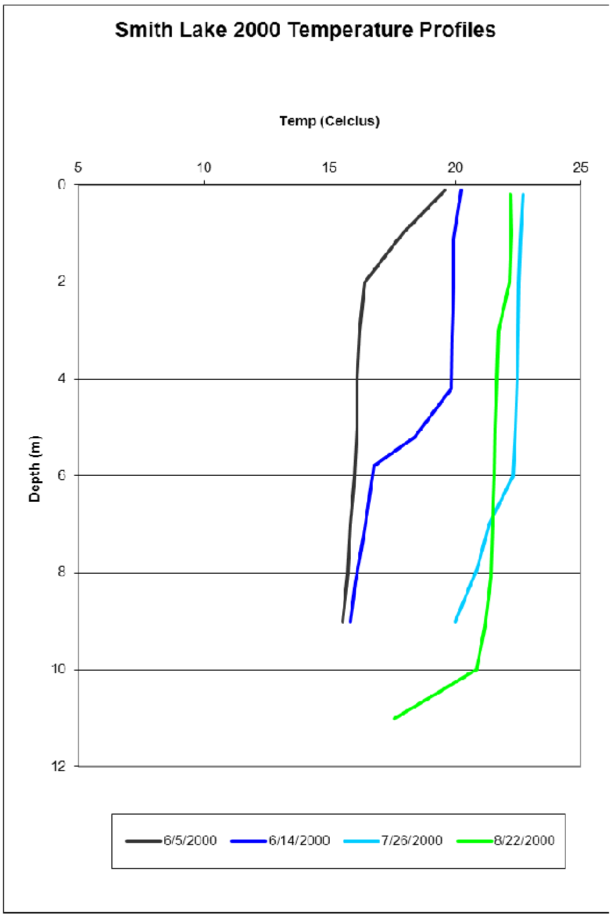
References

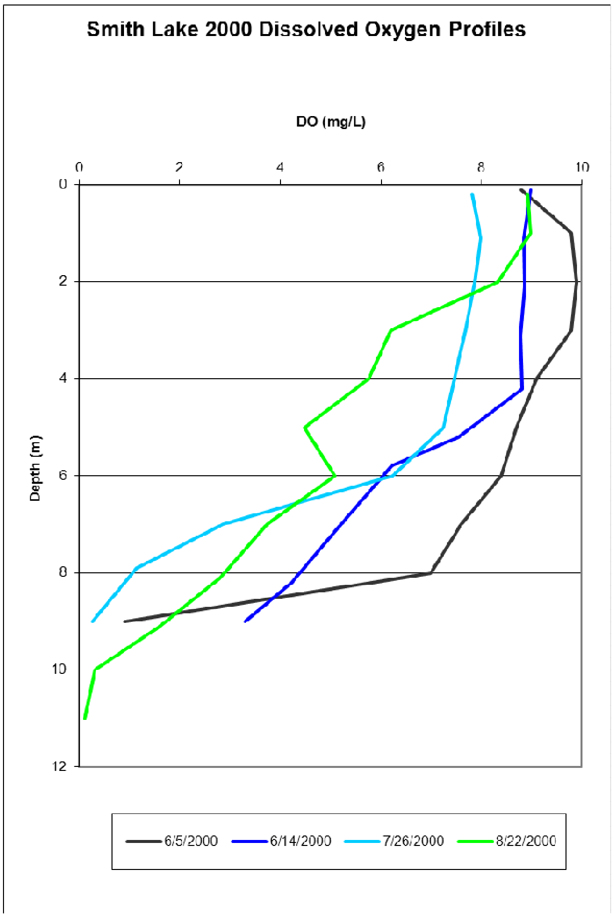
Nurnberg, G. 1997. Coping with water quality problemsdue to hypolimnetic anoxia in central Ontario lakes. Water Qual. Res. J. Canada, Volume 32, No. 2, 391-405.

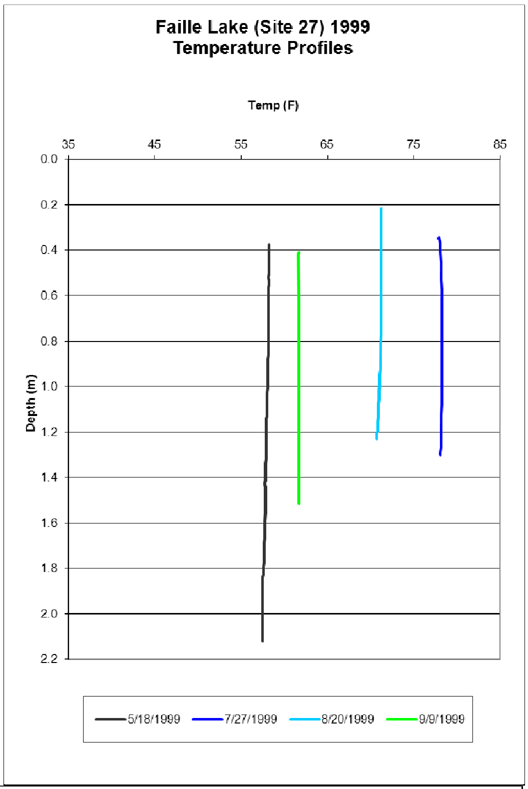
Ragotzie, R.A. 1978. Heat Budget of Lakes. Chapter 1, pages 1-19 in A. Lerman (editor). Lakes: Chemistry, geology, physics. Springer-Verlag, New York, New York.

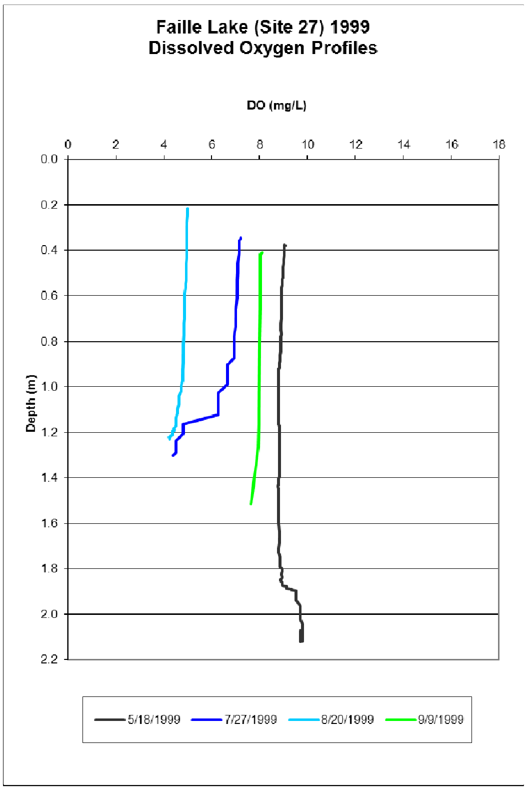
Appendix C

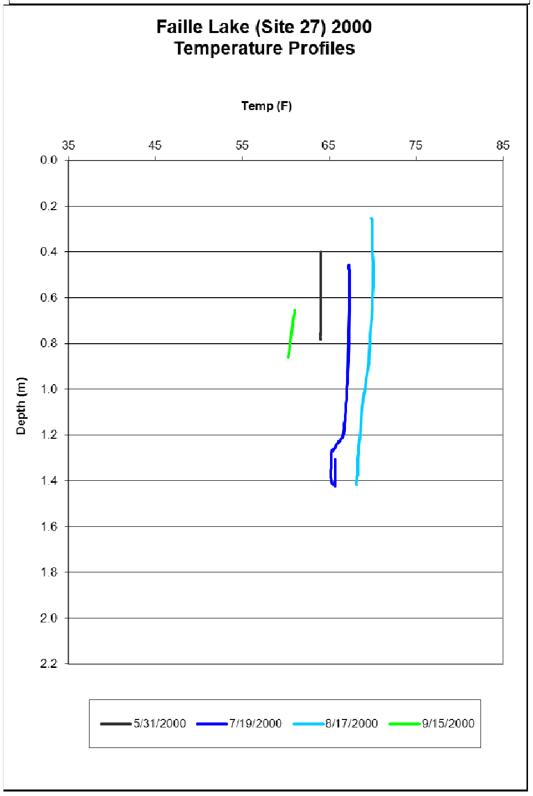
Temperature and Dissolved Oxygen Profiles

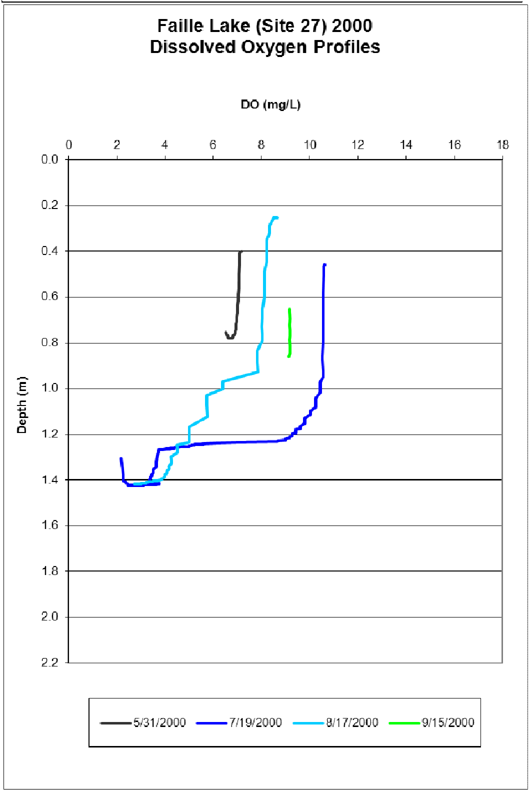

Smith Lake 2000 Temperature Profiles
Temp (Celcius)
5
10
15
20
25
0
2
4
6
8
10
12
Depth (m)
6/5/2000
6/14/2000
7/26/2000
8/22/2000


Smith Lake 2000 Dissolved Oxygen Profiles
DO (mg/L)
0
2
4
6
8
10
0
2
4
6
8
10
12
Depth (m)
6/5/2000
6/14/2000
7/26/2000
8/22/2000


Faille Lake (Site 27) 1999
Temperature Profiles


Faille Lake (Site 27) 1999
Dissolved Oxygen Profiles


Faille Lake (Site 27) 2000
Temperature Profiles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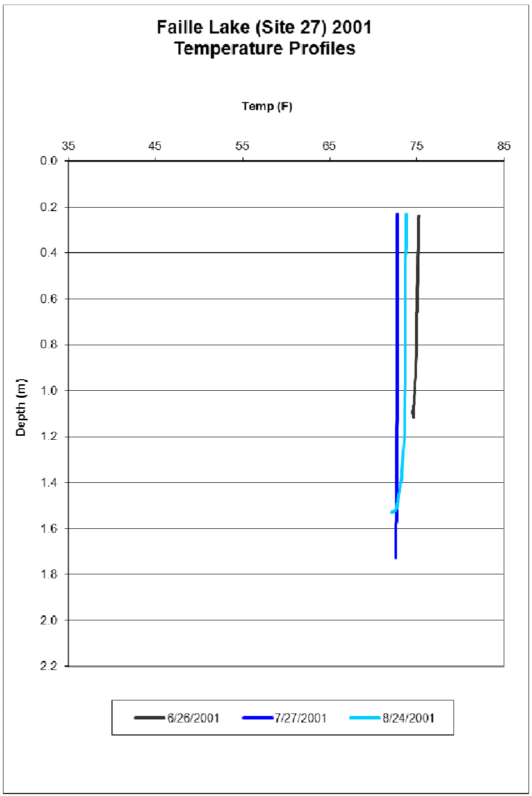
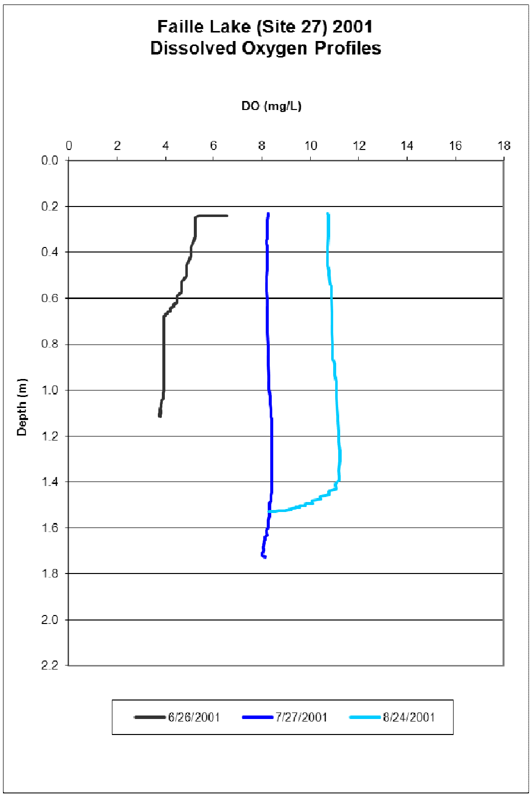
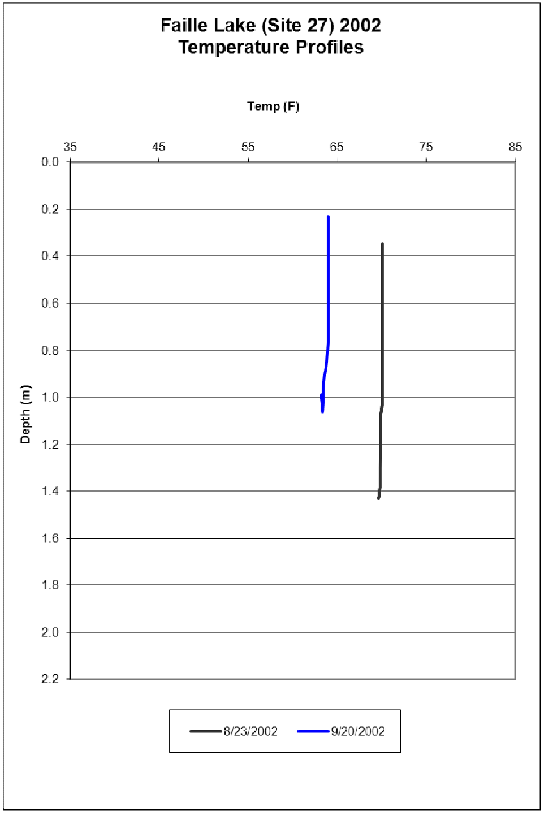
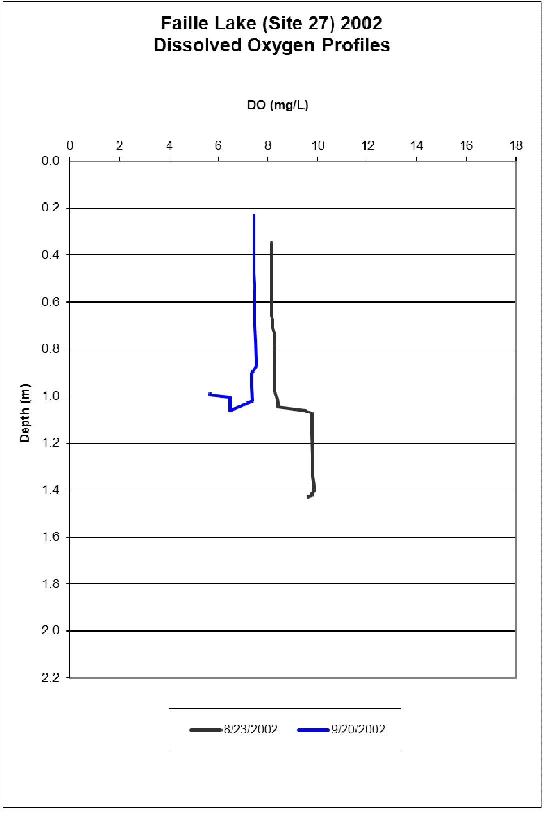
Dissolved Oxygen Profiles


Faille Lake (Site 27) 2001
Temperature Profiles


Faille Lake (Site 27) 2001
Dissolved Oxygen Profiles


Faille Lake (Site 27) 2002
Temperature Profiles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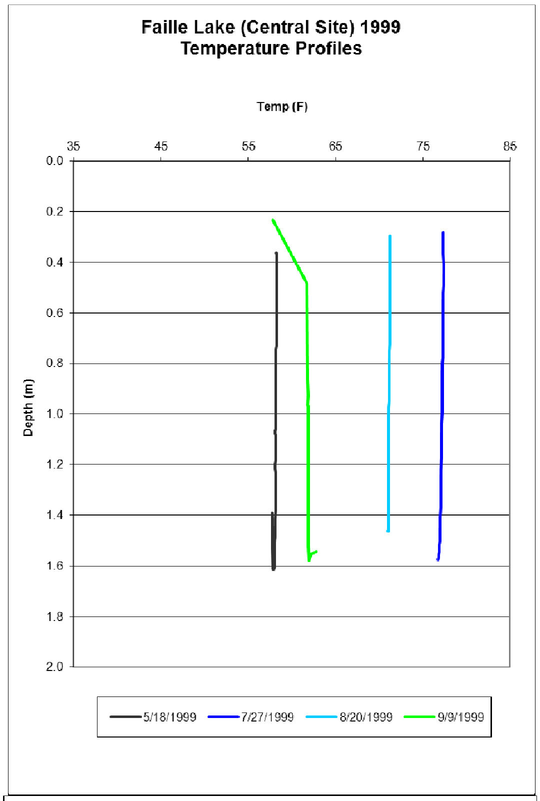
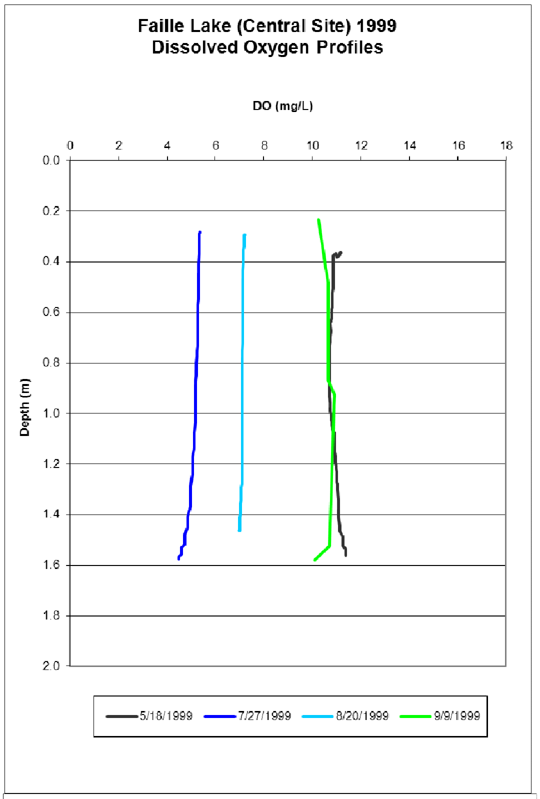
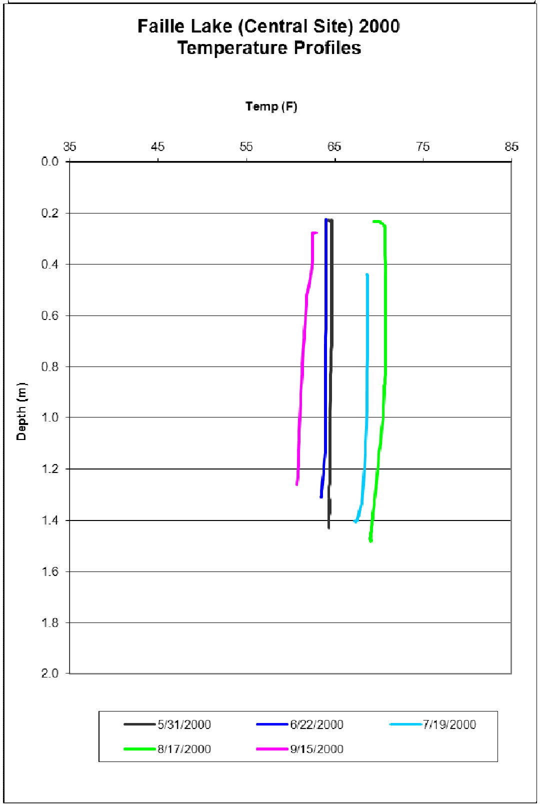
Dissolved Oxygen Profiles



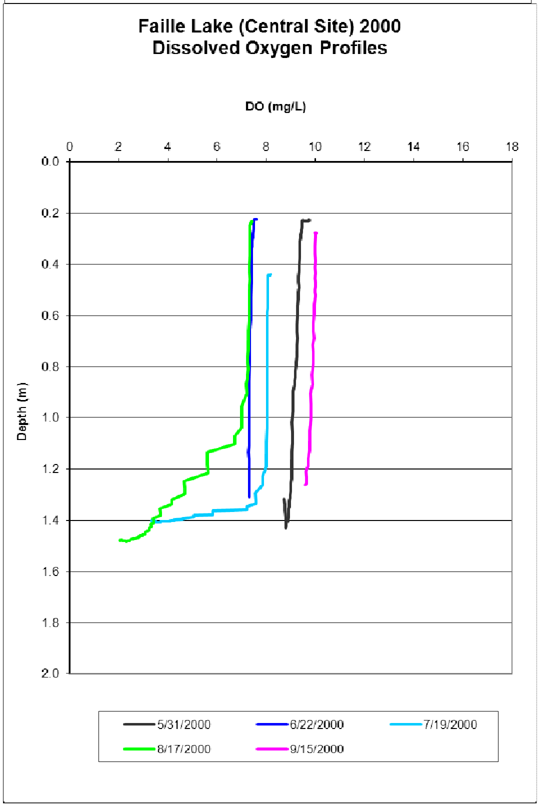
Faille Lake (Central Site) 1999
Temperature Profiles



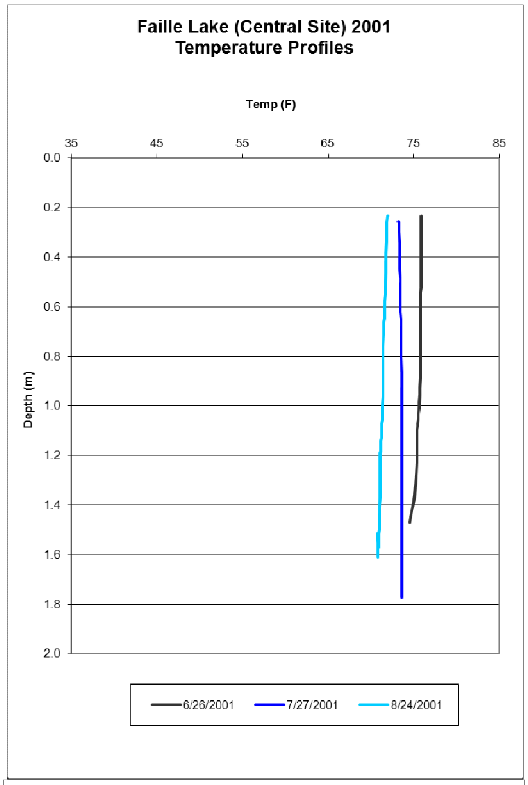
Faille Lake (Central Site) 1999
Dissolved Oxygen Profiles



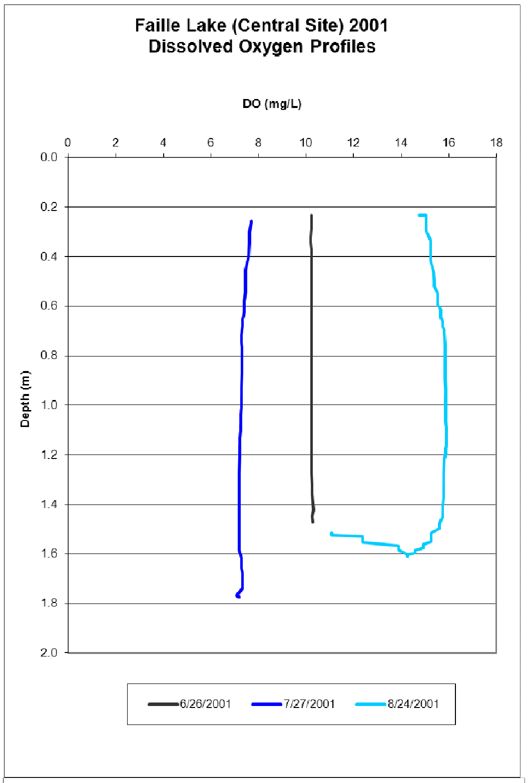
Faille Lake (Central Site) 2000
Temperature Profiles



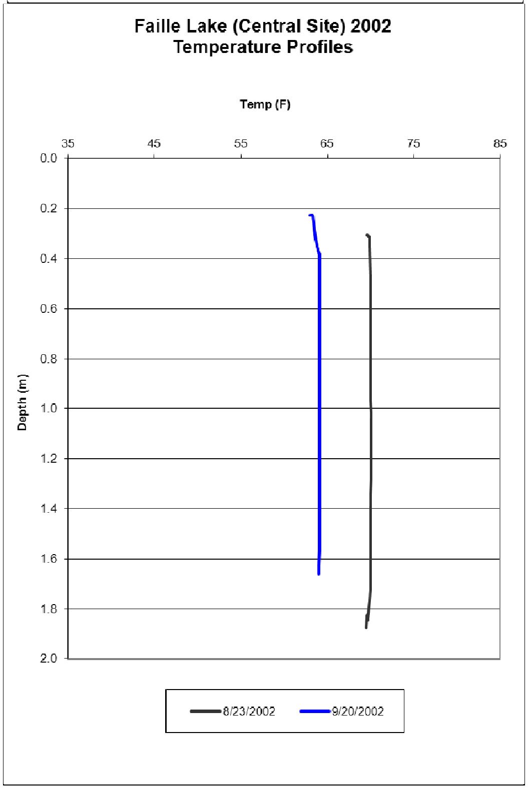
Faille Lake (Central Site) 2000
Dissolved Oxygen Profiles



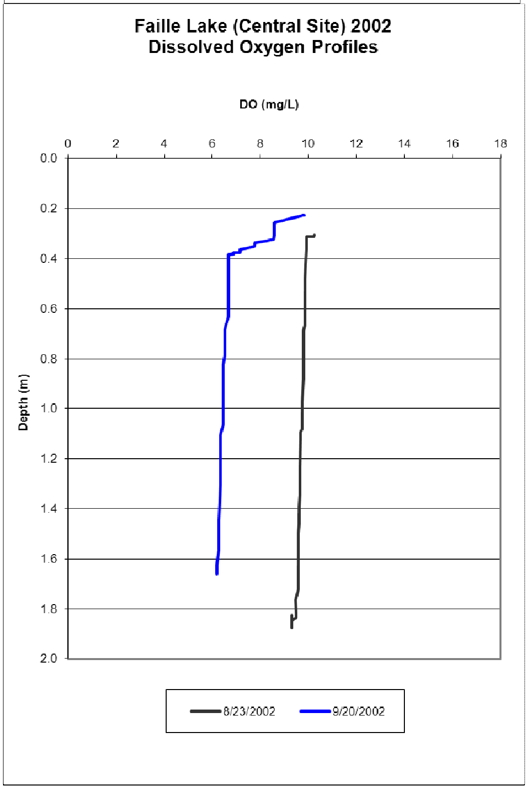
Faille Lake (Central Site) 2001
Temperature Profiles



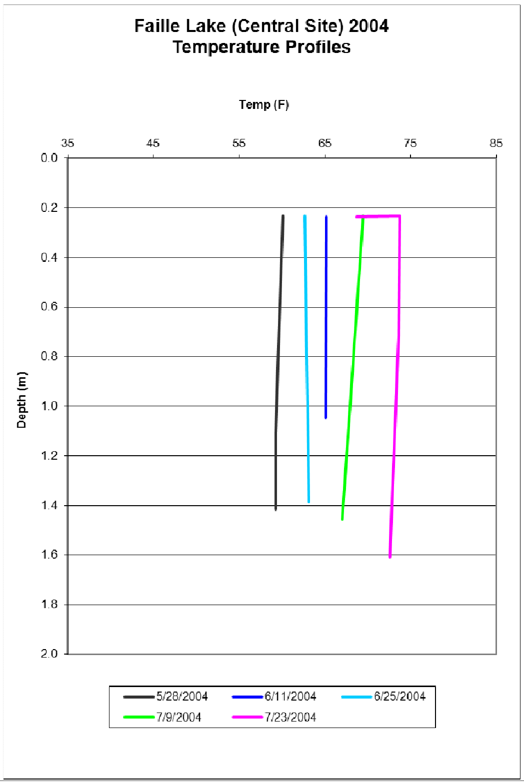
Faille Lake (Central Site) 2001
Dissolved Oxygen Profiles

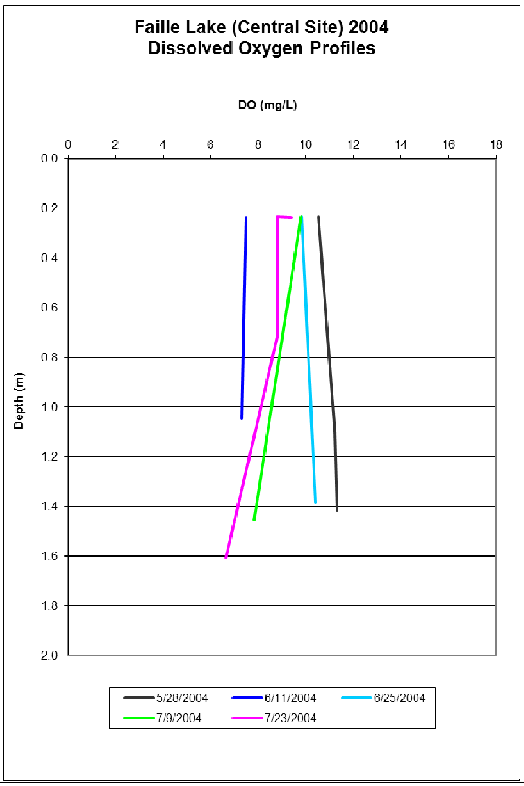


Faille Lake (Central Site) 2002
Temperature Profiles



Faille Lake (Central Site) 2002
Dissolved Oxygen Profiles


Faille Lake (Central Site) 2004
Temperature Profiles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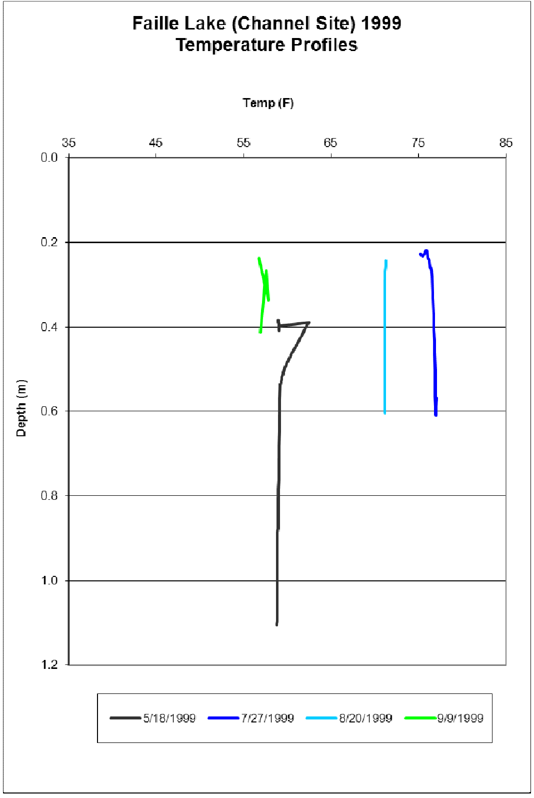
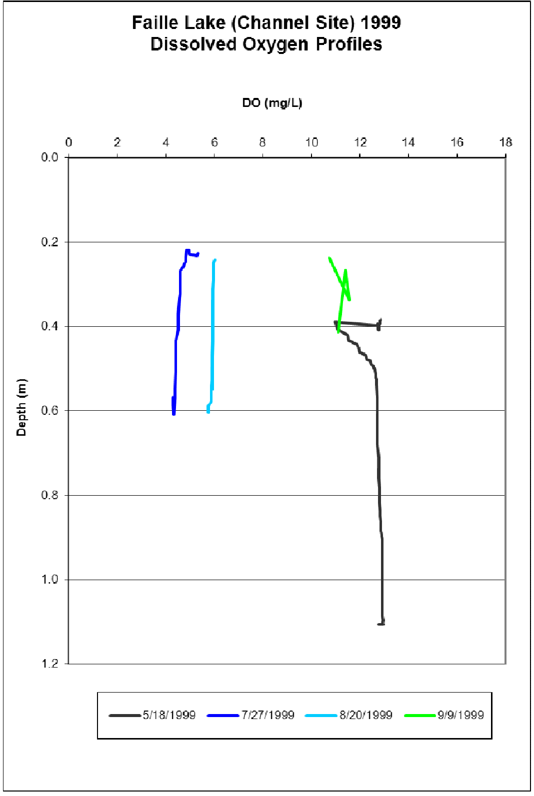
Dissolved Oxygen Profiles


Faille Lake (Channel Site) 1999
Temperature Profiles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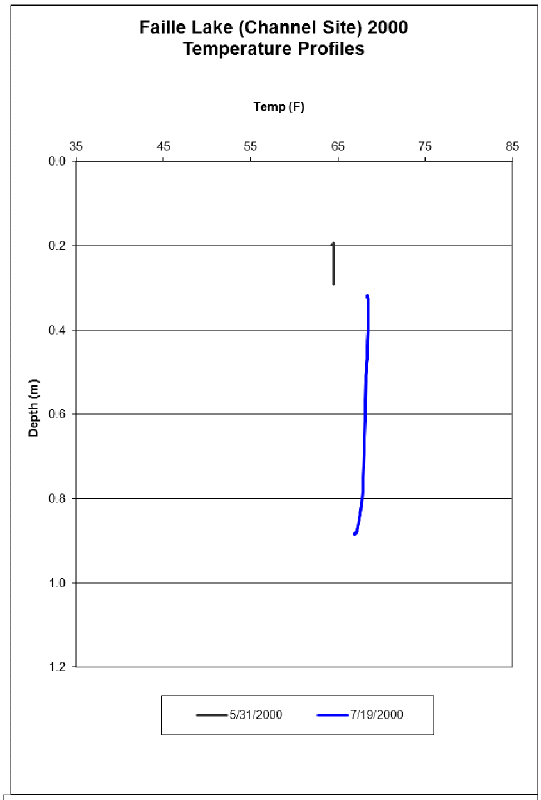
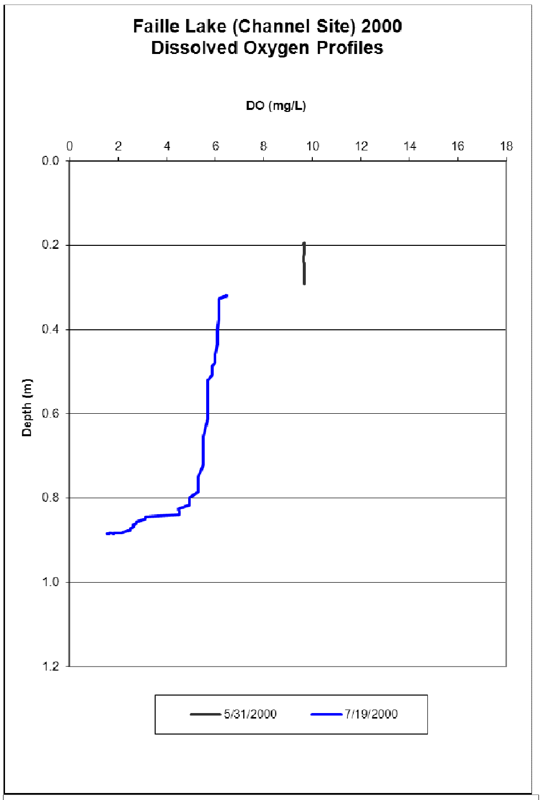
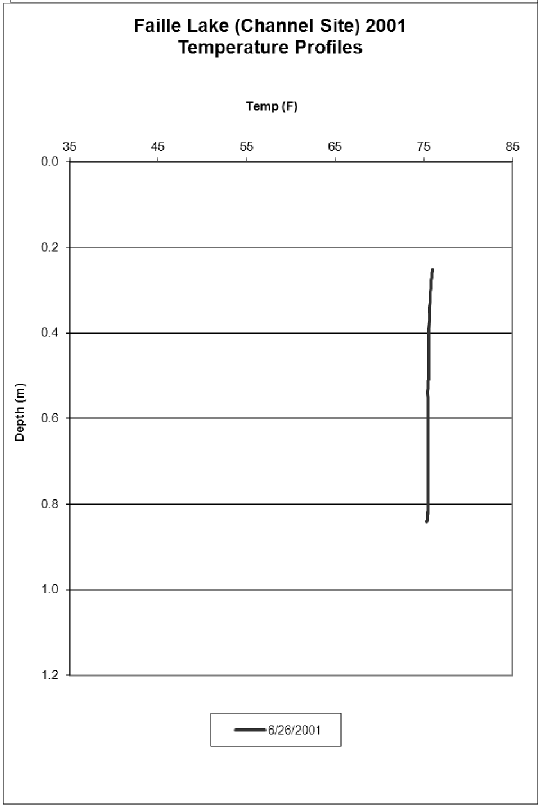
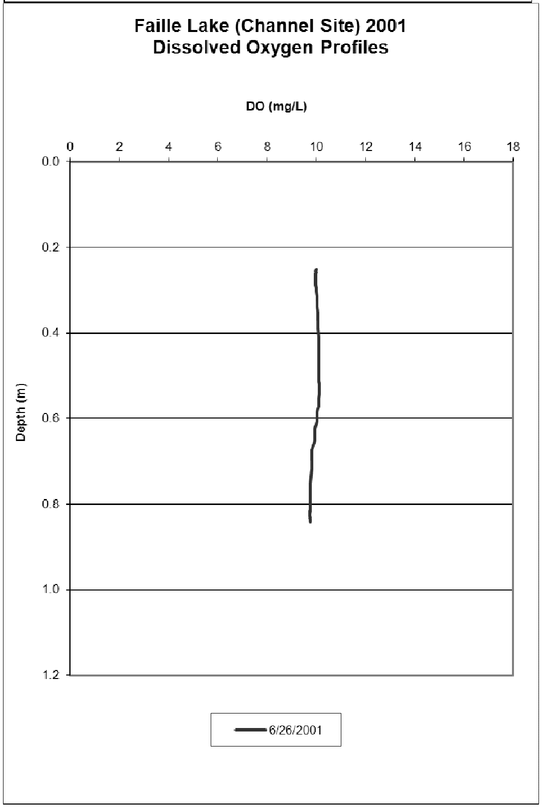
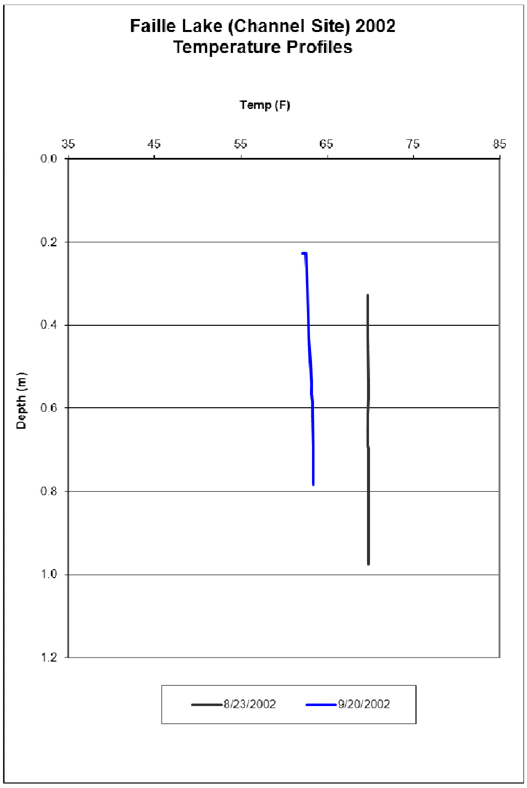
Dissolved Oxygen Profiles

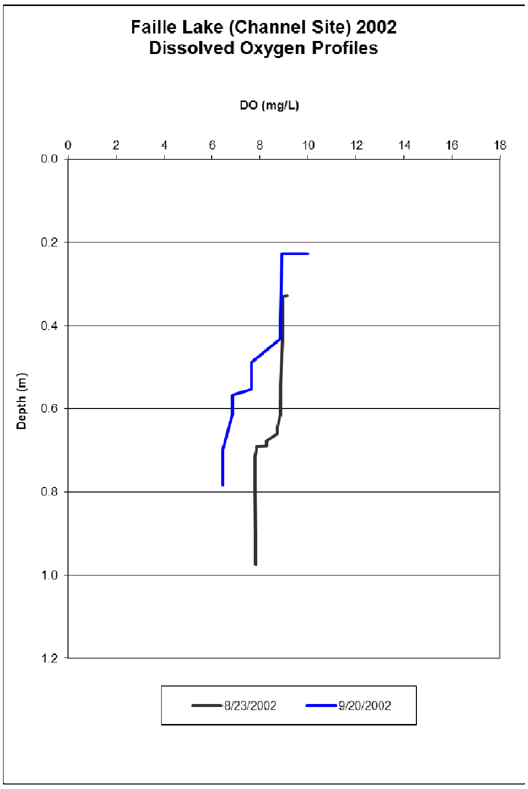

Faille Lake (Channel Site) 2000
Temperature Profiles
Temp (F)
35
45
55
65
75
85
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (m)
5/31/2000
7/19/2000

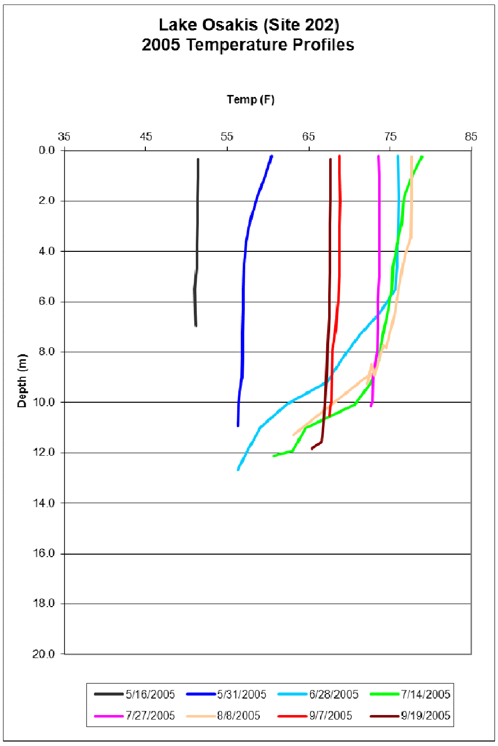

Faille Lake (Channel Site) 2000
Dissolved Oxygen Profiles
DO (mg/L)
0
2
4
6
8
10
12
14
16
18
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (m)
5/31/2000
7/19/2000

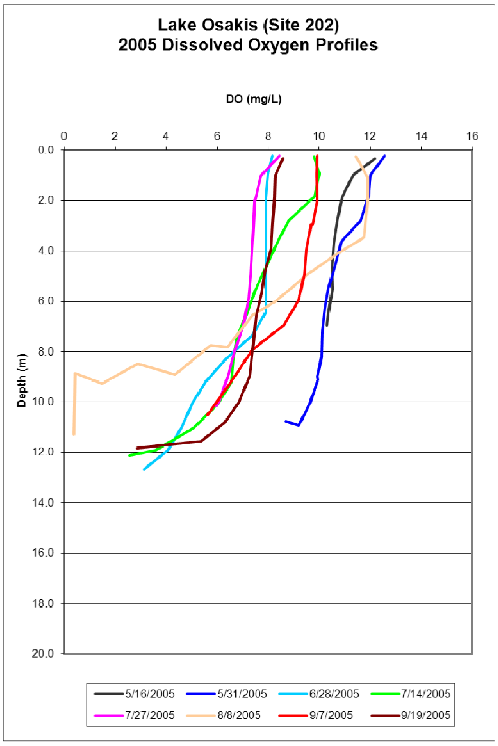

Faille Lake (Channel Site) 2001
Temperature Profiles
Temp (F)
35
45
55
65
75
85
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (m)
6/26/2001

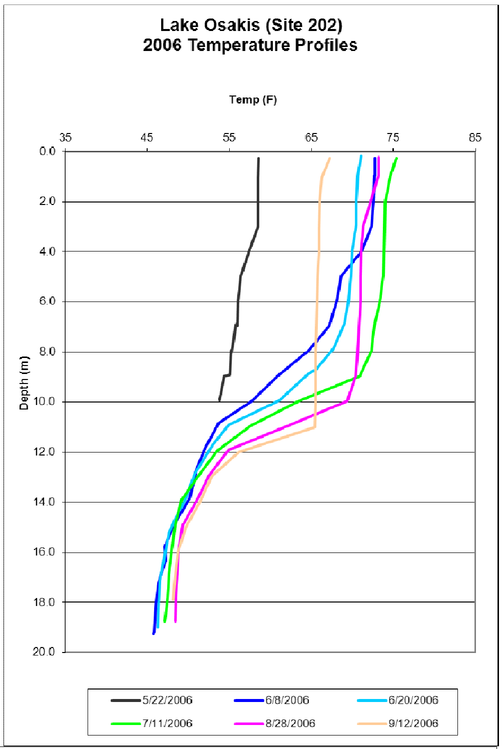

Faille Lake (Channel Site) 2001
Dissolved Oxygen Profiles
DO (mg/L)
0
2
4
6
8
10
12
14
16
18
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (m)
6/26/2001


Faille Lake (Channel Site) 2002
Temperature Profiles
Temp (F)
35
45
55
65
75
85
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (m)
8/23/2002
9/20/2002

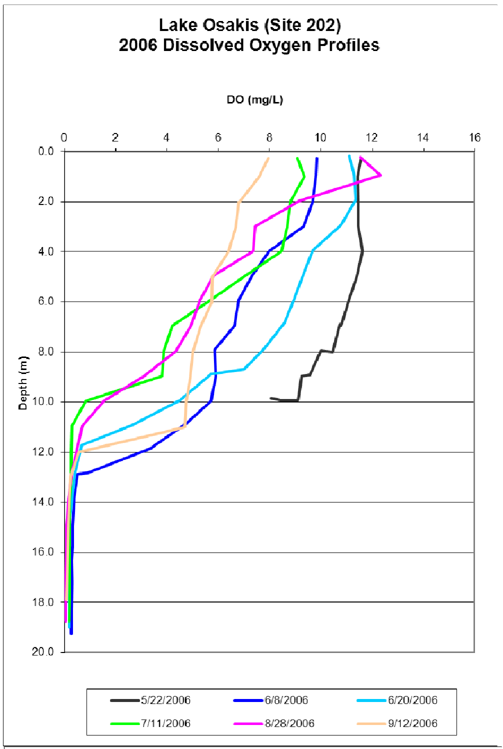

Faille Lake (Channel Site) 2002
Dissolved Oxygen Profiles
DO (mg/L)
0
2
4
6
8
10
12
14
16
18
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (m)
8/23/2002
9/20/2002


Lake Osakis (Site 202)
2005 Temperature Profiles
Temp (F)
35
45
55
65
75
85
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Depth (m)
5/16/2005
5/31/2005
6/28/2005
7/14/2005
7/27/2005
8/8/2005
9/7/2005
9/19/2005

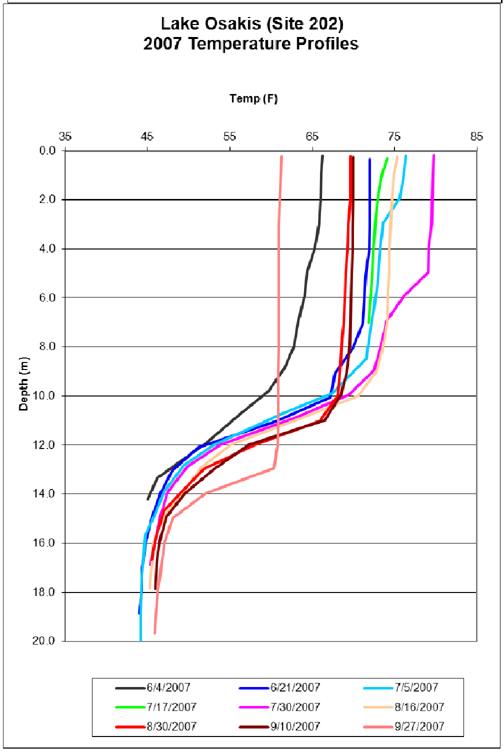

Lake Osakis (Site 202)
2005 Dissolved Oxygen Profiles
DO (mg/L)
0
2
4
6
8
10
12
14
16
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Depth (m)
5/16/2005
5/31/2005
6/28/2005
7/14/2005
7/27/2005
8/8/2005
9/7/2005
9/19/2005



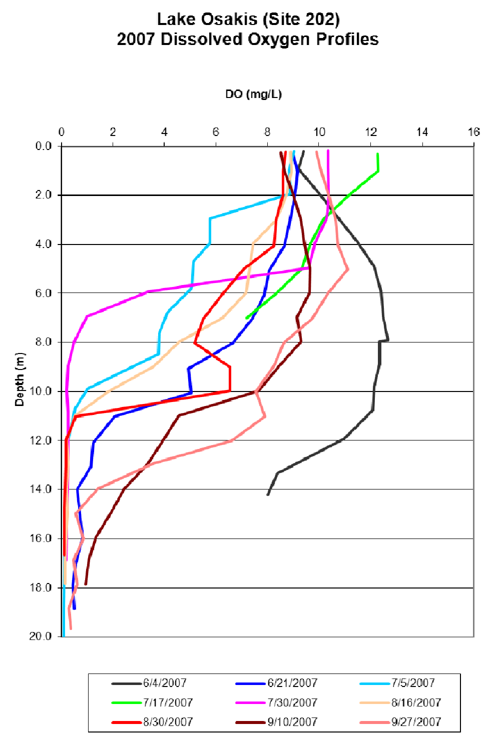
Lake Osakis (Site 202)
2006 Temperature Profiles



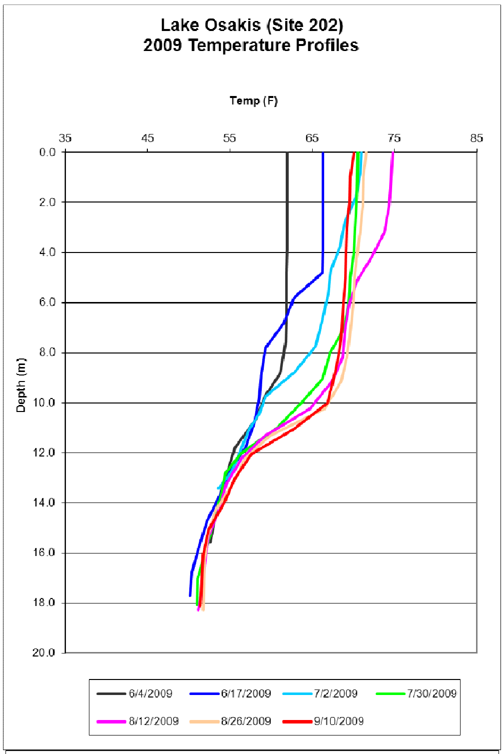
Lake Osakis (Site 202)
2006 Dissolved Oxygen Profiles

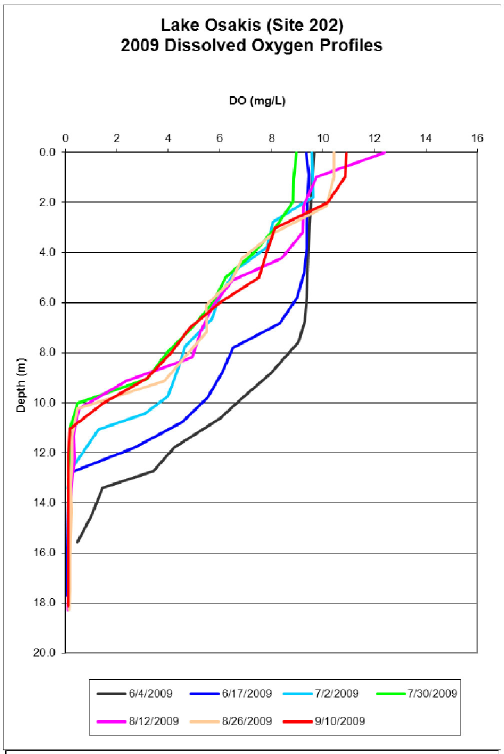


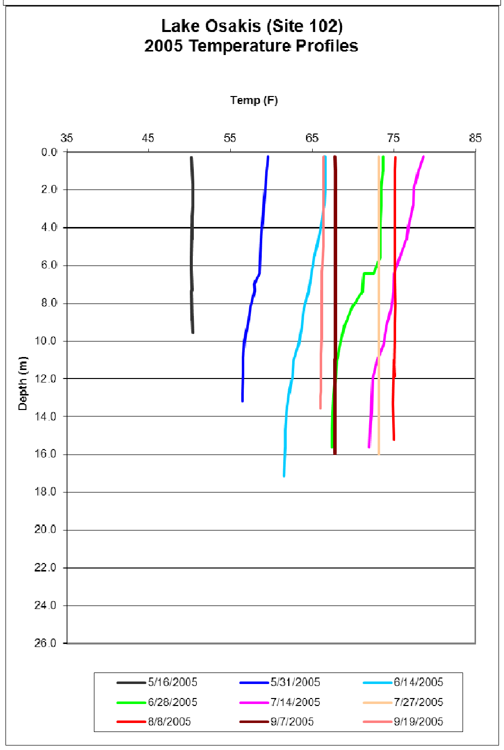
Lake Osakis (Site 202)
2007 Temperature Profiles

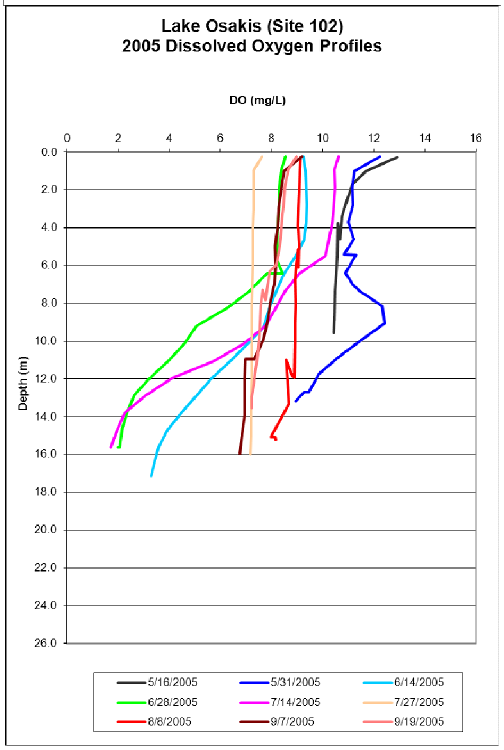


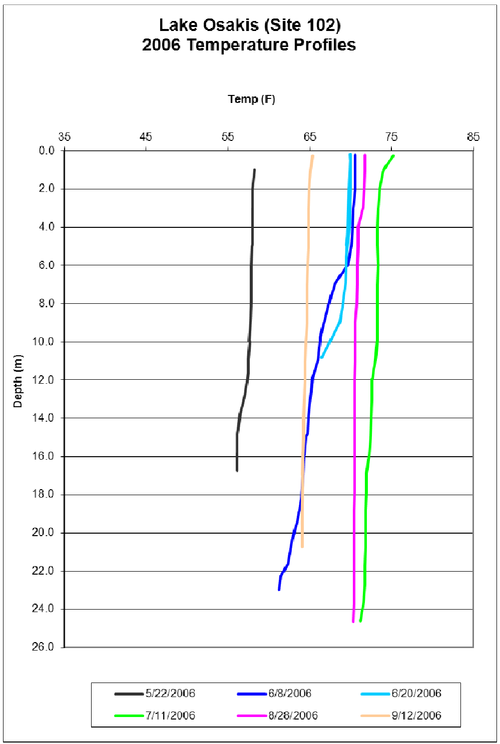
Lake Osakis (Site 202)
2007 Dissolved Oxygen Profiles

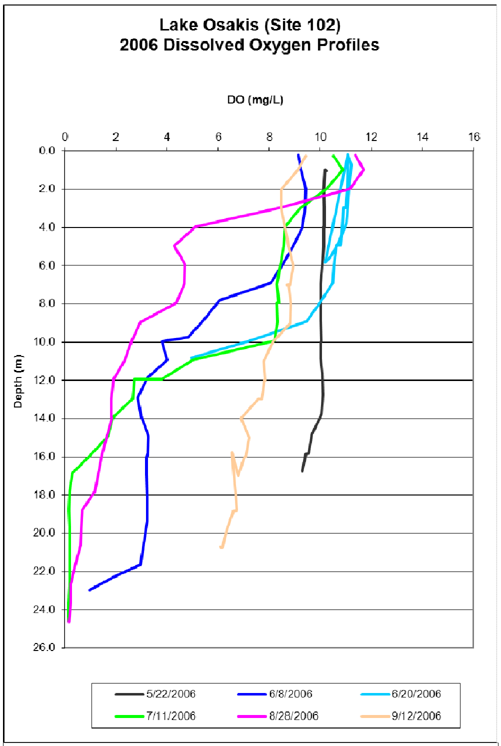

Lake Osakis (Site 202)
2009 Temperature Profiles

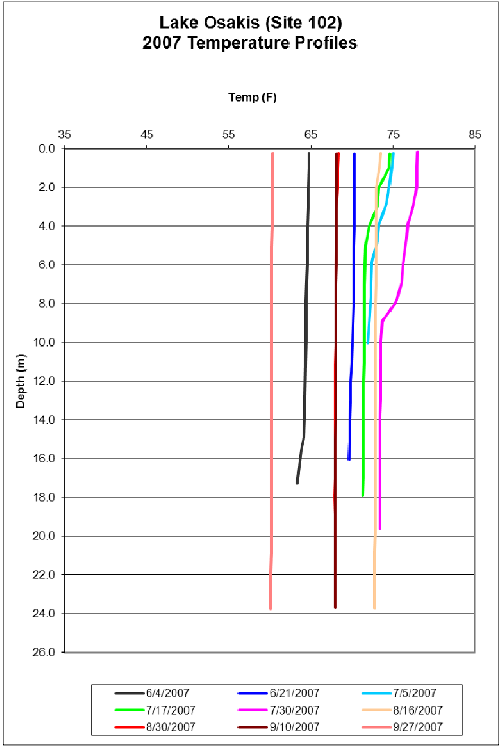

Lake Osakis (Site 202)
2009 Dissolved Oxygen Profiles

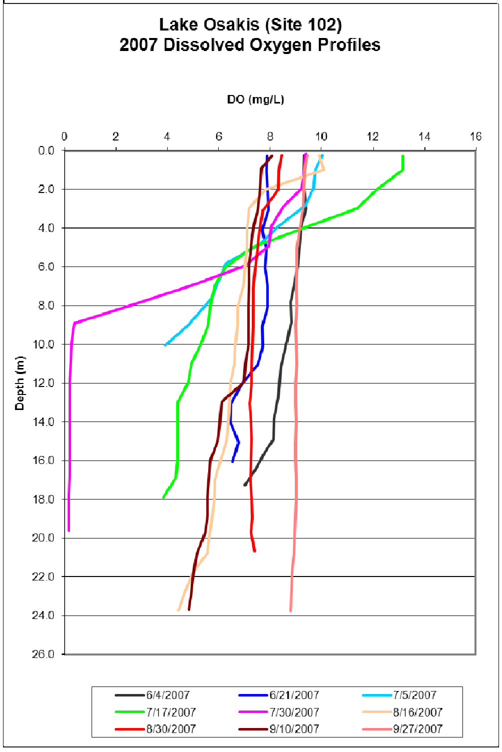

Lake Osakis (Site 102)
2005 Temperature Profiles

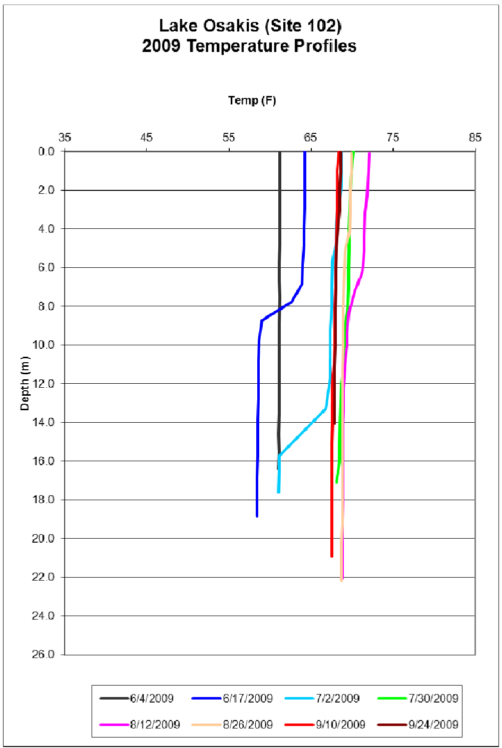

Lake Osakis (Site 102)
2005 Dissolved Oxygen Profiles

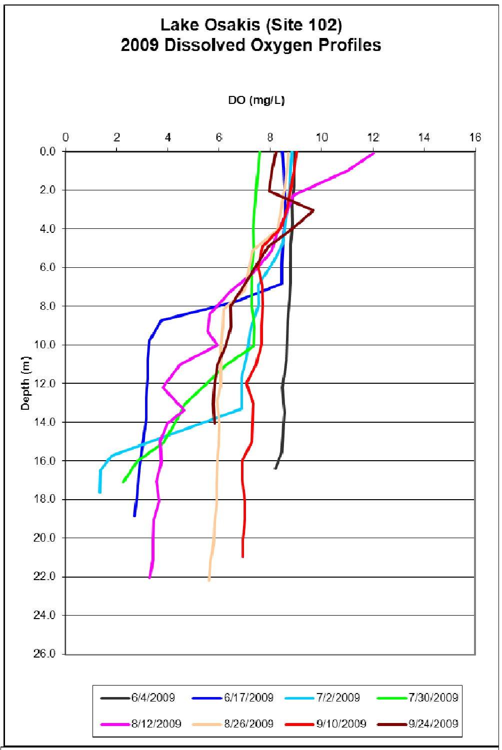

Lake Osakis (Site 102)
2006 Temperature Profiles
Temp (F)
35
45
55
65
75
85
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
5/22/2006
6/8/2006
6/20/2006
7/11/2006
8/28/2006
9/12/2006

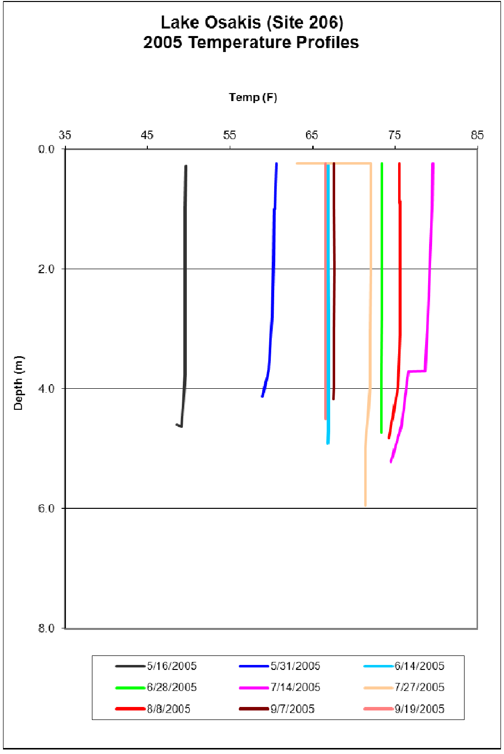

Lake Osakis (Site 102)
2006 Dissolved Oxygen Profiles
DO (mg/L)
0
2
4
6
8
10
12
14
16
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
5/22/2006
6/8/2006
6/20/2006
7/11/2006
8/28/2006
9/12/2006

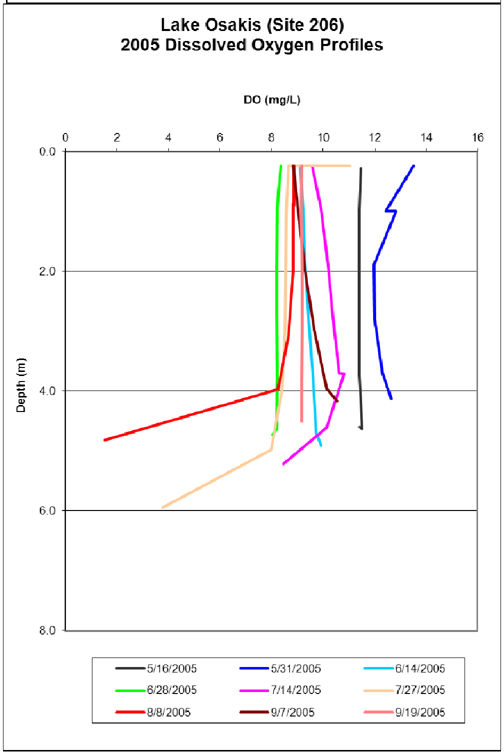

Lake Osakis (Site 102)
2007 Temperature Profiles
Temp (F)
35
45
55
65
75
85
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
6/4/2007
6/21/2007
7/5/2007
7/17/2007
7/30/2007
8/16/2007
8/30/2007
9/10/2007
9/27/2007

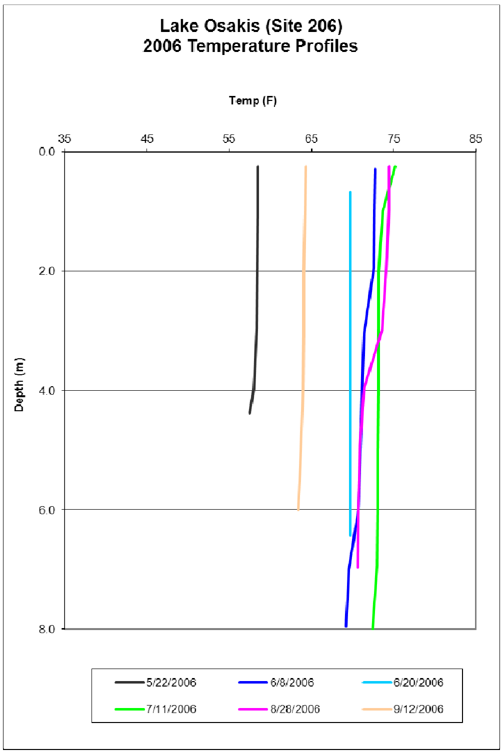

Lake Osakis (Site 102)
2007 Dissolved Oxygen Profiles
DO (mg/L)
0
2
4
6
8
10
12
14
16
Depth (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
6/4/2007
6/21/2007
7/5/2007
7/17/2007
7/30/2007
8/16/2007
8/30/2007
9/10/2007
9/27/2007

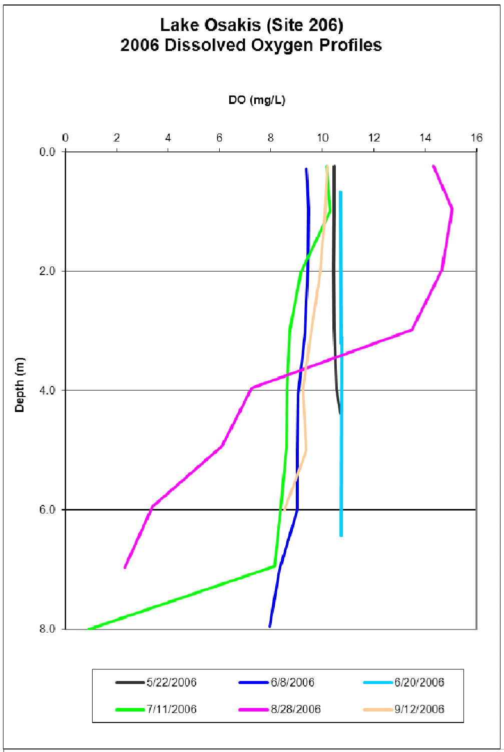

Lake Osakis (Site 102)
2009 Temperature Profiles

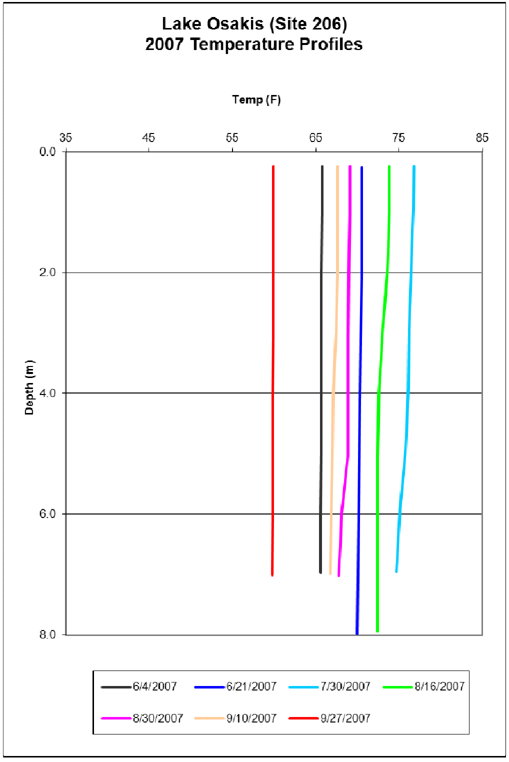

Lake Osakis (Site 102)
2009 Dissolved Oxygen Profiles

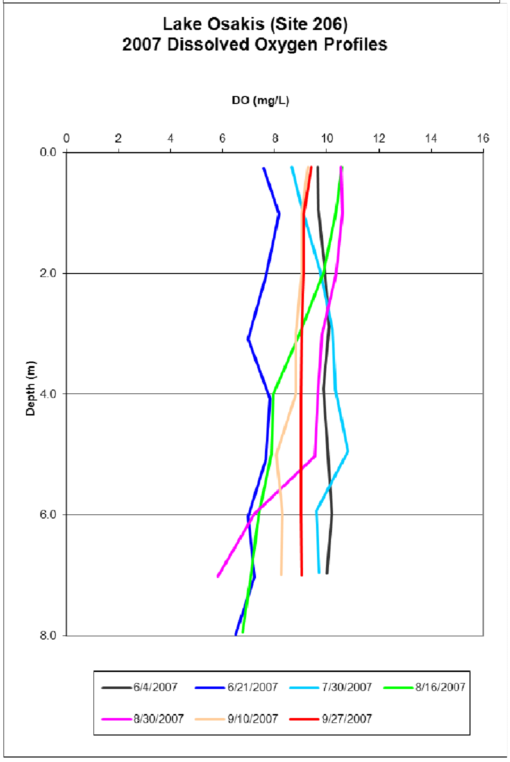

Lake Osakis (Site 206)
2005 Temperature Profiles


Lake Osakis (Site 206)
2005 Dissolved Oxygen Profiles


Lake Osakis (Site 206)
2006 Temperature Profiles
Temp (F)
35
45
55
65
75
85
0.0
2.0
4.0
6.0
8.0
Depth (m)
5/22/2006
6/8/2006
6/20/2006
7/11/2006
8/28/2006
9/12/2006


Lake Osakis (Site 206)
2006 Dissolved Oxygen Profiles
DO (mg/L)
0
2
4
6
8
10
12
14
16
0.0
2.0
4.0
6.0
8.0
Depth (m)
5/22/2006
6/8/2006
6/20/2006
7/11/2006
8/28/2006
9/12/2006


Lake Osakis (Site 206)
2007 Temperature Profiles
Temp (F)
35
45
55
65
75
85
0.0
2.0
4.0
6.0
8.0
Depth (m)
6/4/2007
6/21/2007
7/30/2007
8/16/2007
8/30/2007
9/10/2007
9/27/2007


Lake Osakis (Site 206)
2007 Dissolved Oxygen Profiles
DO (mg/L)
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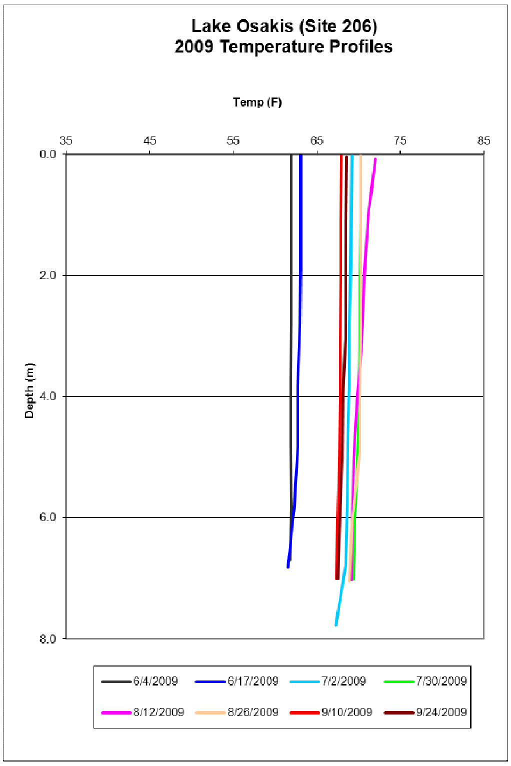
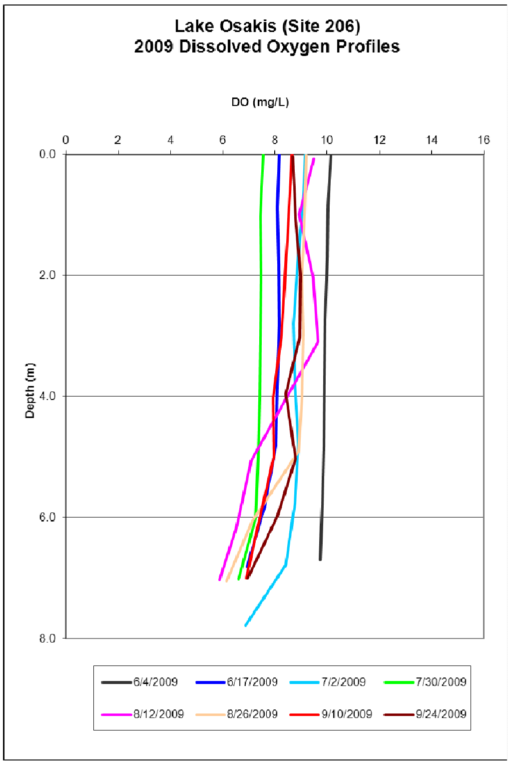
2
4
6
8
10
12
14
16
0.0
2.0
4.0
6.0
8.0
Depth (m)
6/4/2007
6/21/2007
7/30/2007
8/16/2007
8/30/2007
9/10/2007
9/27/2007



Lake Osakis (Site 206)
2009 Temperature Profiles



Lake Osakis (Site 206)
2009 Dissolved Oxygen Profiles

Appendix D

Aquatic Vegetation of Osakis Lake

Aquatic Vegetation of
Osakis Lake (DOW 77-0215-00)
Todd County, Minnesota

May 23, 24, 26, 31 and June 1, 7, 12, 2006

Osakis Lake (77-0215-00), May 26, 2005

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Report Review: Wendy Crowell and Steve Enger, MnDNR Division of Ecological Services
Jed Anderson, MnDNR Area Fisheries, Glenwood

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Osakis Lake (77-0215-00), May 31, 2006

Summary

This survey assessed the spring plant community of Osakis Lake (77-0215-00) in Todd County, central Minnesota. The zone from shore to a depth of 20 feet was sampled using a point-intercept, or grid, survey method. Within this area, 77 percent of the sample sites contained vegetation.

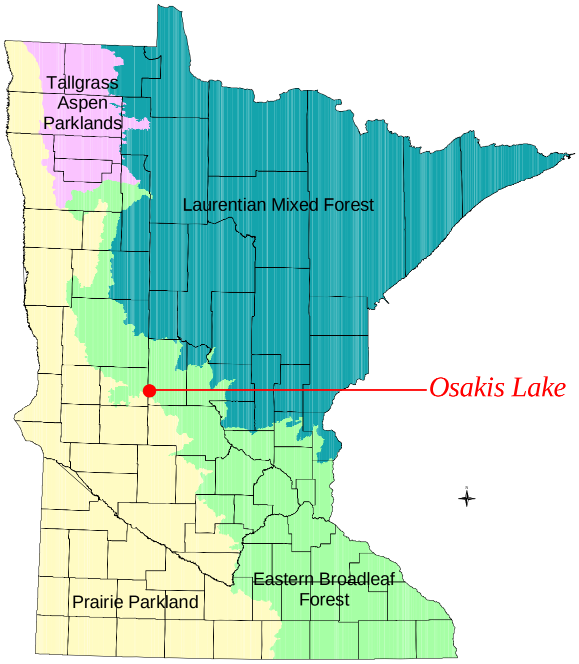
The non-native, submerged plant, curly-leaf pondweed (*Potamogeton crispus*) dominated the plant community and was found in 46 percent of the survey sites. Curly-leaf pondweed was most common in water depths of 10 to 15 feet, where it occurred in 72 percent of the survey sites. It was one of the few plant species found in depths greater than nine feet and the only plant found in the 19 to 20 feet depth zone.

Lower mid-summer water clarity in Osakis Lake likely restricts native aquatic plants to shallow water where they can obtain sufficient light. Native plants occurred in 43 percent of the sample sites. Sixteen native plant species were recorded and common species included bulrush (*Scirpus* sp.), star duckweed (*Lemna trisulca*), muskgrass (*Chara* sp.), coontail (*Ceratophyllum demersum*), and northern watermilfoil (*Myriophyllum sibiricum*). A mid-summer survey would be required to adequately assess the native plant community.

Introduction

Osakis Lake (DOW 77-0215-00) is located in central Minnesota, along the border of Todd and Douglas Counties. The lake occurs within the ecological region called the Eastern Broadleaf Forest, which is the transition zone between the prairie lands of the southwest and the forested region of the northeast (Fig. 1).

Figure 1. Osakis Lake (77-0215-00) Todd Co, MN



Osakis Lake is the headwaters of the Sauk River Watershed (*Click here for a detailed map:* Sauk River Watershed.) Flow enters Osakis Lake from several tributaries and outlets through the Sauk River, which drains the watershed to the south and east. The majority of land within this watershed has been converted to agriculture. The shoreline of Osakis Lake is heavily developed by both agricultural land and residential homes (Fig. 2).

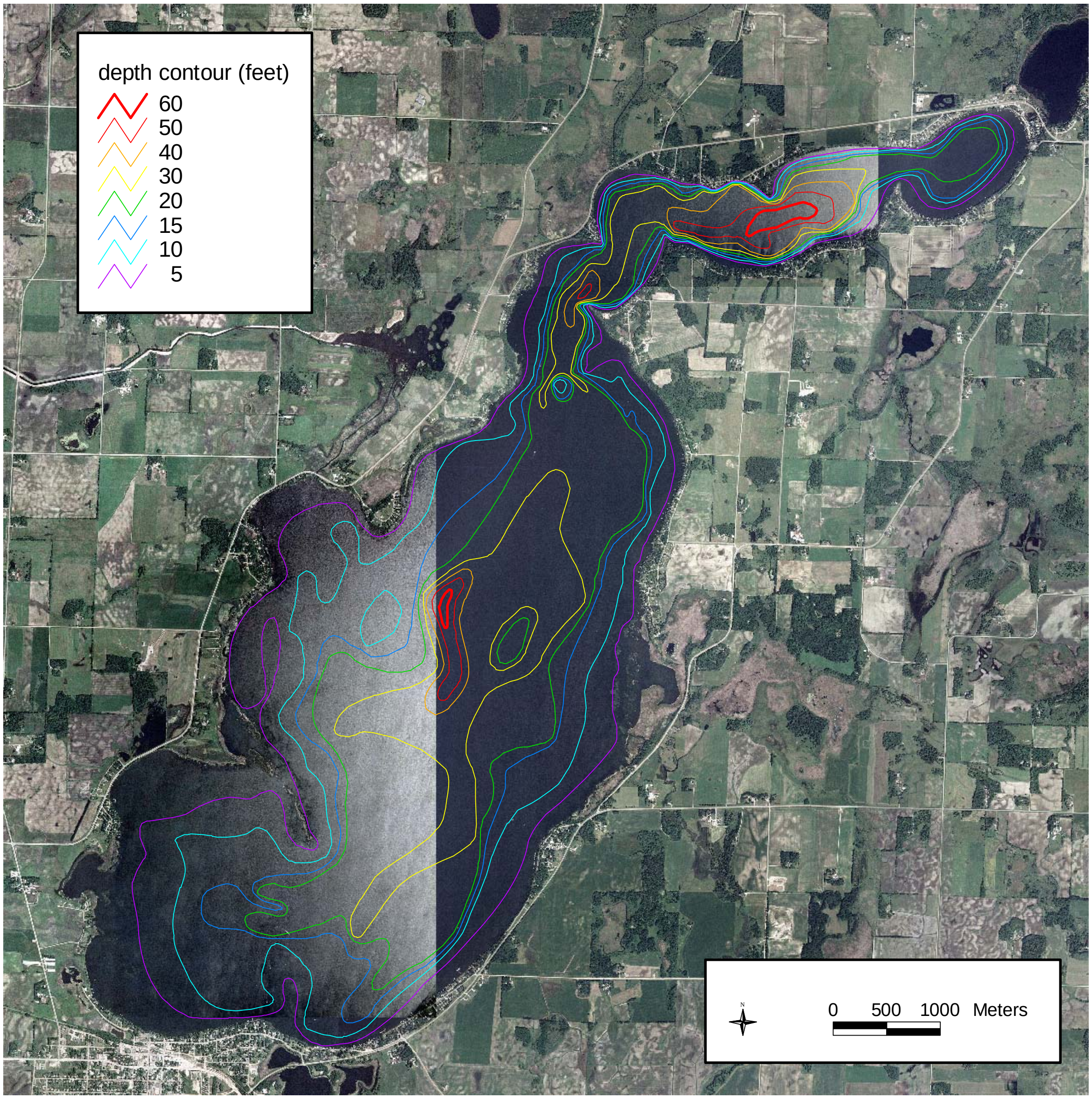
Osakis Lake has a surface area of about 6270 acres with a main, oval shaped basin and an elongated bay at its northeast end (Fig 2). The lake has a maximum depth of about 70 feet and approximately 54 percent of the basin is less than 15 feet in depth. Public boat launches occur at the south, west and northeast shores.

A 1993 water quality study found that Osakis Lake had higher nutrient levels and lower water clarity than other lakes in central Minnesota and a watershed management project was implemented to improve lake water quality (Anon. 2004). Water quality appeared to have improved by 1998 (Anon. 2004) but the lake continues to experience periodic summer algal blooms. Between 1998 and 2004, mean summer water clarity, as measured by Secchi disc reading, ranged from 4.8 feet to 9.9 feet, with a mean of 7.4 feet (MPCA 2006).

Historical surveys of Osakis Lake recorded extensive bulrush (*Scirpus*) stands in the southern basin and submerged vegetation scattered around the basin to a depth of about 15 feet in 1981 and to 12 feet in 1994. Common submerged species included coontail (*Ceratophyllum demersum*), wild celery (*Vallisneria americana*), muskgrass (*Chara* sp.), sago pondweed (*Stuckenia pectinata*), clasping-leaf pondweed (*Potamogeton richardonsii*), and water milfoil (*Myriophyllum* sp.) (MnDNR Fisheries Lake Files).

The non-native submerged plant, curly-leaf pondweed (*Potamogeton crispus*) occurs in Osakis Lake. Within the Sauk RiverWatershed, curly-leaf pondweed has been documented in at least 47% of the lakes that are 100 acres or more in size (compiled by D. Perleberg using data available from MnDNR Invasive Species Program).

Figure 2. Depth contours of Osakis Lake (77-0215-00)   Source: MnDNR 1969.



Vegetation Survey Objectives

The purpose of this vegetation survey was to describe the 2006 population of the non-native species, curly-leaf pondweed in Osakis Lake. Information on native vegetation was also recorded but most native plants do not reach maturity until mid to late summer. Specific objectives of this spring survey include:

1) Estimate the maximum depth of rooted vegetation
2) Estimate the percent of the lake occupied by rooted vegetation
3) Record the aquatic plant species that occur in the lake
4) Estimate frequencies of occurrence of individual species
5) Develop distribution maps for the common species

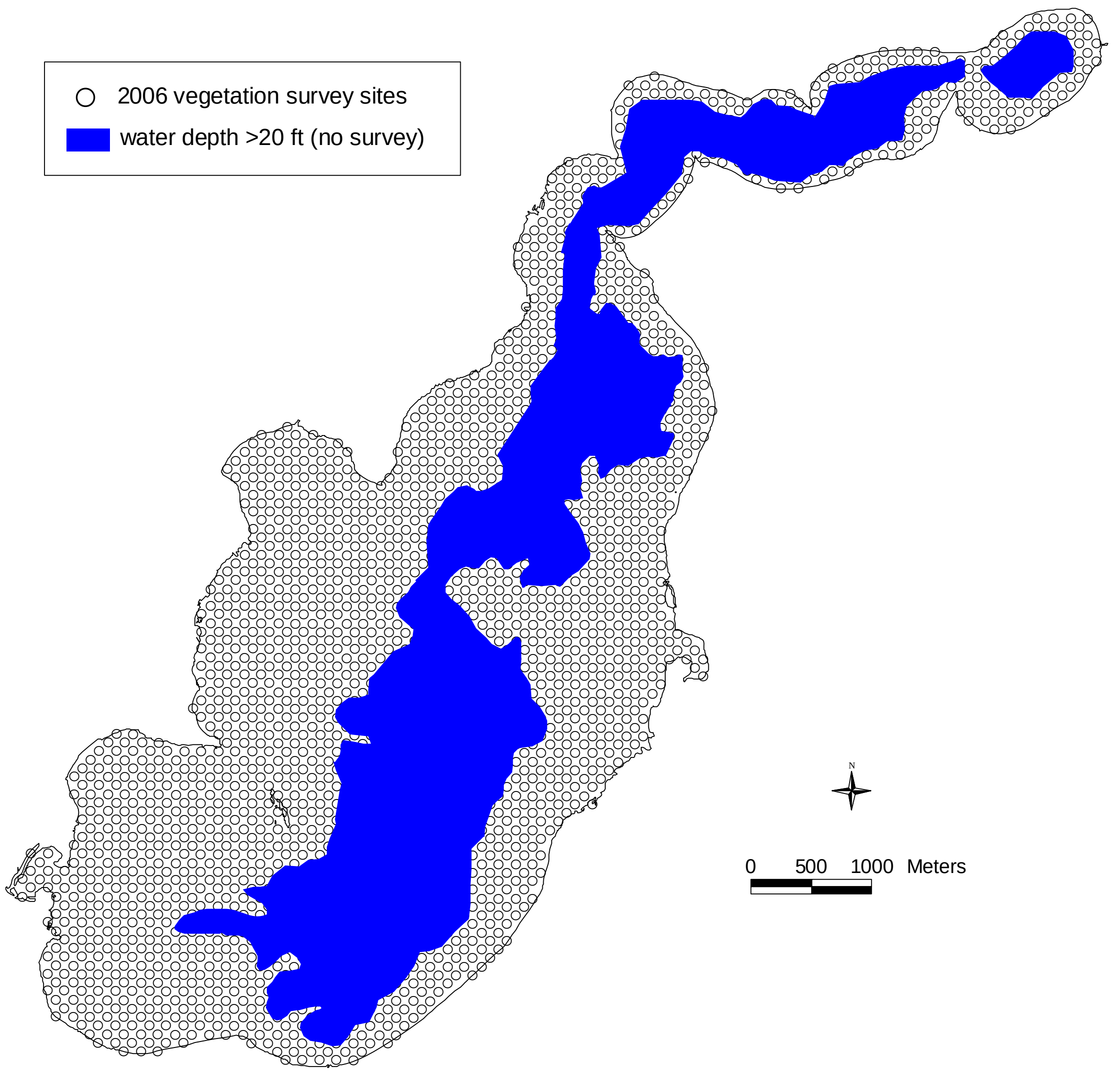
Methods

A Point-Intercept vegetation survey of Osakis Lake was conducted on May 23, 24, 26, 31 and June 1, 7, 12, 2006. The surveys followed the methods described by Madsen (1999). Surveys included two survey crews, each consisting of one boat and two to three surveyors.

Survey waypoints were created and downloaded into a Global Positioning System (GPS) receiver. Survey points were spaced 100 meters apart on Osakis Lake. In the field, surveyors sampled all survey points between shore and 20 feet for a total of 1601 sample sites (Fig. 3).

The GPS unit was used to navigate the boat to each sample point. One side of the boat was designated as the sampling area. At each site, water depth was recorded in one foot increments using a measured stick in water depths less than eight feet and an electronic depth finder in water

Figure 3. 2006 vegetation survey points on Osakis (77-0215-00).



depths greater than eight feet. The surveyors recorded all plant species found within a one meter squared sample site at the pre-designated side of the boat. A double-headed, weighted garden rake, attached to a rope was used to survey vegetation not visible from the surface (Fig. 4).

Figure 4. Sampling vegetation on Osakis Lake, June 1, 2006.

Nomenclature followed Crow and Hellquist (2000). Voucher specimens were collected for most plant species and are stored at the MnDNR in Brainerd. Data were entered into a Microsoft Access database and frequency of occurrence was calculated for each species as the number of sites in which a species occurred divided by the total number of sample sites.

Example:
In Osakis Lake there were 1601 samples sites in the zone from shore to the 20 feet depth.
Curly-leaf pondweed occurred in 741 of those sites.
Frequency of curly-leaf pondweed in the shore to 20 feet depth zone of Osakis Lake
= 741/1601 (*100) = 46%

Frequency was calculated for the entire area from shore to 20 feet and sampling points were also grouped by water depth and separated into seven depth zones for analysis (Table 1).

Table 1. Sampling effort by water depth zone Osakis Lake (77-0215-00).

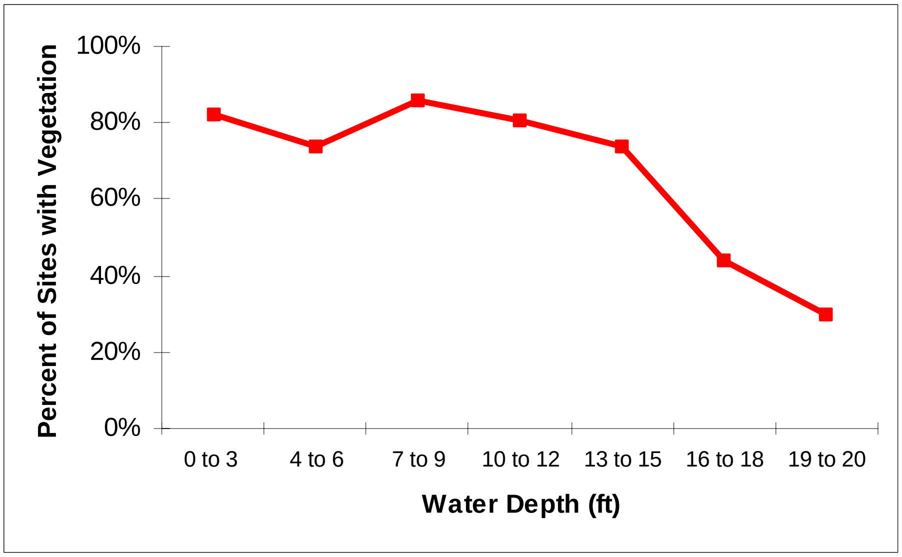
Depth interval in feet	Number of sample points
0 to 3	165
4 to 6	308
7 to 9	460
10 to 12	313
13 to 15	214
16 to 18	104
19 to 20	37
Total number of sample points	1601

Results

Distribution and plants with water depth

Aquatic plants were found to a maximum depth of 20 feet (the maximum depth sampled) in Osakis Lake and 77 percent of the sample sites within that depth interval contained vegetation. Plant abundance was greatest from shore to a water depth of 15 feet depth; in depths greater than 15 feet, only 40 percent of sites were vegetated (Fig. 5).

Figure 5. Frequency of vegetation vs. water depth, Osakis Lake (77-0215-00). May-June, 2006



Number and types of plant species recorded

Curly-leaf pondweed, (*Potamogeton crispus*), a non-native, submerged aquatic plant species was documented in Osakis Lake. A total of 16 native aquatic plant species were also recorded including 12 submerged, two free-floating, and two emergent plants (Table 2). Emergent species and most submerged species were restricted to water depths less than ten feet (Fig. 6). Curly-leaf pondweed was the only species found in depths greater than 18 feet.

Figure 6. Number of plant species vs. water depth. Osakis Lake (77-0215-00). May-June, 2006

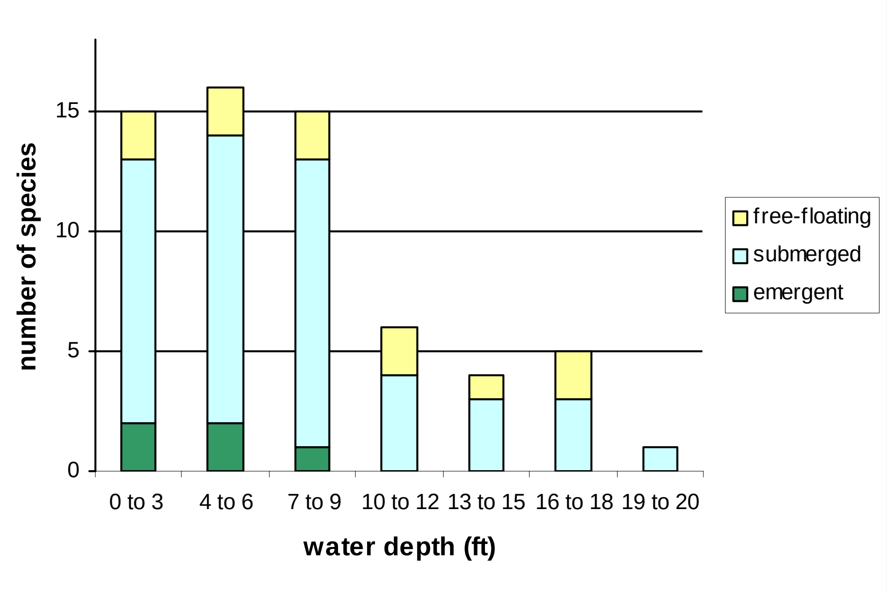


Table 1. Aquatic Plants of Osakis Lake (Todd County).
May 23, 24, 26, 31 and June 1, 7, 12, 2006.

Frequency calculated for zone from shore to 20 feet depth
Frequency = percent of sites in which species occurred

	Common name	Scientific name	2006 %
Submerged	Curly Leaf Pondweed	*Potamogeton crispus*	46
	Muskgrass	Chara sp.	11
	Northern watermilfoil	*Myriophyllum sibiricum*	7
	Coontail	*Ceratophyllum demersum*	7
	Flatstem pondweed	*Potamogeton zosteriformis*	2
	Whitestem pondweed	*Potamogeton praelongus*	1
	Clasping-leaf pondweed	*Potamogeton richardsonii*	1
	Narrowleaf pondweed	*Potamogeton* sp.	1
	Sago pondweed	*Stuckenia pectinata*	1
	Water stargrass	*Heteranthera dubia*	1
	Bushy pondweed	*Najas flexilis*	1
	Wild Celery	*Vallisneria americana*	<1
	Canada waterweed	*Elodea canadensis*	<1
Free-floating	Star Duckweed	*Lemna trisulca*	18
	Stonewort	*Nitella sp.*	5
Emergent	Bulrush	*Scirpus* sp.	9
	Cattail	*Typha* sp.	1
	Total number of species	17	

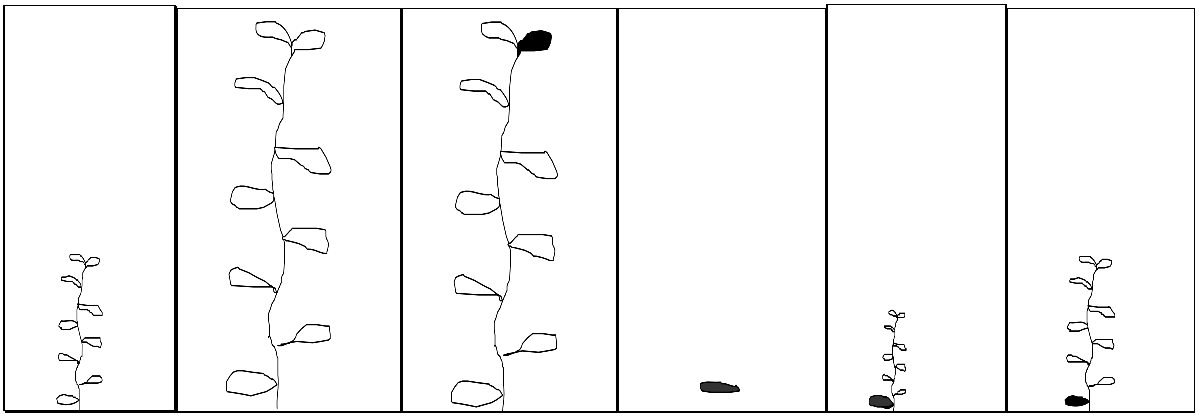
Curly-leaf pondweed in Osakis Lake

Figure 7. Curly-leaf plant in Osakis Lake (77-0215-00), May 26, 2006

Curly-leaf pondweed (*Potamogeton crispus*) was the most abundant species in Osakis Lake and occurred in 46 percent of the sample sites (Table 1). Curly-leaf pondweed is a submerged plant that is named for its wavy leaf margins (Fig. 7). It grows below the water surface but may reach the water surface at certain depths and create dense mats. It may also form flowers that extend above the water surface.

Curly-leaf pondweed is a not native to Minnesota but has been present in the state since at least 1910 (Moyle and Hotchkiss 1945) and is now found in at least 700 Minnesota lakes (Invasive Species Program 2005). Like many native submerged plants, it is perennial (regrowing from rootstalk each season) but it has a unique life cycle that may provide a competitive advantage over native species. Curly-leaf pondweed is actually dormant during late summer and begins new growth in early fall (Fig. 8). Winter foliage is produced and continues to grow under ice (Wehrmeister and Stuckey, 1978). Curly-leaf reaches its maximum growth in May and June, when water temperatures are still too low for most native plant growth. In late spring and early summer, curly-leaf plants form structures called "turions" which are hardened stem tips that break off and fall to the substrate (Fig. 8). Turions remain dormant through the summer and germinate into new plants in early fall (Catling and Dobson, 1985). During its peak growth in spring, curly-leaf may reach the water surface at certain depths and create dense mats.

Figure 8. Life cycle of Curly-leaf pondweed (*Potamogeton crispus*).



Winter Plants continue Growing Under ice

Spring Plants reach maximum growth

Late Spring Plants die back and form turions

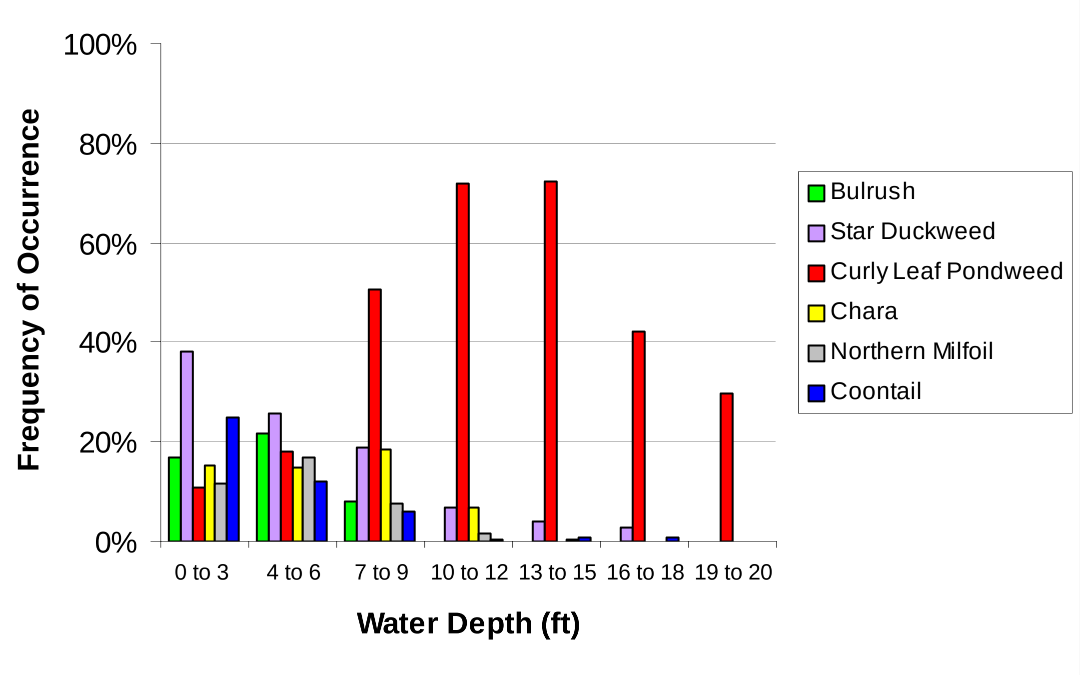
Summer Turions remain dormant

Fall Turions germinate

Winter New plants sprout from turions

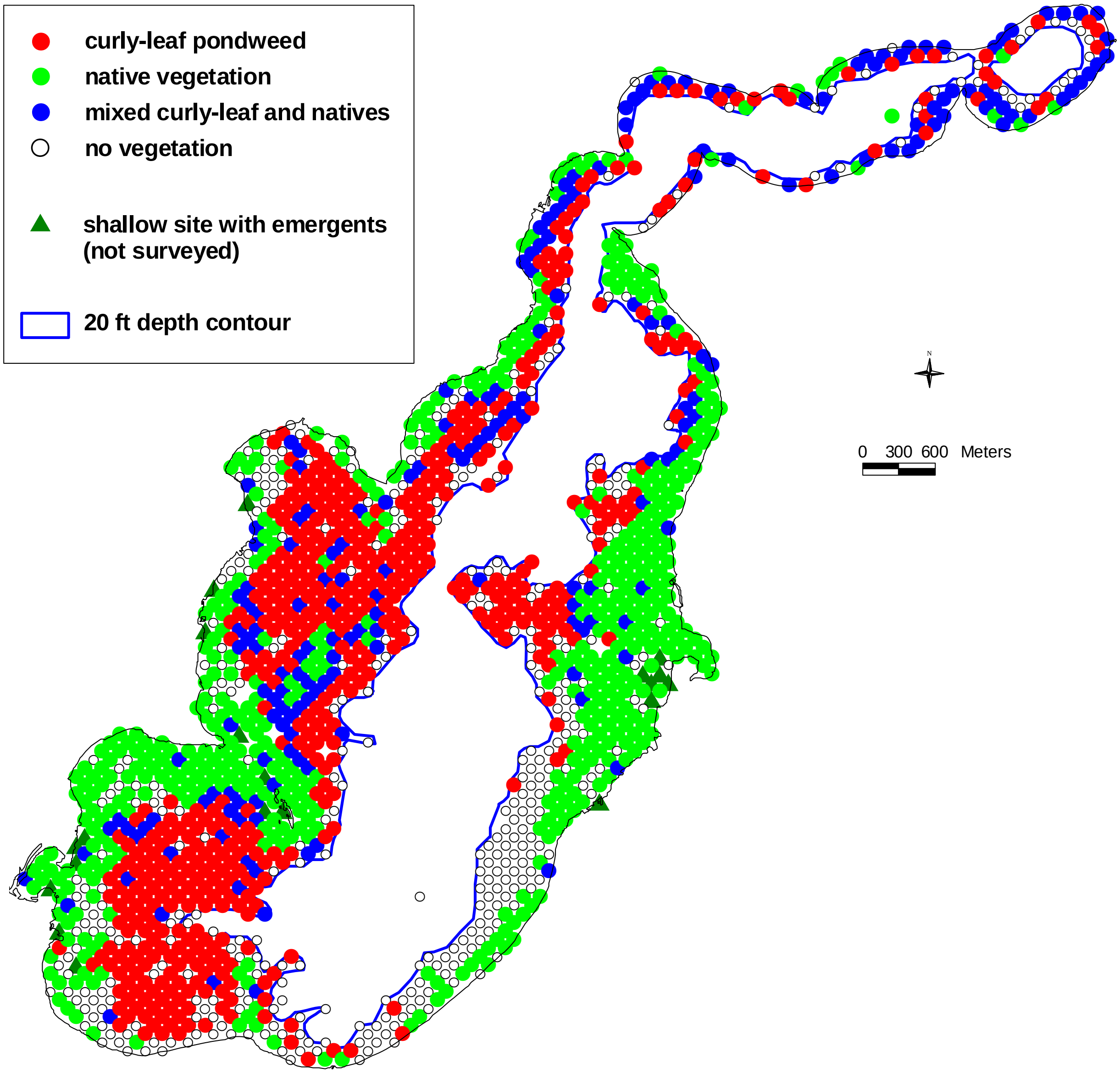
During the spring of 2006, curly-leaf pondweed occurred at all depth sampled in Osakis Lake, but it dominated the plant community in water depths from seven to 20 feet (Fig. 9). In depths less than seven feet, curly-leaf occurred in less than 20 percent of the sample sites and it reached it's maximum frequency in the 10 to 15 feet water depth, where it occurred in 72 percent of the sample sites (Fig. 9).

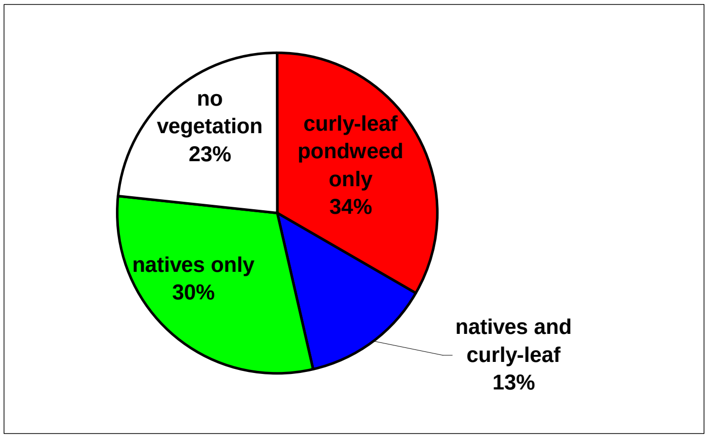
Figure 9. Frequency of common plant species by water depth. Osakis Lake (77-0215-00), May-June 2006.



The southwest and west-central ends of Osakis Lake have extensive areas within the seven to 20 feet water depth range and curly-leaf was well distributed in those areas (Fig. 10). Curly leaf was often the only species found in depth greater than 13 feet (Fig. 9) and 34 percent of all survey sites contained only curly-leaf pondweed (Fig. 10).

Figure 10. Types of vegetation found in Osakis Lake (77-0215-00), May-June 2006.





Native vegetation in Osakis Lake

Native vegetation was found in 43 percent of the sample sites but was primarily restricted to water depths less than 10 feet (Fig. 8). Areas dominated by native vegetation included the eastern shore and southwestern shores (Fig. 9). It is important to remember that this survey aimed to estimate the abundance and distribution of curly-leaf pondweed. For an accurate assessment of the native plant community, a mid-summer survey would be required. During an August, 2006 fisheries survey, DNR staff noted extensive stands of wild celery (*Vallisneria americana*).

Bulrush (*Scirpus* sp.) formed extensive beds along the western and east-central shores of Osakis Lake (Fig. 11). Although it was found in only nine percent of the sample sites (Table 2) bulrush is one of the more common species in the lake. It occurred at numerous sites that were too shallow to sample and its actual abundance in the lake is greater than what is recorded by this survey method.

Star duckweed (*Lemna trisulca*) was the most common native species found in sample sites and occurred in 18 percent of the sites (Table 2). It is a free-floating species that is often found submerged but not anchored to the lake bottom and it can drift with water currents. It was one of the few native species found in depths of ten feet and greater, but was most common from shore to a depth of six feet (Fig. 9) and was widely distributed around the lake (Fig. 11).

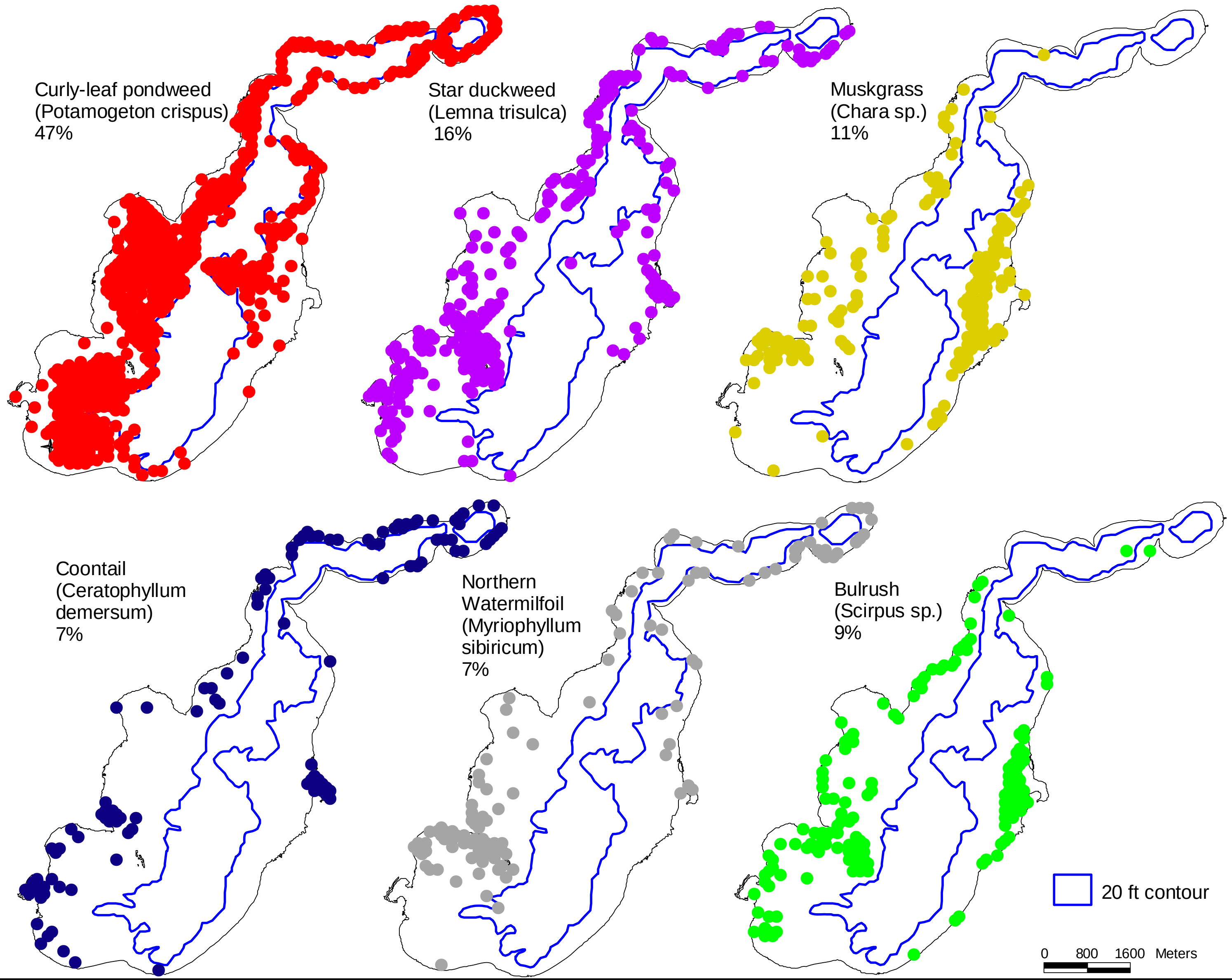
Muskgrass (*Chara* sp.) occurred in 11 percent of the sample sites (Table 2) and was only found in depths of 12 feet and less (Fig. 9). Muskgrass is a submerged, macroscopic algae that is common in many hardwater Minnesota lakes. It is named for its characteristic musky odor. Because this species does not form true stems, it is a low-growing plant, often found entirely beneath the water surface where it may form low "carpets" on the lake bottom. Muskgrass is adapted to variety of substrates and is often the first species to invade open areas of lake bottom where it can act as a sediment stabilizer. In Osakis Lake, muskgrass was often found at sandy sites where curly-leaf pondweed did not occur (Fig. 11).

Coontail (*Ceratophyllum demersum*) was present in seven percent of the sample sites (Table 2) and most common in depths less than 10 feet (Fig. 9). This perennial grows entirely submerged and is adapted to a broad range of lake conditions, including turbid water. It is often found growing in deeper water than other native species because it is more tolerant of low light conditions. In Osakis Lake, coontail was one of the few native species found in depths greater than 10 feet but it was only found in a few of these deeper water sites. Coontail was most often found in protected bays of Osakis Lake (Fig. 11)

Northern watermilfoil (*Myriophyllum sibiricum*) occurred in seven percent of the sample sites (Table 2) and was most common in depths of six feet and less (Fig. 9). It was found in the northeast bay, the southwest end of the lake, and scattered along other shores (Fig. 11). This perennial submerged species prefers soft substrates and is not tolerant of turbidity.

All other native species were present in less than six percent of the sample sites (Table 2).

Figure 11. Distribution of common plant species in Osakis Lake (77-0215-00), May-June, 2006.



Discussion

Curly-leaf pondweed is probably not a recent invader in Osakis Lakes. It has been present in Minnesota for at least 100 years and common in central Minnesota lakes for at least the past 20 years. It is difficult to know when it first invaded Osakis Lake because historical plant surveys were conducted in mid to late summer, after curly-leaf would have already died. Spring water clarity in Osakis Lake has reportedly increased in the past few years (possibly due to watershed management improvements and/or lack of snow cover) and that may have allowed an increase in curly-leaf pondweed growth.

Rooted aquatic plants are generally restricted to water depths where they can obtain sufficient sunlight for growth. As a general rule, native plants may grow to a depth of about twice the mid-summer Secchi Disc reading. In Osakis Lake, plants would not be expected to grow beyond a depth of 15 feet. Curly-leaf pondweed, however, can take advantage of relatively clear water in the spring before native species are present, and it therefore is found growing in deeper water. As curly-leaf dies back in early summer, water clarity may further decline as the dying curly-leaf releases nutrients that may result in increased algal growth.

All vegetation, native and non-native can benefit a lake by providing habitat for fish and invertebrates, buffering the shorelines from wave action, stabilizing sediments and utilizing nutrients that would otherwise be available for algae. Native vegetation can be of greater value because it has coevolved with the native fish and wildlife species that utilize the lake. (Click here for more information on: value of aquatic plants).

Curly-leaf pondweed has the potential to cause recreational problems on lakes, particularly if it forms extensive surface mats that interfere with boat use. These problems are temporary because the plant typically dies back by early July. Longer-term ecological problems may occur if extensive stands of curly-leaf form annually and contribute significant nutrient loads to the lake. For more information on management of curly-leaf pondweed see page 51 in this report: MnDNR Invasive Species Annual Report

Monitoring changes in aquatic plant community

The types and amounts of aquatic vegetation that occur within a lake are influenced by a variety of factors including water clarity and water chemistry. Monitoring change in the aquatic plant community can be helpful in determining whether changes in the lake water quality are occurring and for estimating the quality of vegetation habitat available for fish and wildlife communities. Data from the 2006 vegetation survey can also be used to monitor annual changes in curly-leaf pondweed plant species composition. Again, a mid-summer survey would be helpful to monitor change in the native plant community.

In general, factors that may lead to change in native and non-native aquatic plant communities include:

- Change in water clarity
  If water clarity in Osakis Lake increases, submerged vegetation is expected to expand in distribution and grow at greater water depths.

- Snow and ice cover
  Curly-leaf pondweed, in particular, may fluctuate in abundance in response to snow cover. Many native submerged plants also have the ability to grow under the ice, especially if there is little snow cover and sunlight reaches the lake bottom. In years following low snow cover, and/or a reduced ice-over period, curly-leaf and some native submerged plants may increase in abundance.
- Water temperatures / length of growing season
  In years with cool spring temperatures, submerged plants may be less abundant than in years with early springs and prolonged warm summer days.
- Natural fluctuation in plant species.
  Many submerged plants are perennial and regrow in similar locations each year. However, a few species such as bushy pondweed (*Najas flexilis*) are annuals and are dependant on the previous years seed set for regeneration.
- Aquatic plant management activities
  Humans can impact aquatic plant communities directly by destroying vegetation with herbicide or by mechanical means. For information on the laws pertaining to aquatic plant management: MnDNR APM Program. Motorboat activity in vegetated areas can be particularly harmful for species such as bulrush. Shoreline and watershed development can also indirectly influence aquatic plant growth if it results in changes to the overall water quality and clarity. Herbicide and mechanical control of aquatic plants can directly impact the aquatic plant community. Monitoring these control activities can help insure that non-target species are not negatively impacted.

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Appendix E

Stream Total Phosphorus Sampling by Site

Site: Year	Count	Ave TP (ug/L)
S002-647: 1989	13	134
S002-647: 1990	7	255
S002-647: 1991	2	109
S002-647: 2004	9	80
S002-647: 2005	14	172
S002-647: 2006	11	110
S002-647: 2007	17	198
S002-647: 2009	15	142
S002-647: 2010	9	119
S002-650: 1989	6	254
S002-650: 1990	8	364
S002-650: 1991	3	445
S002-650: 1995	3	262
S002-652: 1989	13	98
S002-652: 1990	9	48
S002-652: 1991	2	45
S002-652: 2006	11	35
S002-653: 1989	13	179
S002-653: 1990	8	239
S002-653: 1991	2	174
S002-653: 1998	4	300
S002-653: 1999	6	193
S002-653: 2000	6	211
S002-653: 2001	3	153
S002-653: 2002	5	187
S003-293: 1996	11	770
S003-293: 1997	5	268
S003-294: 1996	11	173
S003-294: 1997	6	75
S003-295: 1995	5	201
S003-295: 1996	15	197
S003-295: 1997	10	412
S003-295: 1998	10	235
S003-295: 1999	12	219
S003-295: 2000	6	301
S003-295: 2001	12	268
S003-295: 2002	13	140
S003-296: 1995	10	147

Site: Year	Count	Ave TP (ug/L)
S003-296: 1996	11	187
S003-296: 1997	12	130
S003-296: 1998	7	663
S003-296: 1999	11	102
S003-296: 2000	8	194
S003-296: 2001	11	242
S003-296: 2002	11	228
S003-296: 2003	14	256
S003-296: 2004	10	156
S003-296: 2005	24	262
S003-296: 2006	10	148
S003-296: 2007	14	168
S003-296: 2009	14	213
S003-297: 1996	11	167
S003-297: 1997	5	110
S003-298: 1996	2	145
S003-298: 2009	12	440
S003-299: 1996	11	231
S003-299: 1997	6	135
S003-300: 1996	12	168
S003-300: 1997	5	118
S003-301: 1996	12	168
S003-301: 1997	6	187
S003-302: 1995	15	66
S003-302: 1996	14	69
S003-302: 1997	16	54
S003-302: 1998	8	181
S003-302: 1999	4	56
S003-302: 2000	2	75
S003-302: 2001	11	112
S003-303: 1995	14	162
S003-303: 1996	26	225
S003-303: 1997	21	115
S003-303: 1998	14	175
S003-303: 1999	12	203
S003-303: 2000	11	146
S003-303: 2001	16	159
S003-303: 2002	10	175
S003-303: 2003	12	223
S003-303: 2004	12	86

Site: Year	Count	Ave TP (ug/L)
S003-303: 2005	15	188
S003-303: 2006	12	114
S003-303: 2007	16	179
S003-303: 2009	15	143
S003-303: 2010	12	136
S003-304: 1996	7	99
S003-304: 1997	2	85
S003-537: 1995	1	800
S003-537: 1996	1	320
S003-537: 1997	1	360
S003-538: 1995	1	350
S003-538: 1996	1	170
S003-538: 1997	1	140
S003-539: 1995	1	810
S003-539: 1996	1	560
S003-539: 1997	1	340
S003-540: 1995	1	340
S003-540: 1996	1	460
S003-540: 1997	1	320
S003-541: 1995	1	550
S003-541: 1996	1	630
S003-541: 1997	2	650
S003-878: 2004	8	76
S003-878: 2007	10	271
S003-878: 2009	4	169
S003-879: 2004	8	83
S003-879: 2007	10	179
S003-879: 2009	4	123

Appendix F

Runoff Coefficients and TP Concentrations by HRU

HRU (Landuse, Erosion Potential-Water Capacity, Slope)	Runoff Coefficient	Runoff TP Conc. (µg/L)
Alfalfa/Wheat/Rye,HighLow,<4	0.11	224
Alfalfa/Wheat/Rye,HighLow,>8	0.17	224
Alfalfa/Wheat/Rye,HighLow,4-8	0.14	224
Alfalfa/Wheat/Rye,HighModerate,<4	0.15	224
Alfalfa/Wheat/Rye,HighModerate,>8	0.26	224
Alfalfa/Wheat/Rye,HighHigh,<4	0.31	224
Alfalfa/Wheat/Rye,HighModerate,4-8	0.19	224
Alfalfa/Wheat/Rye,LowHigh,<4	0.18	224
Alfalfa/Wheat/Rye,LowHigh,>8	0.31	224
Alfalfa/Wheat/Rye,LowHigh,4-8	0.22	224
Alfalfa/Wheat/Rye,LowLow,<4	0.11	224
Alfalfa/Wheat/Rye,LowLow,>8	0.17	224
Alfalfa/Wheat/Rye,LowLow,4-8	0.14	224
Alfalfa/Wheat/Rye,LowModerate,<4	0.12	224
Alfalfa/Wheat/Rye,ModerateLow,<4	0.11	224
Alfalfa/Wheat/Rye,ModerateLow,>8	0.17	224
Alfalfa/Wheat/Rye,ModerateLow,4-8	0.14	224
Alfalfa/Wheat/Rye,ModerateModerate,<4	0.12	224
Alfalfa/Wheat/Rye,ModerateModerate,>8	0.21	224
Alfalfa/Wheat/Rye,ModerateModerate,4-8	0.16	224
Corn/Soybean,HighHigh,<4	0.18	224
Corn/Soybean,HighHigh,>8	0.31	224
Corn/Soybean,HighHigh,4-8	0.22	224
Corn/Soybean,HighLow,<4	0.11	224
Corn/Soybean,HighLow,>8	0.17	224
Corn/Soybean,HighLow,4-8	0.14	224
Corn/Soybean,HighModerate,<4	0.15	224
Corn/Soybean,HighModerate,>8	0.26	224
Corn/Soybean,HighModerate,4-8	0.19	224
Corn/Soybean,LowHigh,<4	0.18	224
Corn/Soybean,LowHigh,>8	0.31	224
Corn/Soybean,LowHigh,4-8	0.22	224
Corn/Soybean,LowLow,<4	0.11	224
Corn/Soybean,LowLow,>8	0.17	224
Corn/Soybean,LowLow,4-8	0.14	224
Corn/Soybean,LowModerate,<4	0.12	224
Corn/Soybean,LowModerate,>8	0.21	224
Corn/Soybean,LowModerate,4-8	0.16	224

HRU (Landuse, Erosion Potential-Water Capacity, Slope)	**Runoff Coefficient**	**Runoff TP Conc. (µg/L)**
Corn/Soybean,ModerateHigh,<4	0.18	224
Corn/Soybean,ModerateHigh,4-8	0.22	224
Corn/Soybean,ModerateLow,<4	0.11	224
Corn/Soybean,ModerateLow,>8	0.17	224
Corn/Soybean,ModerateLow,4-8	0.14	224
Corn/Soybean,ModerateModerate,<4	0.12	224
Corn/Soybean,ModerateModerate,>8	0.21	224
Corn/Soybean,ModerateModerate,4-8	0.16	224
Forested	0.08	28
General Agriculture,HighLow,<4	0.11	224
General Agriculture,HighLow,>8	0.17	224
General Agriculture,HighLow,4-8	0.14	224
General Agriculture,HighModerate,<4	0.15	224
General Agriculture,HighModerate,>8	0.26	224
General Agriculture,HighModerate,4-8	0.19	224
General Agriculture,LowHigh,<4	0.18	224
General Agriculture,LowHigh,>8	0.31	224
General Agriculture,LowHigh,4-8	0.22	224
General Agriculture,ModerateLow,<4	0.11	224
General Agriculture,ModerateLow,>8	0.17	224
General Agriculture,ModerateLow,4-8	0.14	224
General Agriculture,ModerateModerate,<4	0.12	224
General Agriculture,ModerateModerate,>8	0.21	224
General Agriculture,ModerateModerate,4-8	0.16	224
High Density Urban	0.52	224
Low Density Urban	0.20	189
Medium Density Urban	0.30	210
Pasture/Hay,HighHigh,<4	0.23	224
Pasture/Hay,HighHigh,>8	0.38	224
Pasture/Hay,HighHigh,4-8	0.31	224
Pasture/Hay,HighLow,<4	0.09	224
Pasture/Hay,HighLow,>8	0.23	224
Pasture/Hay,HighLow,4-8	0.15	224
Pasture/Hay,HighModerate,<4	0.18	224
Pasture/Hay,HighModerate,>8	0.34	224
Pasture/Hay,HighModerate,4-8	0.26	224
Pasture/Hay,LowHigh,<4	0.23	224
Pasture/Hay,LowHigh,>8	0.38	224
Pasture/Hay,LowHigh,4-8	0.31	224
Pasture/Hay,LowLow,<4	0.09	224

HRU (Landuse, Erosion Potential-Water Capacity, Slope)	Runoff Coefficient	Runoff TP Conc. (µg/L)
Pasture/Hay,LowLow,>8	0.23	224
Pasture/Hay,LowLow,4-8	0.15	224
Pasture/Hay,LowModerate,<4	0.14	224
Pasture/Hay,LowModerate,>8	0.28	224
Pasture/Hay,LowModerate,4-8	0.21	224
Pasture/Hay,ModerateHigh,<4	0.23	224
Pasture/Hay,ModerateHigh,>8	0.38	224
Pasture/Hay,ModerateHigh,4-8	0.31	224
Pasture/Hay,ModerateLow,<4	0.09	224
Pasture/Hay,ModerateLow,>8	0.23	224
Pasture/Hay,ModerateLow,4-8	0.15	224
Pasture/Hay,ModerateModerate,<4	0.14	224
Pasture/Hay,ModerateModerate,>8	0.28	224
Pasture/Hay,ModerateModerate,4-8	0.21	224
Transportation	0.55	175
Wetlands/Open Water	0.00	-

Appendix G

Sediment and Internal Phosphorus

Scanned
Nov. 2011

Sediment and Internal Phosphorus

Loading Evaluation of Lake Osakis, Clifford and Faille

Prepared for the
Sauk River Watershed District

June 2006

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Sediment and Internal Phosphorus

Loading Evaluation of Lake Osakis, Clifford and Faille

Prepared for the
Sauk River Watershed District

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Sediment and Internal Phosphorus Loading Evaluation of Lake Osakis, Clifford and Faille

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Introduction

Sediment sampling was conducted on Lake Osakis in an initial effort to identify the magnitude of internal loading and if internal loading is having an effect on water quality in the lake. Along with sediment analysis, nutrient related water quality parameters were also analyzed to obtain a better understanding of the system as a whole. Sediment from Clifford and Faille was collected to determine the fate of alum that was applied to these lakes and estimate the effectiveness of the treatment.

Water Quality

Dissolved Oxygen

Low oxygen levels in lake water present a number of problems for biota and lake water quality. Game fish generally become stressed at dissolved oxygen concentrations less than 4 or 5 mg/L during summer months while Carp and other rough fish can survive at lower levels. As oxygen concentrations decline near the sediment-water interface at the bottom of a lake, phosphorus in the sediment that is normally bound up in the sediment (to iron and manganese) can then be released. Phosphorus release from the sediment typically occurs at oxygen concentrations below 2 mg/L as microorganisms begin reducing iron and manganese in the sediment causing the release of phosphorus. This phosphorus may then become available for uptake by algae, increasing algal growth in lakes. Because Lake Osakis appears to be polymictic (stratifies and mixes multiple times during the year), the phosphorus that is released from sediment becomes available to algae throughout the summer when it is transported from the bottom of the lake to the top it has been mixed into the photic zone (the upper portion of the lake exposed to light).

To better understand dissolved oxygen levels in Lake Osakis and the potential effect of low oxygen levels on phosphorus release; data collected in Lake Osakis in 2005 was evaluated. Dissolved oxygen (DO) was measured in Lake Osakis during 2005 at three locations (North End, Deep Hole and South End). Because of the sheltered nature of the northern end of the lake (i.e., Lindberg Point), stratification, and thus dissolved oxygen depletion was more pronounced during the summer months. Concentrations of less than 2 mg/L were detected at water column depths below 15 feet during at least one sampling period (Figure 1). Because most sampling events did not include DO measurements below 20 feet it is difficult to determine the magnitude and duration of oxygen depletion throughout the summer.

Data collected from the middle of the lake near the deep hole also shows that stratification and DO depletion occurred during the summer months (Figure 1). DO depletion occurred at greater deepth here than in the north end of the lake and this is likely due to the long fetch and greater wind mixing at this location (i.e., Four Mile Hole). Nonetheless, oxygen concentrations were at or below 2 mg/L during multiple sampling events in the summer of 2005.

DO measurements at the sampling station located at the southern end of the lake (i.e., Town Bay) indicated low levels of oxygen during August and September with concentrations below 2 mg/L at water column depths below approximately 28 feet (Figure 1). The DO depletion level was higher than that seen at the middle of lake and is likely due to the limited length of the cord that was used for DO measurements.

Figure 1. Dissolved oxygen concentrations at the three sampling locations in Lake Osakis

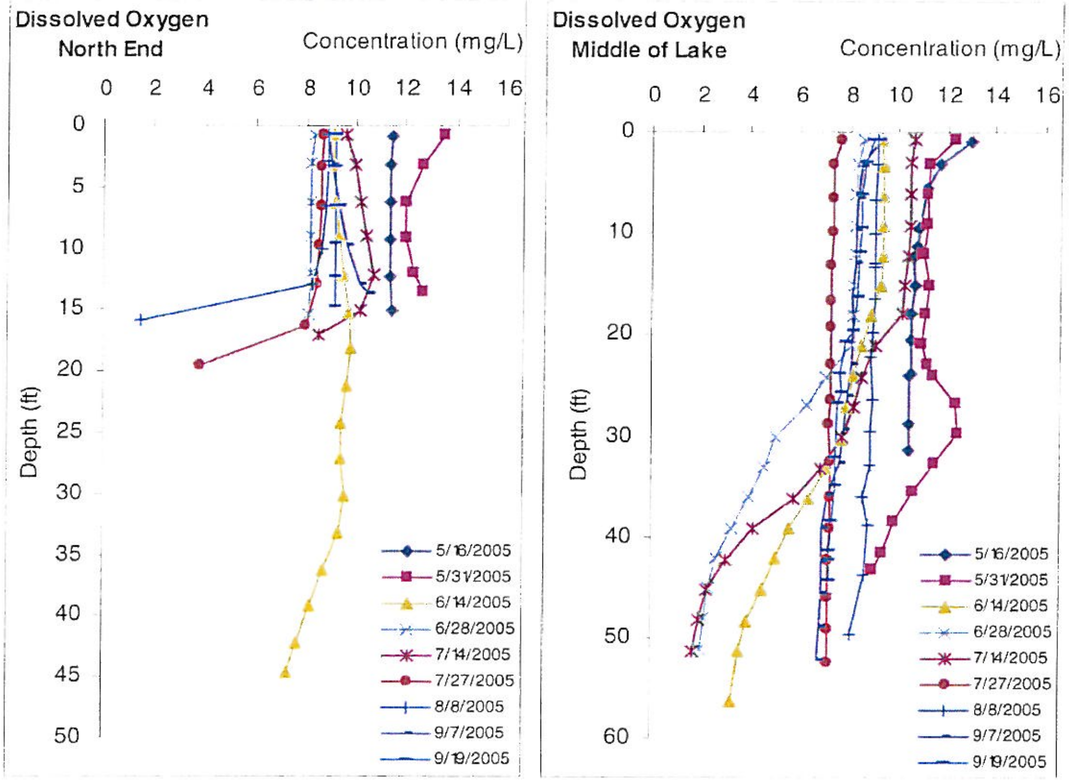
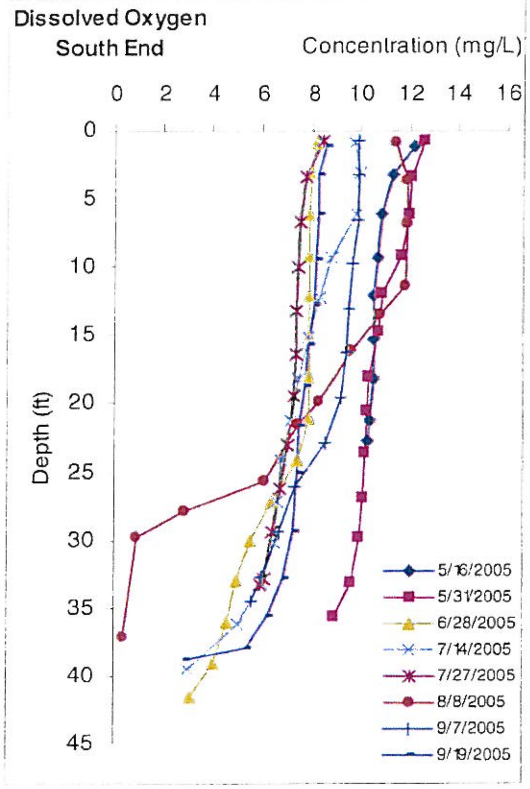


Figure 1. Continued…



Based on the DO data collected in 2005, the area of the lake that experiences sustained anoxic conditions was estimated to be 2075 acres, about 1/3 of the total lake area, and this area is shown in Figure 2. Because DO data was not complete for the lake, this area should be considered only as an estimate until further DO data can be collected to better determine the area of the lake affected by anoxia as well as the duration of anoxia.

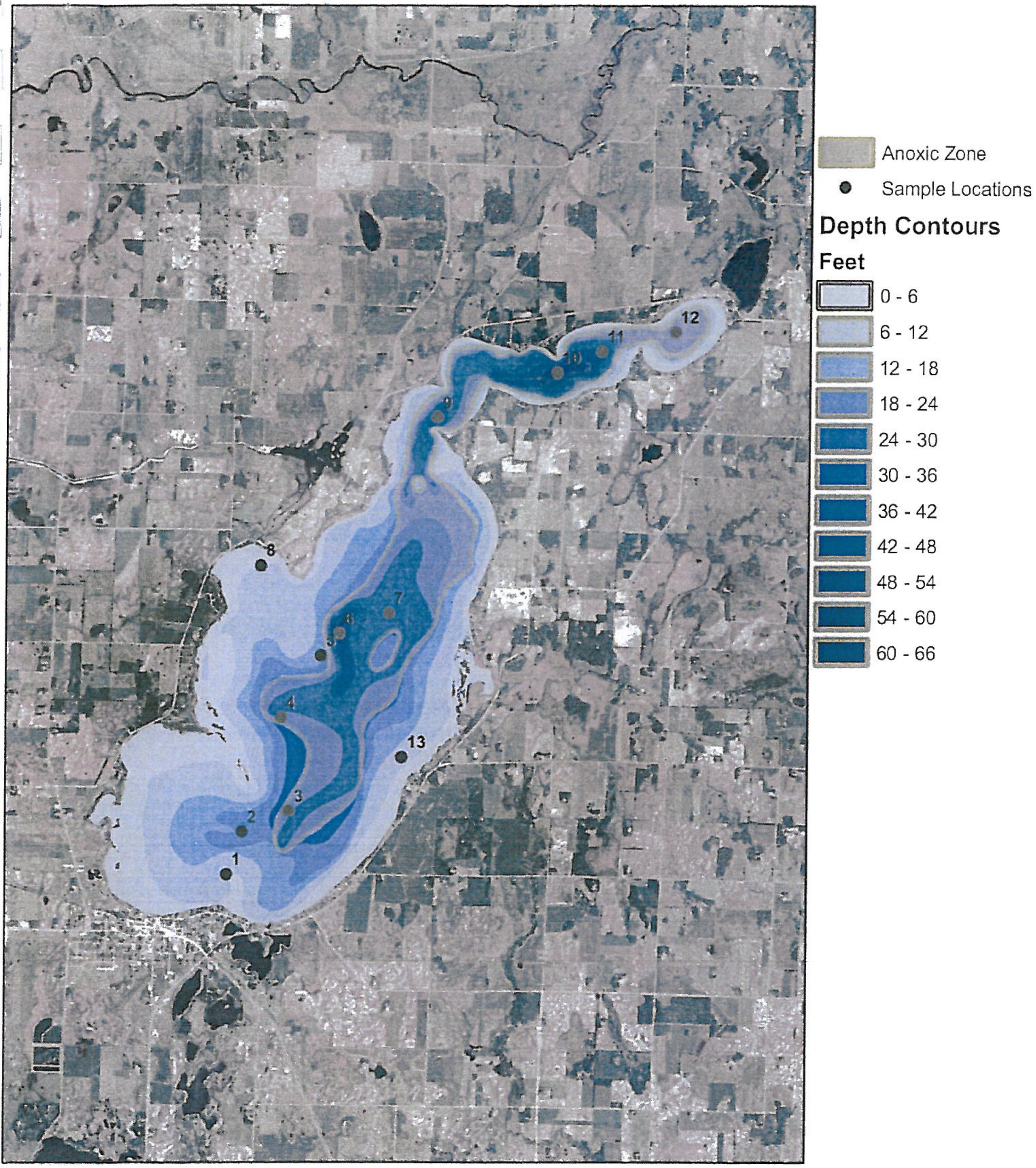


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Figure 2
Estimated Extent of Anoxic Zone in Lake Osakis

Barr Footer: Date: 5/5/2006 10 15 00 AM File: P:\23\73\092\Osakis\Osakis\Osakis_Anoxia.mxd User: KMP

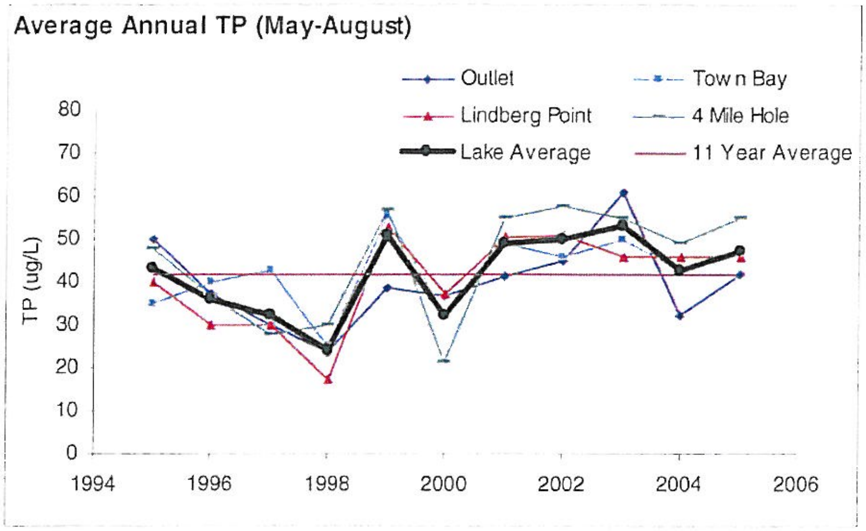
Total Phosphorus, Chlorophyll-a and Secchi Depth

Total Phosphorus (TP), Chlorophyll-a (Chl-a) and Secchi Disc depth are nutrient related water quality parameters used to estimate the condition of freshwater lakes. TP, Chl-a and Secchi depth for the four sampling points in Lake Osakis were averaged both monthly and annually to evaluate how these parameters vary at different time scales. Trends among the different sampling stations were similar; therefore, lake wide averages will be discussed. Annual averages were based on the months from May through September to avoid unbalanced averages during years when additional samples were taken.

Total Phosphorus

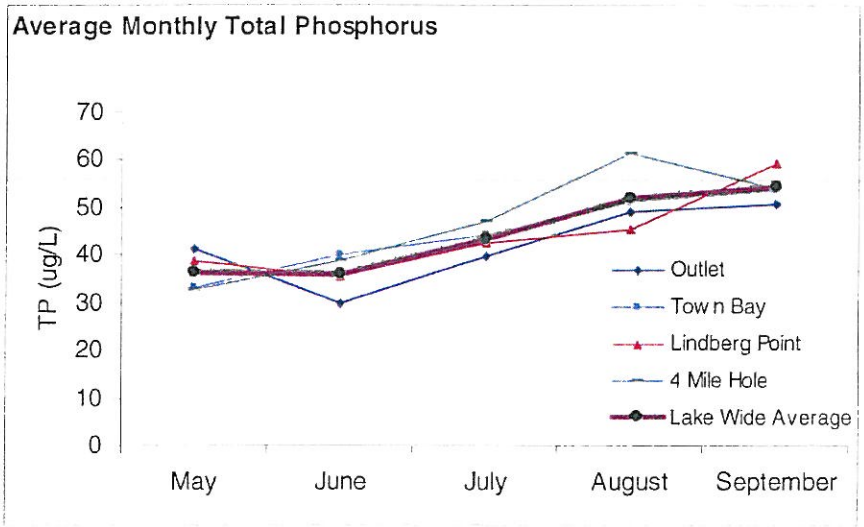
TP concentrations were collected at 4 different locations in Lake Osakis during the past 11 years (Outlet to Sauk River, Town Bay, Lindberg Point and 4 Mile Hole). There was not a significant trend in average annual TP concentrations between 1995 and 2005 (Figure 3). Average annual TP peaked in 2003 at 53 ug/L and was lowest in 1997 at 33 ug/L.

Figure 3. Average Annual Total Phosphorus in Lake Osakis.



Average monthly TP concentrations were calculated using the 11 year data set and are shown in Figure 4. On average, TP steadily increases during the summer growing season from 37 ug/L in May to 54 ug/L in September. The increase in TP concentration in the lake indicates additional phosphorus input to the lake during the summer either from external or internal sources, however, the consistent and smooth trend suggests that internal loading is playing a role.

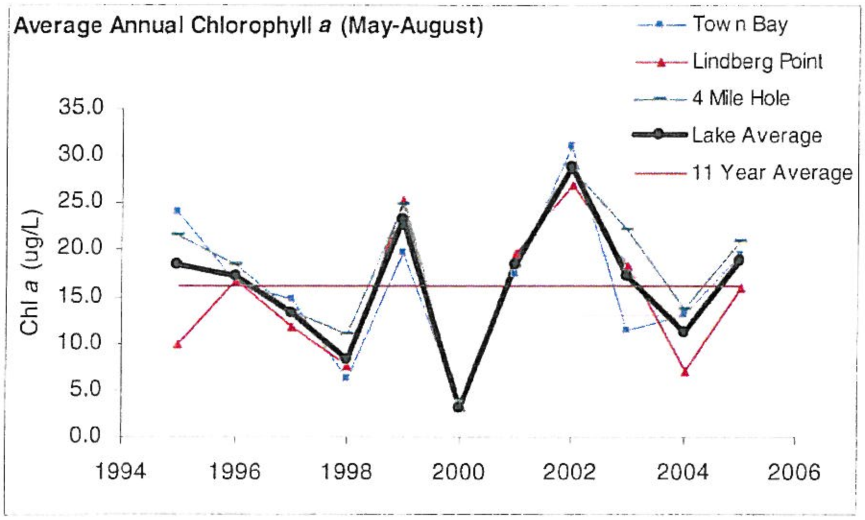
Figure 4. Average Monthly Total Phosphorus in Lake Osakis.



Chlorophyll-a

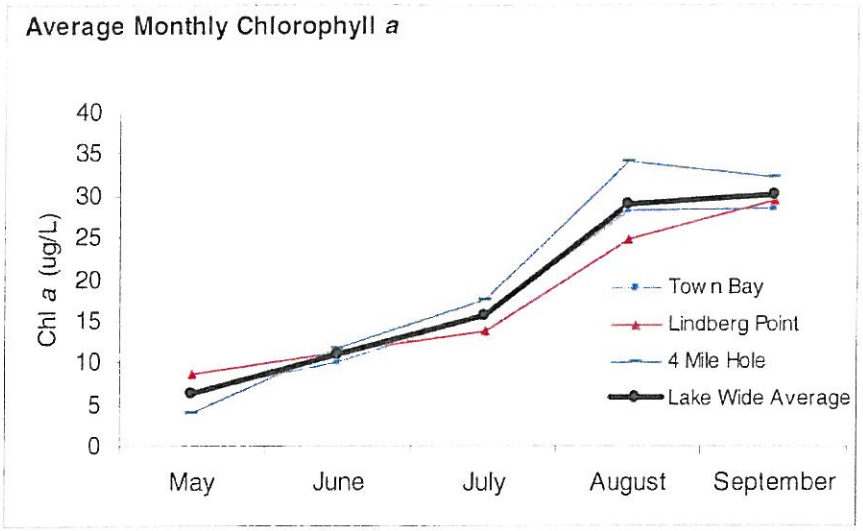
Chl-a samples were collected at three locations on Lake Osakis between 1995 and 2005 (Town Bay, Lindeberg Point and 4 Mile Hole). There was no clear trend in average annual Chl-a concentrations in Lake Osakis during the past 11 years. Chl-a was highest in 2002 at 28 ug/L and lowest in 2000 at 3.2 ug/L (Figure 5).

Figure 5. Average annual chlorophyll-a in Lake Osakis.



Along with TP concentrations, monthly averages for Chl-a demonstrated a pattern of increasing during the summer growing season. Chl-a readings were lowest in May (6.4 ug/L) and increased to 30.1 ug/L by September (Figure 6).

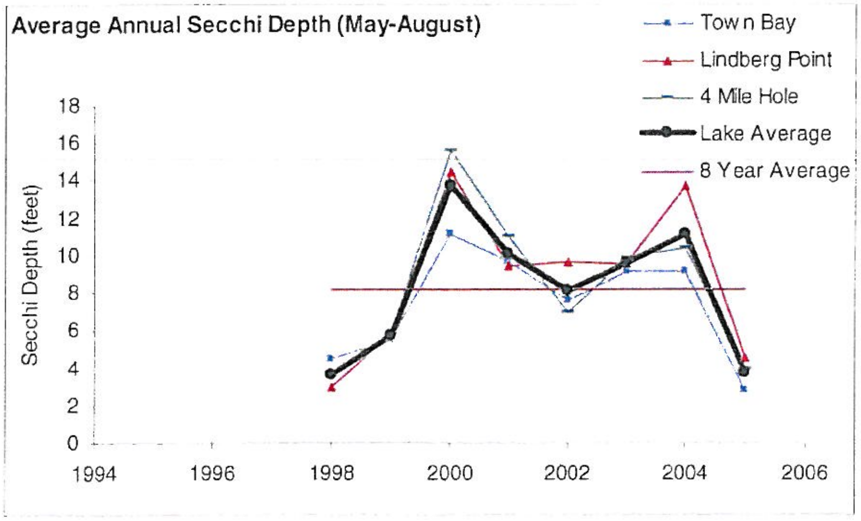
Figure 6. Average monthly chlorophyll-a in Lake Osakis.



Secchi Depth

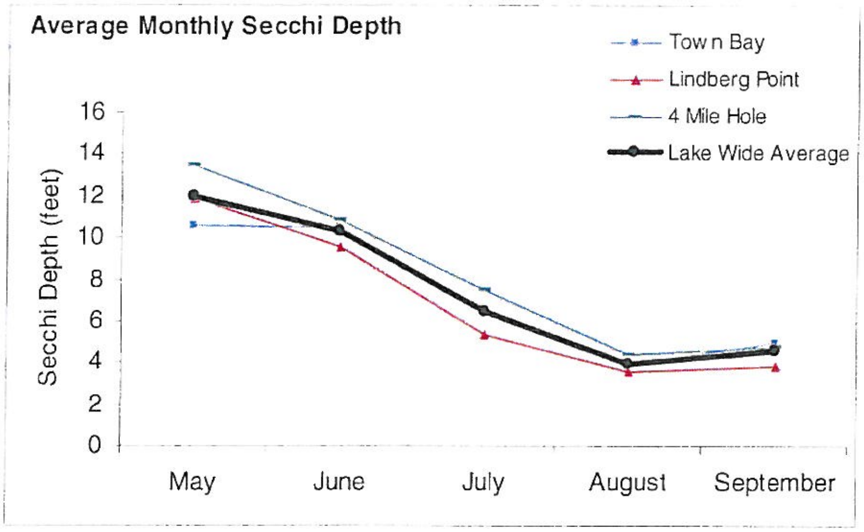
Secchi depth data has been collected every year since 1998 (Figure 7). As with Chl-a, no clear trend emerged from the average annual Secchi disc depth calculations. Secchi depth was lowest in 1998 at 3.7 feet and highest in 2000 measuring 13.7 feet. The overall average for Lake Osakis during the eight years that the lake has been sampled is 8.2 feet.

Figure 7. Average annual Secchi disk depth in Lake Osakis.



On average over the past 11 years, monthly Secchi depth readings demonstrated a pattern of declining through the summer and stabilizing in August and September. On average readings dropped from from 12 feet in May to a low of 4 feet in August (Figure 8). This correlates well with the increase in algal biomass (i.e., Chl-a) during the summer months.

Figure 8. Average monthly Secchi disk depth in Lake Osakis.



Sediment and Internal Loading

Internal phosphorus loading in lakes is a natural process whereby phosphorus is recycled from the sediment into the water column. Sediment in lakes can be either a source or a sink for phosphorus during different times of the year. In nutrient rich systems, the sediment sorption capacity becomes overloaded, such that, even after external loads have been controlled, phosphorus continues to be contributed to the water column via the sediment.

Internal phosphorus loading can occur under both oxic (oxygen rich, aerobic) or anoxic (oxygen poor, anaerobic) conditions. Release of phosphorus from sediment in aerobic areas occurs through oxidation of organic material as well as microzones of anoxia with anaerobic activity. Under certain conditions, internal phosphorus loading in shallow areas can equal or exceed internal loading in deeper areas of the lake. Even when internal loading in shallow areas is low, the phosphorus that is released can be available for immediate uptake by algae. This is in contrast to stratified lakes, whereby the majority of phosphorus released from the sediment becomes available only after the water column destabilizes or turns over. However, internal loading is generally higher under anoxic than under oxic conditions (these conditions tend to persist in the deeper areas of lakes) due to the reduction of iron (and to a smaller extent manganese) and subsequent release of phosphorus into the water column.

In the past, estimates for internal loading were based on mass balance calculations or laboratory release experiments. Current research (Pilgrim et al. 2006) has shown that internal loading rate can be estimated by analyzing the concentration of phosphorus in the sediment. However, there are several types of phosphorus in sediment. An important type is called "**mobile phosphorus.**" Mobile phosphorus includes phosphorus that resides in water that exists between the grains of material that make up sediment, and phosphorus that is stuck to iron. Another type of phosphorus is called **"organically bound phosphorus."** This phosphorus type can also become mobile phosphorus as it decomposes. Mobile phosphorus is considered the pool of phosphorus that contributes directly to internal phosphorus loading.

Lake Osakis Sediment

In order to accurately determine internal phosphorus loading in a lake, it is important to properly characterize mobile phosphorus in the sediment of a lake both across the lake and within the sediment. Therefore, multiple sediment cores were collected from the lake to better define the spatial distribution of mobile phosphorus in the sediment (Figure 9).

Figure 9. Photos of sediment sampling on Lake Osakis, 2006.

Sediment cores were collected from 13 points across Lake Osakis to determine the distribution of mobile phosphorus across the lake. Using a gravity sediment coring device, sediment cores were collected from the deep holes as well as representative shallower areas in the lake. Sediment cores were sliced into 2-cm increments down to 4 cm and then in 4-cm increments down to 20 cm. Data from the sediment analysis is available in Appendix A and sample locations are indicated in Figure10.

Surface concentration (upper 2 cm) of mobile phosphorus ranged from 0.03 mg/g (Core 1) to 0.37 mg/g (Core 9) across the lake (Table 1). Mobile phosphorus concentrations generally were highest in the deeper areas of the lake (i.e., Cores 2, 6, 10, 11, and 12). This level of phosphorus was near the lower end when compared to a number of lakes in the Twin Cities and Wisconsin (Huser and Pilgrim 2006). For example, mobile phosphorus concentrations in seven lakes listed below (Table 1) range from 0.25 to 3.42 mg/g in the top 5 cm of sediment.

Table 1. Mobile phosphorus concentrations (mg/g) in surficial sediment from Lake Osakis and other selected lakes.

	Lake Osakis							
Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5	Core 6	Core 7	Core 8
(0-2)	0.03	0.28	0.14	0.09	0.13	0.26	0.20	0.11
(2-4)	0.03	0.19	0.13	0.04	0.15	0.24	0.13	0.07
(4-6)	0.05	0.15	0.14	0.04	0.18	0.31	0.19	0.05
	Core 9	Core 10	Core 11	Core 12	Core 13			
(0-2)	0.37	0.26	0.26	0.30	0.01			
(2-4)	0.20	0.17	0.21	0.22				
(4-6)	0.17	0.16	0.12	0.18				

Depth (cm)	Cedar	Isles	Crystal	Langdon	Long	Susan	Wappogasset	
(0-1)	0.64	0.39	0.59	0.26	0.43	1.44	1.80	0.86
(1-2)	0.70	0.52	0.83	0.28	0.37	3.42	2.41	0.78
(2-3)	0.39	0.85	0.88	0.26	0.36	2.14	1.58	0.60
(3-4)	0.23	0.96	0.70	0.26	0.39	1.58	1.57	0.57
(4-5)	0.20	0.64	0.59	0.25	0.41	1.09	1.61	0.39

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Figure 10
Sediment Sampling Locations

Excess mobile phosphorus in the sediment was found at all sampling locations (Cores 1-12). Mobile phosphorus is considered to be in excess when the concentration near the surface is higher than that found in deeper layers, which are used to estimate the background level of mobile phosphorus. Phosphorus bound to organic material was also elevated in the surface sediments, similar to mobile phosphorus (Appendix A). Organic phosphorus is a concern because it can degrade over time, and contribute to the mobile phosphorus pool in the sediment. Phosphorus bound to organic material in the sediment ranged from 0.003 mg/g in the shallow zone on the eastern side (Core 13) to 0.75 mg/g at the deep hole in the middle of the lake (Core 6).

Internal Phosphorus Loading

By converting the concentrations of sediment mobile phosphorus into mass (taking into account sediment density and water content), it was possible to estimate internal phosphorus loading rate at each sampling point. This was conducted using a relationship developed between internal phosphorus loading rate and sediment mobile phosphorus in 17 Minnesota lakes (Equation 1).

The mass of mobile phosphorus in sediment was highest at the deep hole in the middle of the lake (0.23 $g/m^2/cm$) and lowest at the southern most sampling location (0.05 $g/m^2/cm$). Using the data collected from all 13 cores, a model was developed to determine mobile phosphorus distribution across the lake (Figure 11). As the map shows, mobile phosphorus generally was higher in the deepest areas of the lake.

Equation 1. The relationship between internal phosphorus loading rate and mobile phosphorus in the sediment (Pilgrim. et al. 2006).

$$\text{Internal P release rate } (mg/m^2/d) = 15.1*(\text{mobile P } (g/m^2/cm)) - 0.7$$

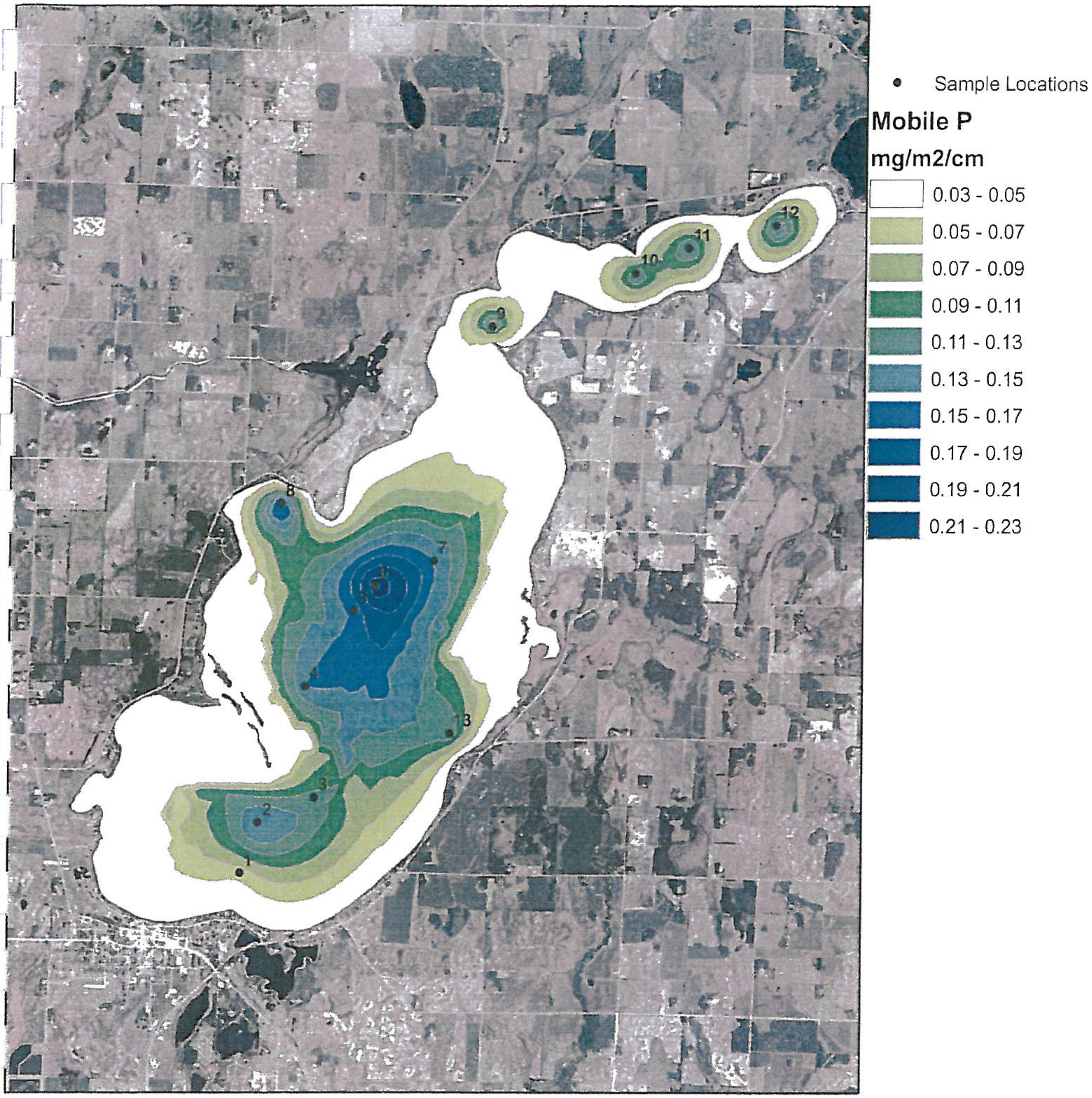

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Figure 11
Mobile Phosphorus
Concentration in
Lake Osakis

Internal loading rates estimated using sediment mobile P content ranged from 0.06 mg/m^2/d to 2.8 mg/m^2/d. Using the anoxic area determined from DO data collected in 2005 (Figure 1), the average internal loading rate within the anoxic area was 0.75 mg/m^2/d. If we estimate that anoxic conditions exist across the lake for an average of 60 days, the mass of phosphorus input to the water column from the sediment is approximately 360 kg during the summer months. Because DO data was limited and a complete mass balance has not been determined for the lake, this should be considered as a preliminary estimate.

Bottom Water Total Phosphorus

Although data are limited with regards to TP near the bottom of Lake Osakis, results indicate that internal load is occurring. TP concentrations as high as 670 µg/L (0.67 mg/L) have been detected in the lake bottom waters (Figure 12). This would be considered in the high range when compared to other lakes in the Twin Cities area (Table 2). More observations are needed, however, to more accurately quantify phosphorus loading from the change in the concentration of phosphorus in the bottom waters of Lake Osakis.

Figure 12. Total Phosphorus in the bottom waters of Lake Osakis.

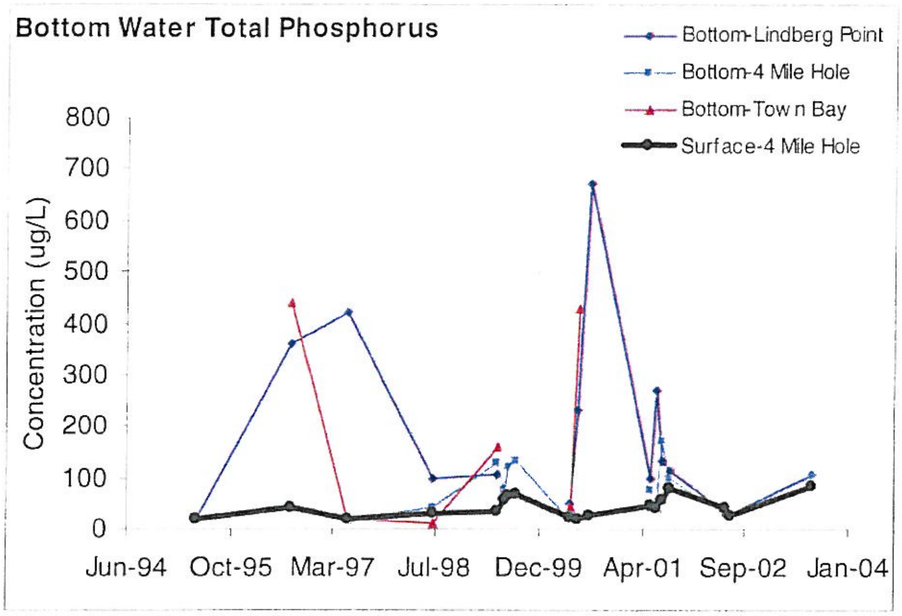


Table 2. Maximum total phosphorus detected above the sediment surface in the Minneapolis Chain of Lakes (Huser 2006).

	Calhoun	Cedar	Isles	Harriet
Max Hypolimnetic TP (ug/L)	432	466	520	556

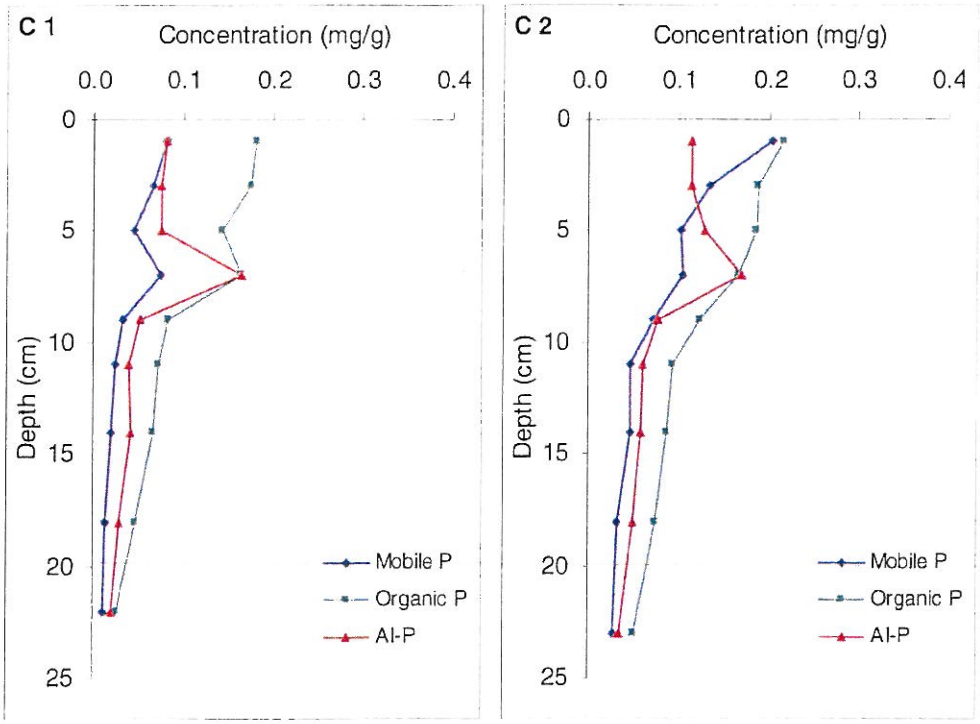
Clifford and Faille

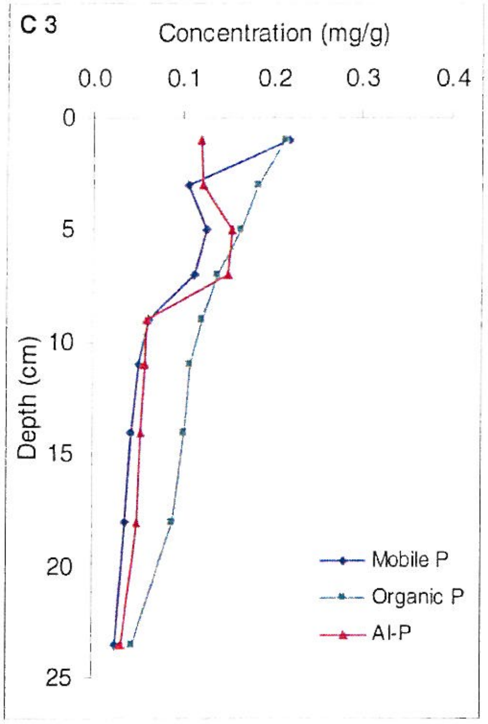
Sediments were collected from Clifford and Faille to assess the fate of alum that was applied to these lakes to control internal loading. Three cores were collected from each lake and phosphorus fractions were determined by laboratory analysis. Mobile phosphorus and aluminum bound phosphorus (which is formed as a result of the alum treatment, and hence acts as a tracer for the location of the alum in sediment) were analyzed to determine the location of the alum that was applied, the inferred outcome of the alum treatment, and whether internal phosphorus loading persists in these lakes. Data are contained in Appendix B.

Clifford

Mobile, organic and aluminum bound phosphorus (Al-P) concentrations are shown in Figure 13. Al-P was elevated in the upper 10 cm, clearly the result of the alum application, peaking at approximately 7 cm sediment depth in all three cores. An average of 1.25 g/m^2 of mobile P was converted to Al-P due to alum treatment and 933 kg (2053 pounds) of phosphorus were bound by aluminum throughout the lake. Mobile phosphorus concentrations were between 0.082 mg/g and 0.21 mg/g in the sediment corresponding to estimated internal loading rates of 1.1 to 2.5 mg/m^2/d, or an average loading rate of 2 mg/m^2/d. Organic bound phosphorus was also elevated in the upper sediment indicating it will contribute to the mobile phosphorus pool after degradation.

Figure 13. Sediment phosphorus fractions in Clifford.

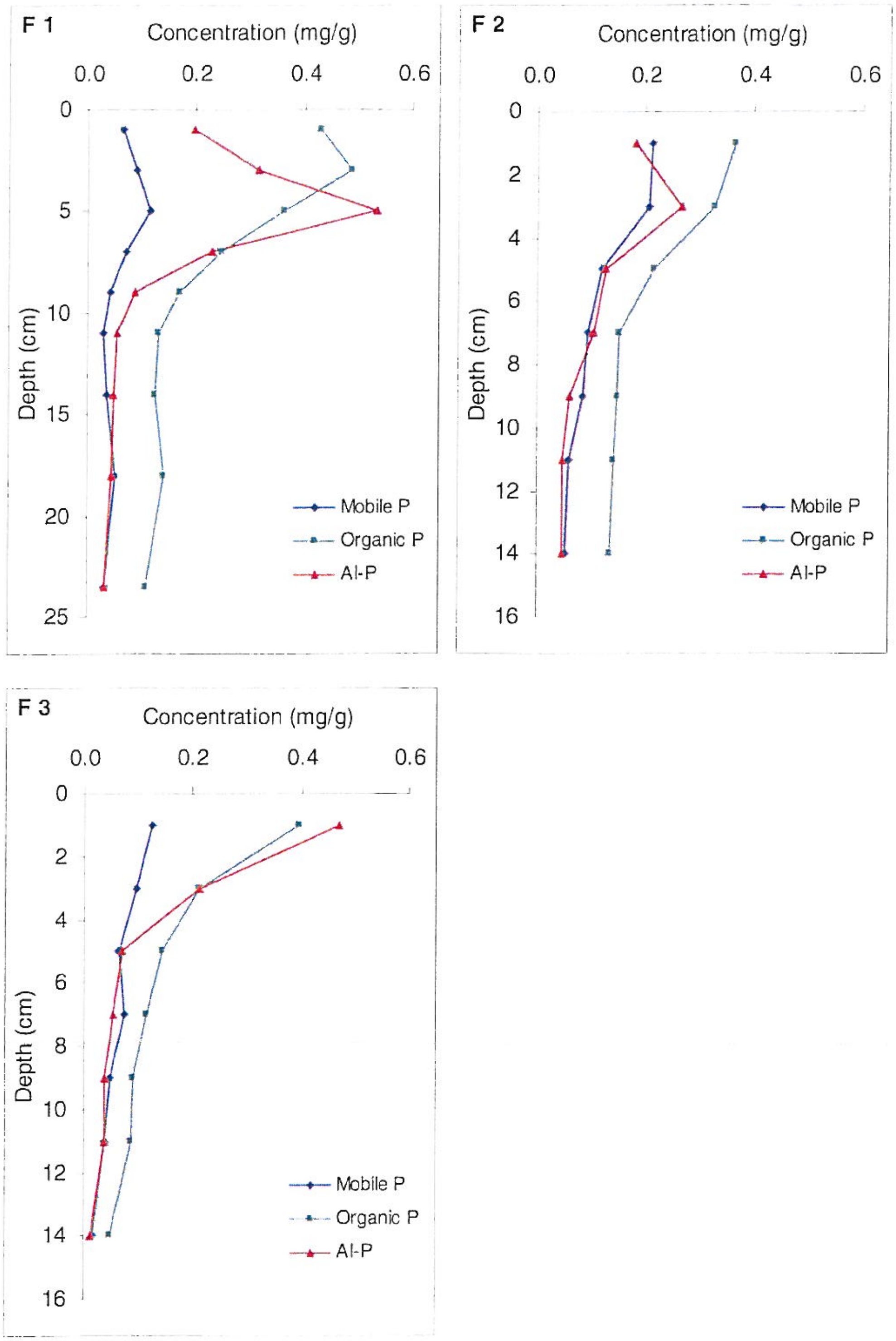




Faille

Mobile phosphorus concentrations were generally lower in Faille when compared to Clifford ranging from 0.065 to 0.213 mg/g (Figure 14). Internal loading rates were also lower, ranging from 0.39 to 1.25 $mg/m^2/d$ and averaged 0.71 $mg/m^2/d$ across the lake. An average of 1.3 g/m^2 of mobile phosphorus were converted to Al-P due to alum treatment binding 394 kg (868 pounds) of phosphorus in the lake. Similar to Osakis and Clifford, Faille sediment contained elevated concentrations of organic phosphorus near the sediment surface.

Figure 14. Sediment phosphorus fractions in Faille Lake.



Summary and Conclusions

Based on the water quality and sediment data collected from Lakes Osakis, Clifford and Faille, a number of conclusions can be drawn with regards to water quality and internal loading in the lake.

Osakis

- Total phosphorus levels in the bottom waters of Lake Osakis indicate that internal phosphorus loading from the sediments in occurring.
- Total phosphorus increases in the surface waters (where algae can use it) of Lake Osakis throughout the summer in a steady and consistent manner, suggesting that internal phosphorus loading is having an affect on phosphorus levels in the surface waters of Lake Osakis.
- From the sediment data, it is estimated that internal phosphorus loading from the sediment is contributing approximately 360 kg of phosphorus per year to the lake water column. However, it is uncertain how much of this phosphorus is transported from the bottom of the lake to the surface where it can be used for algal growth. The use of a water quality model is necessary to quantify how much of the phosphorus that is released from the sediment actually reaches the surface waters.

Clifford and Faille

- From the sediment data that was collected, it can be concluded that the alum treatment in Clifford and Faille Lake successfully bound phosphorus in the sediments and the alum is still present and active in the sediments.
- The alum treatment inactivated approximately 2,053 lbs and 868 lbs of mobile phosphorus in Clifford and Faille, respectively.
- Average internal phosphorus loading rates in Clifford and Faille have been lowered significantly. Based upon the remaining mobile phosphorus levels in the

sediment it is estimated that release rates average 2.0 mg/m2/d for Lake Clifford and 0.8 mg/m2/d for Faille Lake.

Control of internal phosphorus loading

Even though the average mobile phosphorus in the sediment of Lake Osakis was near the lower end of other lakes sampled for mobile phosphorus, the excess levels of phosphorus detected in the surface sediment indicate that restoration attempts aimed at limiting internal loading are a viable option for reducing phosphorus levels in the lake surface water. Limited data on bottom water TP data also indicate that internal phosphorus loading affects the overall phosphorus concentration in the lake. The effect of limiting internal phosphorus loading from the sediment will depend on the magnitude of other phosphorus sources to the lake in comparison to internal loading as well as water residence time. To evaluate the potential outcome of controlling internal loading, it may be worthwhile to build a lake water quality model. Other phosphorus sources to the lake may include other internal sources (i.e. macrophytes or benthiverous fish) and external inputs. If internal loading is substantial in comparison to other sources of phosphorus, internal phosphorus load reduction will improve water quality in Lake Osakis.

Recommendations

To accurately determine the extent that internal loading is affecting the concentration of total phosphorus in the surface waters of Lake Osakis, completion of a one-year comprehensive diagnostic study is recommended. This study would involve the following:

- Sampling of all inlets and outlets for Lake Osakis during one year for total phosphorus, temperature, dissolved oxygen, and flow.
- Sampling at the existing in-lake locations at Lake Osakis from the surface to the bottom in approximately 1 to 3 meter increments (see Table 3). Parameters that should be measured include total and soluble reactive phosphorus (3-meter

increments), dissolve oxygen (1 meter increment), and temperature (1 meter increment). Sampling should occur immediately after ice-out in the spring through October.

- Macrophytes, such as Curlyleaf Pondweed can contribute to internal phosphorus loading during the summer months. Therefore, macrophyte surveys could be conducted in June and August to assess the impact that macrophytes have on the phosphorus load to Lake Osakis
- Use of a water quality model to determine the extent to which internal phosphorus loading affects phosphorus levels in the surface of Lake Osakis. This model would make use of the sediment data collected in this study, and water and plant data collected as recommended above. Once the model is calibrated; it could be used to estimate the effect of controlling internal on phosphorus levels in the surface of Lake Osakis.

Table 3. Proposed sampling depths for total phosphorus at 4 Mile Hole and Lindberg Point.

Depth (m)	4 Mile Hole TP	Lindberg Point TP
0 (surface)	X	X
1		
2		
3	X	X
4		
5		
6	X	X
7		
8		
9	X	X
10		
11		
12	X	X
13		
14		
15	X	X
16		
17		
18	X	X

References

Carlson, R. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22: 361-369.

Huser, B.J. and K.M. Pilgrim. 2006. Mobile phosphorus concentrations in MN lakes. Unpublished data.

Huser, B.J. 2005. Phosphorus sorption by sediments in eutrophic and acidic lakes. PhD Thesis, University of MN, Minneapolis, MN.

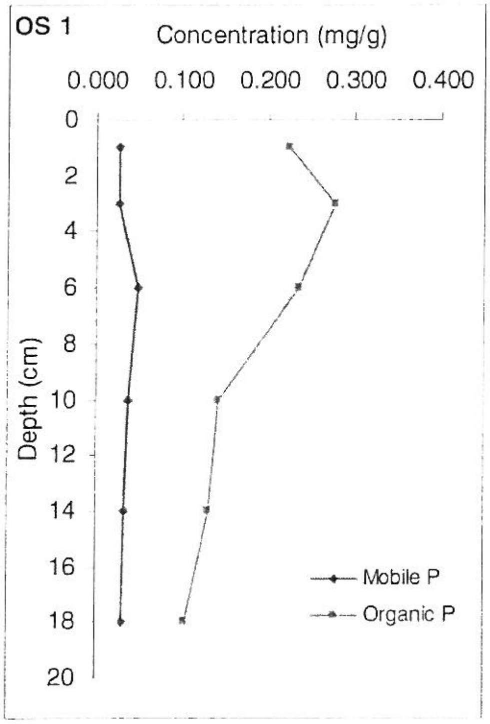
Pilgrim K.M., B.J. Huser and P.L. Brezonik. 2006. A method for comparative evaluation of whole-lake and inflow alum treatment. In review, Water Research.

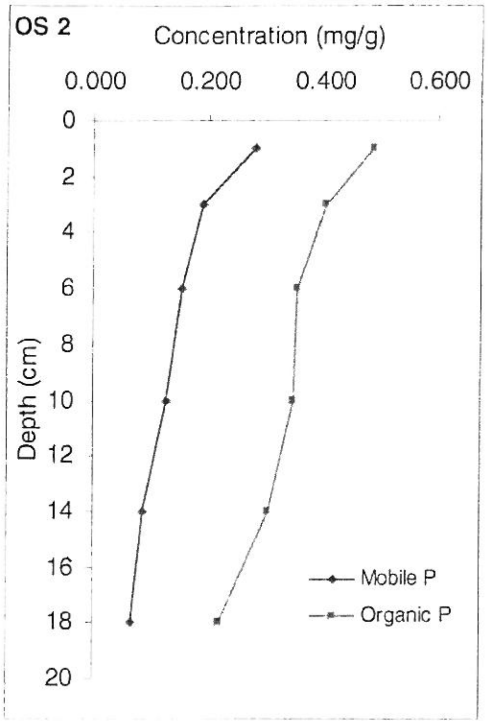
Appendix A

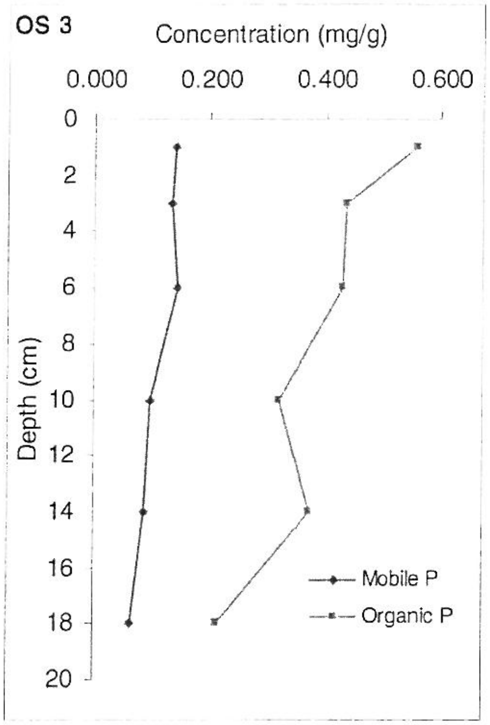
Sediment data for Lake Osakis, Clifford, and Faille

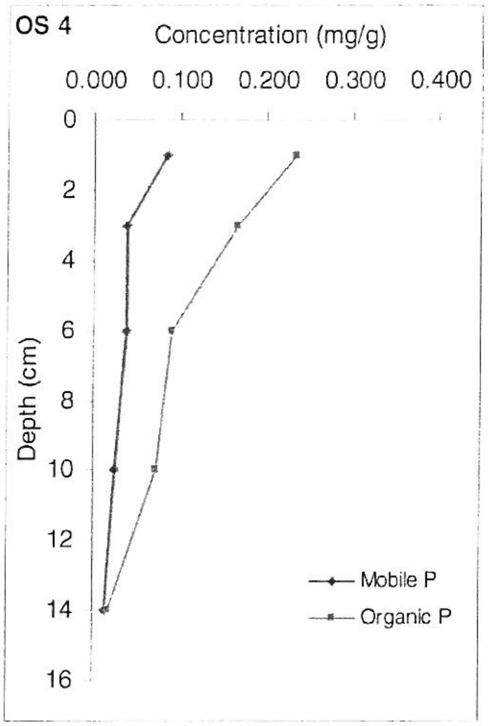
Appendix A

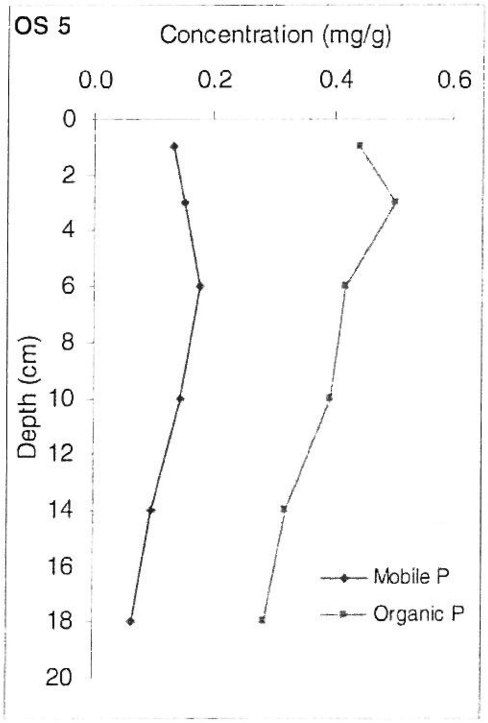
Water Quality Data
Sediment Data
Lake Osakis Mobile P and Organic P Charts

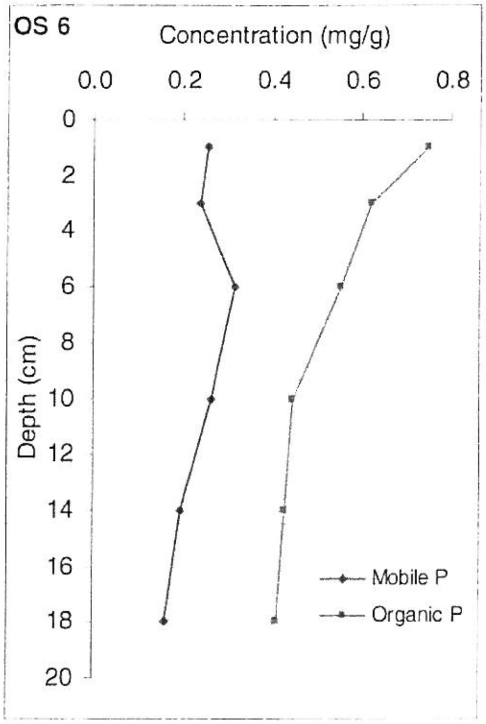


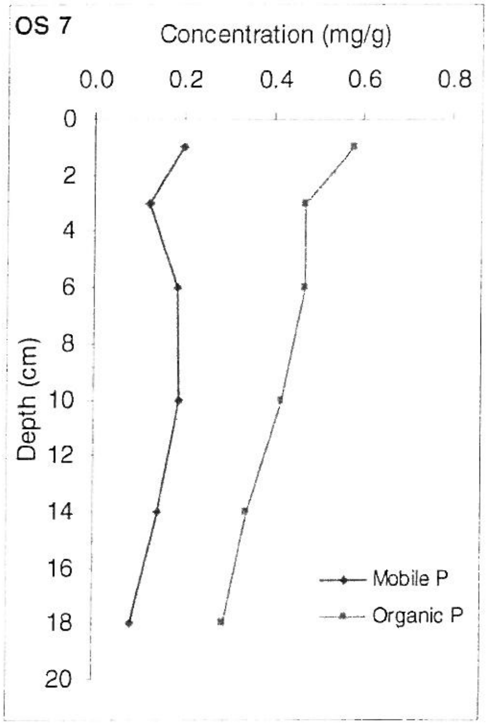


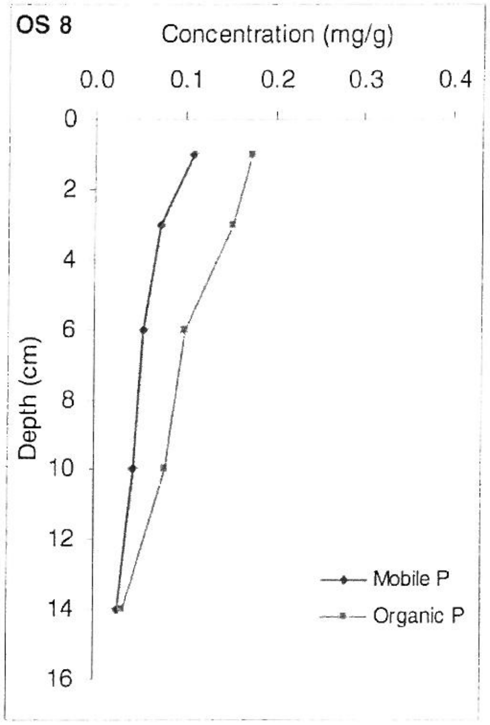

OS 3
Concentration (mg/g)
0.000
0.200
0.400
0.600
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
Mobile P
Organic P

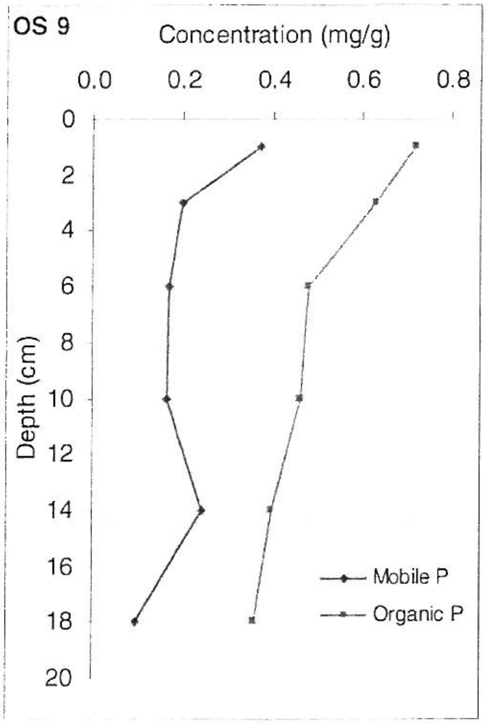

OS 4
Concentration (mg/g)
0.000
0.100
0.200
0.300
0.400
Depth (cm)
0
2
4
6
8
10
12
14
16
Mobile P
Organic P

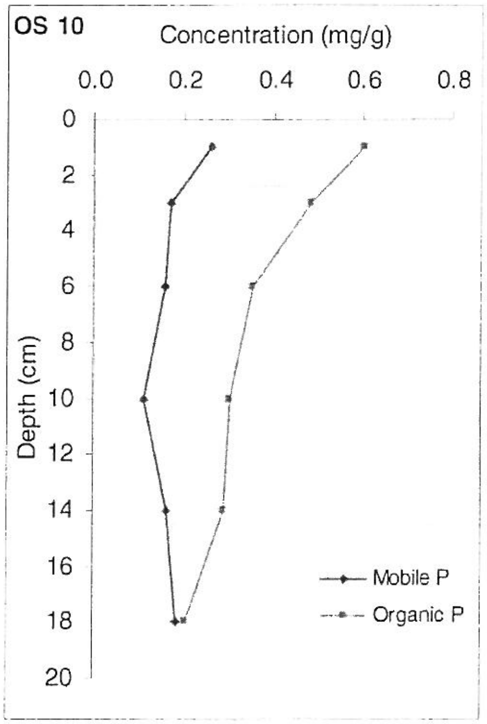

OS 5
Concentration (mg/g)
0.0
0.2
0.4
0.6
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
Mobile P
Organic P

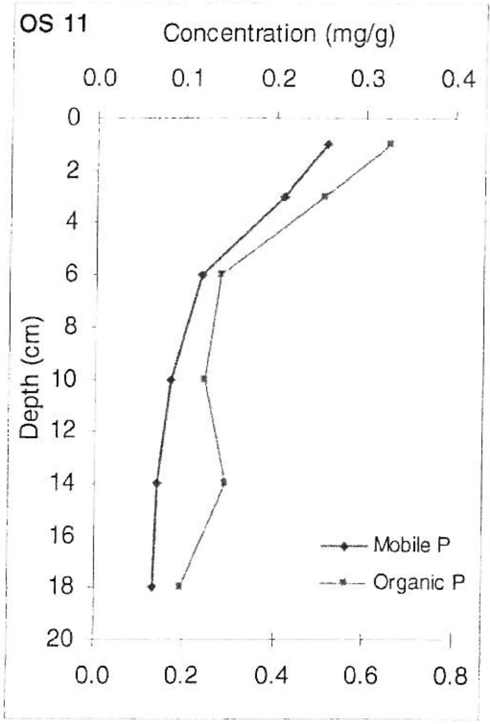

OS 6
Concentration (mg/g)
0.0
0.2
0.4
0.6
0.8
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
Mobile P
Organic P

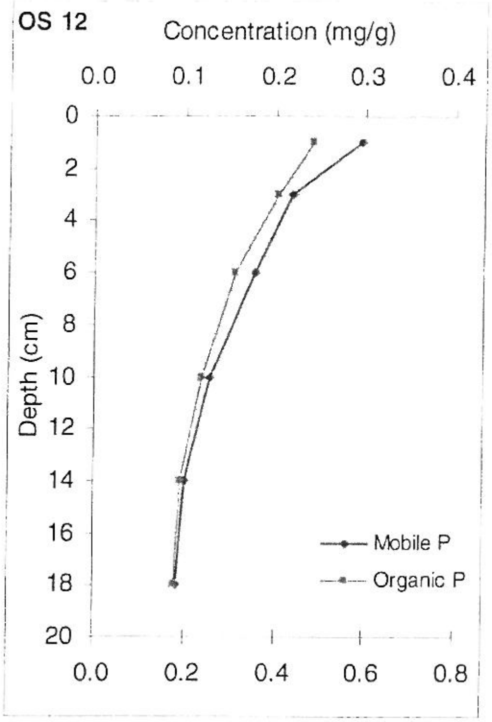

OS 7
Concentration (mg/g)
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
12
14
16
18
20
Depth (cm)
Mobile P
Organic P


OS 8
Concentration (mg/g)
0.0
0.1
0.2
0.3
0.4
0
2
4
6
8
10
12
14
16
Depth (cm)
Mobile P
Organic P


OS 9
Concentration (mg/g)
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
12
14
16
18
20
Depth (cm)
Mobile P
Organic P


OS 10
Concentration (mg/g)
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
12
14
16
18
20
Depth (cm)
Mobile P
Organic P


OS 11
Concentration (mg/g)
0.0
0.1
0.2
0.3
0.4
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
0.0
0.2
0.4
0.6
0.8
Mobile P
Organic P


OS 12
Concentration (mg/g)
0.0
0.1
0.2
0.3
0.4
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
0.0
0.2
0.4
0.6
0.8
Mobile P
Organic P

Lake Osakis Sediment Data

Sample Location	Depth (cm)	Percent Water	Organic Content (%)	Density (g/cm^3)	Mobile P (mg/g)	Organic P (mg/g)	Mobile P (ug/cm^3)
OS 1	1	89.2	18.0	1.06	0.03	0.22	3.0
	3	88.9	20.4	1.06	0.03	0.28	3.0
	6	87.8	19.1	1.06	0.05	0.24	6.4
	10	85.3	17.3	1.08	0.04	0.14	6.0
	14	82.8	17.9	1.10	0.03	0.13	6.4
	18	80.3	15.5	1.11	0.03	0.10	6.8
OS 2	1	93.1	27.1	1.03	0.28	0.49	19.7
	3	92.1	27.9	1.04	0.19	0.40	15.7
	6	91.4	27.8	1.04	0.15	0.35	13.6
	10	90.6	27.1	1.04	0.13	0.35	12.4
	14	90.1	27.3	1.05	0.09	0.30	9.2
	18	88.7	26.6	1.05	0.07	0.22	8.1
OS 3	1	93.5	26.6	1.03	0.14	0.56	9.3
	3	92.3	28.2	1.04	0.13	0.44	10.6
	6	91.3	28.1	1.04	0.14	0.43	13.1
	10	90.1	26.6	1.05	0.10	0.32	10.1
	14	90.5	27.7	1.04	0.09	0.37	8.6
	18	88.1	24.9	1.06	0.06	0.21	7.9
OS 4	1	86.5	13.1	1.08	0.09	0.23	12.4
	3	70.5	13.0	1.19	0.04	0.17	13.4
	6	67.3	6.7	1.23	0.04	0.09	15.1
	10	51.8	6.0	1.39	0.02	0.07	15.7
	14	34.5	3.0	1.64	0.01	0.02	14.7
OS 5	1	92.8	27.8	1.03	0.13	0.44	9.8
	3	91.8	28.7	1.04	0.15	0.50	12.8
	6	90.5	28.7	1.04	0.18	0.42	17.6
	10	89.7	28.1	1.05	0.15	0.39	15.7
	14	89.4	27.5	1.05	0.10	0.32	10.8
	18	88.3	26.7	1.06	0.07	0.29	8.0
OS 6	1	93.0	25.9	1.03	0.26	0.75	18.7
	3	92.1	28.9	1.04	0.24	0.62	19.6
	6	91.2	29.0	1.04	0.31	0.55	28.8
	10	90.6	28.6	1.04	0.26	0.45	25.8
	14	90.0	28.3	1.05	0.20	0.43	20.7
	18	89.5	28.3	1.05	0.16	0.41	17.7
OS 7	1	94.8	26.7	1.02	0.20	0.58	10.7
	3	92.5	27.6	1.03	0.13	0.47	9.6
	6	91.7	27.9	1.04	0.19	0.47	16.3
	10	90.9	28.0	1.04	0.19	0.42	18.1
	14	90.0	27.1	1.05	0.15	0.34	15.4
	18	89.2	25.9	1.05	0.08	0.29	9.6
OS 8	1	79.5	13.8	1.12	0.11	0.18	25.2
	3	77.2	14.5	1.14	0.07	0.15	18.9
	6	73.5	12.6	1.17	0.05	0.10	16.7
	10	67.6	9.8	1.22	0.04	0.08	16.8
	14	52.3	7.7	1.37	0.03	0.03	16.8

Sample Location	Depth (cm)	Percent Water	Organic Content (%)	Density (g/cm^3)	Mobile P (mg/g)	Organic P (mg/g)	Mobile P (ug/cm^3)
OS 9	1	95.0	25.7	1.02	0.37	0.72	19.1
	3	94.0	27.1	1.03	0.20	0.63	12.3
	6	93.0	25.8	1.03	0.17	0.48	12.5
	10	92.6	25.8	1.03	0.17	0.46	12.8
	14	92.0	25.6	1.04	0.24	0.40	20.2
	18	90.7	25.3	1.04	0.10	0.36	9.6
OS 10	1	94.7	25.3	1.02	0.26	0.60	14.1
	3	92.8	24.3	1.03	0.17	0.48	12.8
	6	90.9	23.7	1.04	0.16	0.36	14.9
	10	90.0	20.9	1.05	0.11	0.30	11.5
	14	89.4	19.4	1.06	0.16	0.29	18.1
	18	87.9	0.6	1.08	0.18	0.21	23.9
OS 11	1	93.6	26.3	1.03	0.26	0.66	16.9
	3	92.1	25.3	1.04	0.21	0.51	17.3
	6	91.1	24.0	1.04	0.12	0.28	11.1
	10	90.7	25.8	1.04	0.09	0.25	8.3
	14	90.2	25.3	1.05	0.07	0.30	7.3
	18	89.5	23.9	1.05	0.07	0.20	7.4
OS 12	1	93.8	30.6	1.03	0.30	0.49	18.8
	3	93.0	30.9	1.03	0.22	0.41	15.8
	6	92.1	30.8	1.03	0.18	0.31	14.5
	10	90.2	28.6	1.04	0.13	0.24	13.0
	14	90.1	26.9	1.05	0.10	0.19	10.4
	18	89.3	33.7	1.05	0.09	0.18	10.4
OS 13	2	23.4	2.7	1.85	0.01	0.003	12.1

Clifford Sediment Fractionation Data

Sample Location	Depth (cm)	Percent Water	Organic Content (%)	Density (g/cm^3)	Mobile P (mg/g)	Al-P (mg/g)	Organic P (mg/g)	Mobile P (ug/cm^3)
C 1	1	86.8	28.3	1.06	0.08	0.08	0.18	11.4
	3	83.3	78.2	1.02	0.07	0.07	0.17	11.2
	5	81.4	27.7	1.09	0.04	0.08	0.14	9.0
	7	80.5	25.6	1.10	0.07	0.16	0.17	15.9
	9	74.2	24.7	1.14	0.03	0.05	0.08	9.5
	11	76.2	30.7	1.11	0.02	0.04	0.07	6.3
	14	76.1	32.9	1.11	0.02	0.04	0.07	4.9
	18	72.0	30.9	1.14	0.01	0.03	0.05	4.4
	22	73.4	35.7	1.12	0.01	0.02	0.03	2.9
C 2	1	87.5	28.2	1.06	0.20	0.11	0.22	26.8
	3	85.0	26.8	1.07	0.14	0.11	0.19	21.7
	5	84.4	26.4	1.08	0.10	0.13	0.19	17.2
	7	83.4	27.5	1.08	0.10	0.17	0.17	18.5
	9	82.4	28.4	1.08	0.07	0.08	0.13	13.7
	11	81.6	30.6	1.09	0.05	0.06	0.09	9.6
	14	79.7	31.8	1.09	0.05	0.06	0.09	10.3
	18	77.6	32.0	1.10	0.03	0.05	0.08	8.1
	23	74.5	34.4	1.11	0.03	0.03	0.05	7.8
C 3	1	89.5	27.8	1.05	0.22	0.12	0.21	24.0
	3	86.1	25.3	1.07	0.11	0.12	0.18	15.9
	5	84.3	25.2	1.08	0.13	0.15	0.16	21.3
	7	83.3	29.3	1.08	0.11	0.15	0.14	20.3
	9	82.3	31.2	1.08	0.06	0.06	0.12	11.7
	11	81.3	32.2	1.08	0.05	0.06	0.11	10.2
	14	79.8	30.9	1.09	0.04	0.05	0.10	9.5

Faille Sediment Phosphorus Fraction Data

Sample Location	Depth (cm)	Percent Water	Organic Content (%)	Density (g/cm^3)	Mobile P (mg/g)	Al-P (mg/g)	Organic P (mg/g)	Mobile P (ug/cm^3)
F 1	1	92.9	33.3	1.03	0.06	0.20	0.43	4.7
	3	93.9	34.3	1.03	0.09	0.31	0.49	5.6
	5	90.7	32.0	1.04	0.12	0.53	0.36	11.2
	7	90.2	34.9	1.04	0.07	0.23	0.25	7.3
	9	89.3	38.1	1.04	0.04	0.09	0.17	4.5
	11	87.2	39.2	1.05	0.03	0.05	0.13	4.1
	14	87.7	37.6	1.05	0.04	0.05	0.12	4.5
	18	88.8	35.1	1.05	0.05	0.04	0.14	5.9
	23.5	85.3	39.2	1.06	0.03	0.03	0.11	5.2
F 2	1	93.0	37.0	1.03	0.21	0.18	0.37	15.3
	3	91.9	34.8	1.03	0.21	0.27	0.33	17.2
	5	91.4	34.5	1.04	0.12	0.12	0.22	10.7
	7	91.1	35.1	1.04	0.09	0.10	0.15	8.6
	9	90.6	36.0	1.04	0.08	0.06	0.15	8.0
	11	89.6	34.4	1.04	0.06	0.05	0.14	6.2
	14	89.7	34.3	1.04	0.05	0.05	0.13	5.5
F 3	1	93.2	30.9	1.03	0.13	0.47	0.40	8.7
	3	91.4	31.1	1.04	0.10	0.21	0.21	8.6
	5	90.4	30.5	1.04	0.06	0.07	0.14	6.3
	7	89.2	30.3	1.05	0.07	0.06	0.12	8.2
	9	85.4	29.3	1.07	0.05	0.04	0.09	7.5
	11	81.9	29.8	1.08	0.04	0.04	0.09	7.5
	14	72.1	37.0	1.12	0.02	0.01	0.05	4.7

Appendix H

BATHTUB Model Inputs

Smith Lake and Lake Osakis

(see Section 9.2 for Faille Lake
BATHTUB model from 2023 revision)

Average Loading Summary for Smith Lake

Inflow from Drainage Areas

Water Budgets					**Phosphorus Loading**		
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Watershed Total			4,412	190	1.0	2,282
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*0*	*0*	*4,412*	*190.1*		*2,281.7*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	1606400	2948214.301					
2							
3							
4							
5							
	Summation	*2,948,214*	*0*				*211.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1				--	-	1.0	211
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*211*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	550	29.0	29.0	--	0.24	1.0	131.6
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
550	0.0		0.00	0	1.0	0

Internal

Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
[acre]	[days]			[mg/m^2-day]	[--]	[lb/yr]
550	0.0			0.00	1.0	--
	Net Discharge [ac-ft/yr] =		**4,412**	**Net Load [lb/yr] =**		**2,835**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Average Lake Response Modeling for Smith Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.31	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,835	[lb/yr]
		Q (lake outflow) =	4,414	[ac-ft/yr]
		V (modeled lake volume) =	7,931	[ac-ft]
		T = V/Q =	1.80	[yr]
		P_i = W/Q =	236	[ug/l]
Model Predicted In-Lake [TP]			**51.7**	**[ug/l]**
Observed In-Lake [TP]			**51.7**	**[ug/l]**

TMDL Loading Summary for Smith Lake

Water Budgets	Phosphorus Loading

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Watershed Total			4,412	147	0.78	1,768
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*0*	*0*	*4,412*	*147.3*		*1,768.3*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	1606400	2948214.301					
2							
3							
4							
5							
	Summation	*2,948,214*	*0*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1				--	-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	550	29.0	29.0	--	0.24	1.0	131.6
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
550	0.0		0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
550	0.0			0.00	1.0	--
		Net Discharge [ac-ft/yr] =	**4,412**		**Net Load [lb/yr] =**	**1,900**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

TMDL Lake Response Modeling for Smith Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.31	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,900	[lb/yr]
		Q (lake outflow) =	4,414	[ac-ft/yr]
		V (modeled lake volume) =	7,931	[ac-ft]
		T = V/Q =	1.80	[yr]
		P_i = W/Q =	158	[ug/l]
Model Predicted In-Lake [TP]			**39.9**	**[ug/l]**
Observed In-Lake [TP]			**51.7**	**[ug/l]**

Average Loading Summary for Lake Osakis

Water Budgets	**Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Watershed Total			14,870	247	1.0	10,000
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*0*	*0*	*14,870*	*247.2*		*10,000.0*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	JD2						
2	Direct						
3	Below Maple						
4							
5							
	Summation	*0*	*0*				*2,079.6*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1				13,326.8	57.4	1.0	2,080
2					-	1.0	
3					-	1.0	
	Summation			*13,327*	*57.4*		*3,383*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	6361	27.9	27.9	--	0.24	1.0	1499.0
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
6361	0.0		0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]		Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
6361			0.75	1.0	365
		Net Discharge [ac-ft/yr] = 28,197		**Net Load [lb/yr] =**	**17,326**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Average Lake Response Modeling for Lake Osakis

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.77	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	17,326	[lb/yr]
		Q (lake outflow) =	28,203	[ac-ft/yr]
		V (modeled lake volume) =	108,435	[ac-ft]
		T = V/Q =	3.84	[yr]
		P_i = W/Q =	226	[ug/l]
Model Predicted In-Lake [TP]			**55.3**	**[ug/l]**
Observed In-Lake [TP]			**55.3**	**[ug/l]**

TMDL Loading Summary for Lake Osakis

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	JD2			9,846	100	0.7	2,686
2	Direct			3,351	327.4	0.7	2,985
3	Below Maple			1,673	327.5	0.7	1,490
4				0		1.0	
5				0		1.0	
	Summation	*0*	*0*	*14,870*			*7,162.1*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1							
2							
3							
4							
5							
	Summation	*0*	*0*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Smith Lake			3,747	40.0	0.8	408
2	Faille			4,983	60.0	0.4	813
3	Little Osakis			2,654	34.0	1.0	246
4	Maple Lake			1,943	40.0	1.0	212
	Summation			*13,327*	*44.7*		*1,678*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	6361	27.9	27.9	0.00	0.24	1.0	1499.0
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
6361	0.0		0.00	0	1.0	0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	25.74	0		Oxic		1.0	0
	25.74	8.6		Anoxic	0.8	1.0	365
	Summation						365
			Net Discharge [ac-ft/yr] =	**28,197**		**Net Load [lb/yr] =**	**10,704**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

TMDL Lake Response Modeling for Lake Osakis

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.77	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	4,855	[kg/yr]
		Q (lake outflow) =	34.8	[10^6 m^3/yr]
		V (modeled lake volume) =	133.8	[10^6 m^3]
		T = V/Q =	3.84	[yr]
		P_i = W/Q =	140	[μg/l]
Model Predicted In-Lake [TP]			**40.2**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**