Crow Wing River Watershed TMDL

Quantification of the pollutant reductions needed to improve lake and stream water quality impairments due to excess phosphorus, excess bacteria, or high water temperature.

Minnesota Pollution Control Agency

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List of Acronyms

AF	Anoxic Factor
AFO	Animal Feeding Operation
BD-P	Bicarbonate Dithionite extractable Phosphorus
BOD	Biochemical Oxygen Demand
BMP	Best Management Practice
CAFO	Confined Animal Feeding Operation
CFU	Colony Forming Unit
Chl-a	Chlorophyll-a
CRP	Conservation Reserve Program
CSO	Combined Sewer Overflow
deg C	degrees Celsius
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EMC	Event Mean Concentration
EQIP	Environmental Quality Incentives Program
GIS	Geographic Information Systems
HSPF	Hydrologic Simulation Program Fortran
HUC	Hydrologic Unit Code
IBI	Index of Biological Integrity
ISTS	Individual sewage treatment systems
ITPHS	Imminent Threat to Public Health and Safety
LA	Load Allocation
MDH	Minnesota Department of Health
MN	Minnesota
MN DNR	Minnesota Department of Natural Resources
MOS	Margin Of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
MSDC	Minnesota State Demographic Center
NA	North American
NASS	National Agricultural Statistics Service
NCHF	North Central Hardwood Forests
NLCD	National Land Cover Dataset
NLF	Northern Lakes and Forests
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
P	Phosphorus
QBAA	Quaternary confined Buried Artesian Aquifer
QWTA	Quaternary unconfined Water Table Aquifer
RNR	River Nutrient Region
RR	Release Rate
SDS	State Disposal System
SSTS	Subsurface sewage treatment systems
SWCD	Soil and Water Conservation District

SWPPP	Storm Water Pollution Prevention Program
T	Temperature
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultra Violet
WLA	Waste Load Allocation
WWTF	Waste Water Treatment Facility
WWTP	Waste Water Treatment Plant

TMDL SUMMARY TABLE

USEPA/MPCA Required Elements	Summary	TMDL Section (Page #)
Location	The Crow Wing River Watershed (HUC 07010106) is a tributary to the Mississippi River located in central Minnesota.	1
303(d) Listing Information	(see table below)	1

Waterbody Name (AUID or Lake ID)	Designated Use Class	Year Listed	Target Start/ Completion	Impaired Use: Pollutant/Stressor
Blueberry (80-0034-00)	2B, 3C	2008	2010/2014	*Aquatic Recreation*: – Nutrient/ Eutrophication Biological Indicators
Eighth Crow Wing (29-0072-00)	2B, 3C	2006	2010/2014	
First Crow Wing (29-0086-00)	2B, 3C	2006	2010/2014	
Lower Twin (80-0030-00)	2B, 3C	2008	2010/2014	
Mayo (18-0408-00)	2B, 3C	*2014	2010/2014	
Portage (29-0250-00)	2B, 3C	2006	2010/2014	
Sibley (18-0404-00)	2B, 3C	*2014	2010/2014	
Partridge River (07010106-518)	2B, 3C	*2014	2010/2014	*Aquatic Recreation*: – *Escherichia coli*
Home Brook (07010106-524)	2B, 3C	*2014	2010/2014	
Swan Creek (07010106-527)	2C	*2014	2010/2014	
Cat River (07010106-544)	2C	*2014	2010/2014	
Pillager Creek (07010106-577)	2C	*2014	2010/2014	
Mayo Creek (07010106-604)	2B, 3C	*2014	2010/2014	
Unnamed Creek (07010106-684)	2B, 3C	*2014	2010/2014	
Stoney Brook (07010106-698)	1B, 2A, 3B	*2014	2010/2014	
Corey Brook (07010106-700)	1B, 2A, 3B	*2014	2010/2014	
Farnham Creek (07010106-702)	1B, 2A, 3B	*2014	2010/2014	
Swan Creek (07010106-527)	2C	*2014	2010/2014	*Aquatic Life:* – Dissolved oxygen
Straight River (07010106-558)	2C	2010	2010/2014	
Shell River (07010106-681)	2B, 3C	*2014	2010/2014	
Swan Creek (07010106-527)	2C	2014	2010/2014	*Aquatic Life:* – Macroinvertebrate Bioassessments

<table>
<tr><th>USEPA/MPCA Required Elements</th><th>Summary</th><th>TMDL Section (Page #)</th></tr>
<tr><td>Applicable Water Quality Standards/ Numeric Targets</td><td>
Class 2B Waters Lake Eutrophication Standards, MN Rule 7050.0222 Subpart 4, Northern Lakes and Forests Ecoregion (NLF) and Northern Central Hardwood Forests Ecoregion (NCHF):
<table>
<tr><th>Lake Type</th><th>TP (µg/L)</th><th>Chl-a (µg/L)</th><th>Secchi (m)</th></tr>
<tr><td>NLF – Aquatic Recreation
Lakes: Eighth Crow Wing, Mayo, Portage, Sibley</td><td>< 30</td><td>< 9</td><td>> 2.0</td></tr>
<tr><td>NCHF – Aquatic Recreation – General
Lakes: Lower Twin</td><td>< 40</td><td>< 14</td><td>> 1.4</td></tr>
<tr><td>NCHF – Aquatic Recreation – Shallow Lakes
Lakes: Blueberry, First Crow Wing</td><td>< 60</td><td>< 20</td><td>> 1.0</td></tr>
</table>
Based on clear relationships established between TP, Chl-a, and Secchi for MN lakes it is expected that by meeting the TP goal, Chl-a and Secchi will also be met (Heiskary and Wilson 2005).
Total phosphorus and heating capacity were identified as stressors to aquatic life, with an in-stream concentration goal of 100 µg TP/L and an in-stream temperature goal of 18.5 and 26.5 degrees C for the Straight and Shell Rivers, respectively.
Stream Water Quality Standards, MN Rule 7050.0222:
<table>
<tr><th>Standard</th><th>Units</th><th>Notes</th></tr>
<tr><td>E. coli</td><td>126 orgs per 100 ml</td><td>Geometric mean of ≥ 5 samples per month (April – October)</td></tr>
<tr><td>E. coli</td><td>1,260 orgs per 100 ml</td><td>< 10% of all samples per month (April – October) that individually exceed</td></tr>
</table>
</td><td>8</td></tr>
</table>

USEPA/MPCA Required Elements	Summary: Waterbody Name (AUID or Lake ID)	Loading Capacity					TMDL Section (Page #)
Loading Capacity (expressed as daily load)	**Phosphorus**	**(kg/day)**					**Page**
	Blueberry (80-0034-00)	14.766					95
	Eighth Crow Wing (29-0072-00)	1.822					96
	First Crow Wing (29-0086-00)	15.37					97
	Lower Twin (80-0030-00)	25.595					98
	Mayo (18-0408-00)	2.576					99
	Portage (29-0250-00)	0.376					100
	Sibley (18-0404-00)	4.88					101
	Phosphorus	**High**	**Moist**	**Mid**	**Dry**	**Low**	
		(kg/day)					
	Swan Creek (07010106-527)	2.45	1.37	0.90	0.60	0.36	102
	Heating capacity	**High**	**Moist**	**Mid**	**Dry**	**Low**	
		(millions kJ/day)					
	Straight River (07010106-558)	16,720	12,486	10,783	9,270	7,378	109
	Shell River (07010106-681)	127,915	83,448	63,272	48,909	25,393	110
	E. coli	**High**	**Moist**	**Mid**	**Dry**	**Low**	
		(Billion organisms/day)					
	Partridge River (07010106-518)	365.5	164.9	90.8	36.0	28.7	127
	Home Brook (07010106-524)	402.6	119.4	51.0	23.7	4.1	118
	Swan Creek (07010106-527)	150.3	84.1	55.0	37.1	22.0	121
	Cat River (07010106-544)	173.0	89.9	53.0	33.4	17.8	126
	Pillager Creek (07010106-577)	48.4	27.5	18.6	12.4	7.5	123
	Mayo Creek (07010106-604)	73.9	33.6	24.0	16.1	9.2	124
	Unnamed Creek (07010106-684)	58.3	26.9	17.0	11.6	6.5	127
	Stoney Brook (07010106-698)	141.4	68.2	50.9	35.7	19.5	127
	Corey Brook (07010106-700)	235.4	69.1	29.7	13.7	2.4	125
	Farnham Creek (07010106-702)	55.3	33.2	22.4	15.5	10.1	120

USEPA/MPCA Required Elements	Summary	TMDL Section (Page #)
Wasteload Allocations	Categorical wasteload allocations were assigned to construction and industrial stormwater. Individual wasteload allocations were assigned to WWTPs.	

Source (Permit #)	Waterbody Name (AUID or Lake ID)	Wasteload Allocation					Page
Phosphorus		(kg/day)					
Wolf Lake WWTP (MN0069205)	**Blueberry** (80-0034-00)	0.86*					95
Industrial Stormwater (MNR50000)	**Blueberry** (80-0034-00)	0.001					95
	Eighth Crow Wing (29-0072-00)	0.00014					96
	First Crow Wing (29-0086-00)	0.0011					97
	Lower Twin (80-0030-00)	0.0027					98
	Mayo (18-0408-00)	0.014					99
	Portage (29-0250-00)	0.000011					100
	Sibley (18-0404-00)	0.03					101
Construction Stormwater (MNR100001)	**Blueberry** (80-0034-00)	0.001					95
	Eighth Crow Wing (29-0072-00)	0.00014					96
	First Crow Wing (29-0086-00)	0.0011					97
	Lower Twin (80-0030-00)	0.0027					98
	Mayo (18-0408-00)	0.014					99
	Portage (29-0250-00)	0.000011					100
	Sibley (18-0404-00)	0.03					101
E. coli		**High**	**Moist**	**Mid**	**Dry**	**Low**	
		(Billion organisms/day)					
Bertha WWTP (MN 0022799)	**Partridge River** (07010106-518)	3.1	3.1	3.1	3.1	3.1	127

*Daily wasteload allocations for Minnesota facilities in the SM1 category are calculated from the 2 mg/L concentration assumption and the maximum permitted effluent flow rate of 6”/day over the area of the facility’s discharging cell(s). These controlled discharge facilities are designed to store 180 days worth of influent and to discharge during spring and fall periods of relatively high stream flow and/or low receiving water temperature. Since these facilities discharge intermittently, their daily wasteload allocations do not represent their annual wasteload allocations divided by the days in a year. Rather they reflect the permitted daily effluent loads as described above. Based on these daily allocations, the median number of days per year these facilities may discharge (annual WLA divided by daily WLA) is 27.

USEPA/MPCA Required Elements	Summary	TMDL Section (Page #)
Load Allocations	The load allocation is based on the following sources of phosphorus not requiring NPDES permit coverage, as applicable to each lake: • Watershed runoff • Loading from upstream lakes • Atmospheric deposition • Subsurface sewage treatment systems (SSTS) • Internal loading • Livestock	

Waterbody Name (AUID or Lake ID)	Load Allocation					Page
Phosphorus	(kg/day)					
Blueberry (80-0034-00)	12.507					95
Eighth Crow Wing (29-0072-00)	1.640					96
First Crow Wing (29-0086-00)	13.831					97
Lower Twin (80-0030-00)	23.031					98
Mayo (18-0408-00)	2.290					99
Portage (29-0250-00)	0.338					100
Sibley (18-0404-00)	4.332					101
Phosphorus	**High**	**Moist**	**Mid**	**Dry**	**Low**	
	(kg/day)					
Swan Creek (07010106-527)	2.21	1.24	0.81	0.54	0.32	102
Heating capacity	**High**	**Moist**	**Mid**	**Dry**	**Low**	
	(million kJ/day)					
Straight River (07010106-558)	15,048	11,237	9,705	8,343	6,640	109
Shell River (07010106-681)	115,123	75,103	56,945	44,018	22,854	110
E. coli	**High**	**Moist**	**Mid**	**Dry**	**Low**	
	(Billion organisms/day)					
Partridge River (07010106-518)	325.8	145.3	78.6	29.3	22.7	127
Home Brook (07010106-524)	362.3	107.5	45.9	21.3	3.7	118
Swan Creek (07010106-527)	135.3	75.7	49.5	33.4	19.8	121
Cat River (07010106-544)	155.7	80.9	47.7	30.1	16.0	126
Pillager Creek (07010106-577)	43.6	24.7	16.7	11.2	6.7	123
Mayo Creek (07010106-604)	66.5	30.2	21.6	15.5	8.3	124
Unnamed creek (07010106-684)	52.5	24.2	9.0	10.4	5.8	127
Stoney Brook (07010106-698)	127.3	61.4	45.8	32.1	17.5	127
Corey Brook (07010106-700)	211.9	62.2	26.7	12.3	2.2	125
Farnham Creek (07010106-702)	49.8	29.9	20.2	13.9	9.1	120

USEPA/MPCA Required Elements	Summary	TMDL Section (Page #)
Margin of Safety	**Lakes**: An explicit 10% margin of safety (MOS) was accounted for in the TMDL for each lake. This MOS is sufficient to account for uncertainties in predicting loads to the lakes and predicting how lakes respond to changes in phosphorus loading.	91
	Streams: An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations: Since the TMDL is developed for each of five flow regimes; most of the uncertainty in flow is a result of extrapolating (area-weighting) flows from the hydrologically-nearest stream gage. The explicit MOS, in part, accounts for this. Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes. With respect to the *E. coli* TMDLs, the load duration analysis does not address bacteria re-growth in sediments, die-off, and natural background levels. The MOS helps to account for the variability associated with these conditions.	114
Seasonal Variation	**Lakes**: Critical conditions in these lakes occur in the summer, when TP concentrations peak and clarity is worst. The water quality standards are based on growing season (June – September) averages. The load reductions are designed so that the lakes will meet water quality standards over the course of the growing season.	91
	Streams: Critical conditions and seasonal variation are addressed in this TMDL through several mechanisms. The *E. coli* standard applies during the recreational period, and data was collected throughout this period. The water quality analysis conducted on these data evaluated variability in flow through the use of five flow regimes: from high flows, such as flood events, to low flows, such as baseflow. Through the use of load duration curves and monthly summary figures, *E. coli* loading was evaluated at actual flow conditions at the time of sampling (and by month), and monthly *E. coli* concentrations were evaluated against precipitation and streamflow.	115
Reasonable Assurance	Refer to Section 5 Reasonable Assurances	129
Monitoring	Refer to Section 6 Monitoring Plan	131
Implementation	Refer to Section 7 Implementation Strategy	132
Public Participation	TMDL Public Comment Period: July 14 – August 12, 2014 Refer to Section 8 Public Participation for a complete list of meetings	134

EXECUTIVE SUMMARY

The Clean Water Act (1972) requires that each State develop a plan to identify and restore any waterbody that is deemed impaired by state regulations. A Total Maximum Daily Load Study (TMDL) is required by the Environmental Pollution Control Agency (EPA) as a result of the federal Clean Water Act. A TMDL identifies the pollutant that is causing the impairment and how much of that pollutant can enter the waterbody and still meet water quality standards.

This TMDL study includes seven lakes and twelve streams located in the Crow Wing River Watershed (HUC 07010106), a tributary to the Mississippi River in central Minnesota, that are on the 2014 USEPA's 303(d) list of impaired waters.

Information from multiple sources was used to evaluate the ecological health of each waterbody:

- All available water quality data over the past ten years
- Sediment phosphorus concentrations
- Fisheries surveys
- Plant surveys
- Stream field surveys
- Stressor identification investigations
- Stakeholder input

The following pollutant sources were evaluated for each lake or stream: watershed runoff, loading from upstream waterbodies, atmospheric deposition, lake internal loading, point sources, feedlots, septic systems, and in-stream alterations. An inventory of pollutant sources was used to develop a lake response model for each impaired lake and a load duration curve model for each impaired stream. These models were then used to determine the pollutant reductions needed for the impaired waterbodies to meet water quality standards.

The findings from this TMDL study will be used to aid the selection of implementation activities as part of the Crow Wing River Watershed Restoration and Protection Strategy (WRAPS) process. The purpose of the WRAPS report is to support local working groups and jointly develop scientifically-supported restoration and protection strategies to be used for subsequent implementation planning. Following completion, the WRAPS report will be publically available on the MPCA Crow Wing River Watershed website:

http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/crow-wing-river.html#overview

1 PROJECT OVERVIEW

1.1 Purpose

This Total Maximum Daily Load (TMDL) study addresses aquatic recreation use impairments due to eutrophication (phosphorus) in 7 lakes, aquatic recreation use impairments due to *E. coli* in 10 streams, and aquatic life use impairments due to dissolved oxygen and/or biological indicators in 3 streams in the Crow Wing River Watershed in central Minnesota (Figure 1). The goal of this TMDL is to provide wasteload allocations (WLAs) and load allocations (LAs) and to quantify the pollutant reductions needed to meet the state water quality standards. These TMDLs are being established in accordance with section 303(d) of the Clean Water Act, because the State of Minnesota has determined that these lakes and streams exceed the state established standards.

The findings from this TMDL study will be used to aid the selection of implementation activities as part of the Crow Wing River Watershed Restoration and Protection Strategy (WRAPS) process. The purpose of the WRAPS report is to support local working groups and jointly develop scientifically-supported restoration and protection strategies to be used for subsequent implementation planning. Following completion, the WRAPS report will be publically available on the MPCA Crow Wing River Watershed website:
http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/crow-wing-river.html#overview

1.2 Identification of Waterbodies

Eight lakes and 12 streams within the Crow Wing River Watershed (HUC 07010106) are on the 2014 USEPA 303(d) list of impaired waters for aquatic recreation use impairments due to eutrophication, aquatic recreation use impairments due to *E. coli*, or aquatic life use impairments due to dissolved oxygen and biological indicators (Table 1; Figure 1). A TMDL for Lake Margaret was approved by the USEPA in 2010; therefore, Lake Margaret is not included in this report.

Table 1. Crow Wing River Watershed Impaired Lakes and Streams

AUID/ Lake ID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion	Affected Use: Pollutant/Stressor
80-0034-00	Blueberry Lake	3 miles N of Menagha	2B, 3C	2008	2010/2014	*Aquatic Recreation*: – Nutrient/ Eutrophication Biological Indicators (Phosphorus)
29-0072-00	Eighth Crow Wing Lake	3 miles E of Nevis	2B, 3C	2006	2010/2014	
29-0086-00	First Crow Wing Lake	5 miles W of Badoura	2B, 3C	2006	2010/2014	
80-0030-00	Lower Twin Lake	3 miles NE of Menagha	2B, 3C	2008	2010/2014	
11-0222-00	Lake Margaret	At Lake Shore (Town)	2B, 3C	2006	Approved	
18-0408-00	Mayo Lake	3 miles S of Pequot Lakes	2B, 3C	*2014	2010/2014	
29-0250-00	Portage Lake	4.5 miles NW of Park Rapids	2B, 3C	2006	2010/2014	
18-0404-00	Sibley Lake	At Pequot Lakes	2B, 3C	*2014	2010/2014	
07010106-518	Partridge River	Headwaters to Crow Wing R	2B, 3C	*2014	2010/2014	*Aquatic Recreation*: – *Escherichia coli*
07010106-524	Home Brook	Headwaters (Omen Lk) to Lk Margaret	2B, 3C	*2014	2010/2014	
07010106-527	Swan Creek	T135 R32W S2, N line to Crow Wing R	2C	*2014	2010/2014	
07010106-544	Cat River	Kitten Cr to Crow Wing R	2C	*2014	2010/2014	
07010106-577	Pillager Creek	T133 R30W S5, N line to Crow Wing R	2C	*2014	2010/2014	
07010106-604	Mayo Creek	Unnamed cr to Unnamed cr	2B, 3C	*2014	2010/2014	
07010106-684	Unnamed creek	Unnamed cr to Crow Wing R	2B, 3C	*2014	2010/2014	
07010106-698	Stoney Brook	T136 R29W S32, W line to Upper Gull L	1B, 2A, 3B	*2014	2010/2014	
07010106-700	Corey Brook	T135 T30W S16, N line to Home Bk	1B, 2A, 3B	*2014	2010/2014	
07010106-702	Farnham Creek	Unnamed ditch to T136 R32W S21, W line	1B, 2A, 3B	*2014	2010/2014	
07010106-527	Swan Creek	T135 R32W S2, N line to Crow Wing R	2C	*2014	2010/2014	*Aquatic Life:* – Dissolved oxygen
07010106-558	Straight River	Straight Lk to Fishhook R	1B, 2A, 3B	2010	2010/2014	
07010106-681	Shell River	Fishhook R to Upper Twin Lk	2B, 3C	*2014	2010/2014	
07010106-527	Swan Creek	T135 R32W S2, N line to Crow Wing R	2C	*2014	2010/2014	*Aquatic Life:* – Macroinvertebrate Bioassessments

* Proposed to be listed in 2014

1.3 Priority Ranking

MPCA's projected schedule for TMDL completions (Table 1), as indicated on the 2014 USEPA 303(d) list of impaired waters, implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to, impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

1.4 Description of the Impairments and Stressors

1.4.1 Lake Eutrophication

The lake eutrophication impairments in the Crow Wing River Watershed were characterized by phosphorus and chlorophyll-a concentrations that exceed state water quality standards and Secchi transparency depths below the state water quality standards. Excessive nutrient loads, in particular total phosphorus, lead to an increase in algae blooms and reduced transparency – both of which may significantly impair or prohibit the use of lakes for aquatic recreation.

Phosphorus lake response models were developed and TMDLs calculated for all lake eutrophication impairments.

1.4.2 Stream *E. coli*

The stream bacteria impairments in the Crow Wing River Watershed were characterized by high *E. coli* concentrations during April through October. Minnesota *E. coli* water quality standards were developed to directly protect for primary (swimming and other recreation where immersion and inadvertently ingesting water is likely) and secondary (boating and wading where the likelihood of ingesting water is much smaller) body contact during the warm months since there is very little swimming in Minnesota in the non-summer months.

E. coli load duration curves were developed and TMDLs calculated for all stream bacteria impairments.

1.4.3 Stream Dissolved Oxygen

The aquatic life impairments in the Straight River, lower Shell River, and Swan Creek were characterized by low dissolved oxygen levels. Dissolved oxygen is required for essentially all aquatic organisms to live. When dissolved oxygen drops below acceptable levels, desirable aquatic organisms, such as fish, can be killed or harmed. A stream is considered impaired if more than 10 percent of the "suitable" (taken before 9:00) May through September measurements, or more than 10 percent of the total May through September measurements, or more than 10 percent of the October through April measurements violate the standard, and there are at least three total violations.

A stressor identification was conducted as part of this TMDL study to determine the cause of low dissolved oxygen levels in the Straight River, lower Shell River, and Swan Creek. Primary stressors to low dissolved oxygen that were identified for these stream reaches are summarized in

Table 2 below. Refer to Section 14 and the Crow Wing River Watershed Stressor Identification Report (MPCA 2013b) for more detailed information.

A phosphorus load duration curve was developed and a TMDL calculated for Swan Creek. Excess phosphorus in the stream increases algae and other plant growth. When algae and plant growth reach very high levels, the decomposition of and respiration from algae and aquatic plants can consume large amounts of dissolved oxygen resulting in stream DO levels that are too low to support fish. The phosphorus loading goals for the dissolved oxygen impairment in Swan Creek also apply to the macroinvertebrate bioassessment impairment in Swan Creek, as described in more detail Section 1.4.4 below.

Because temperature cannot directly be described as a load, load duration curves were developed and TMDLs calculated by using the amount of energy in the water at a specific temperature and flows (i.e., heating load) for the impaired reaches of the Straight and Shell rivers. See Section 2.3.1.2 for more details.

Table 2. Primary stressors to low dissolved oxygen levels in the Crow Wing River Watershed impaired reaches

Impaired Stream Reach (AUID)	Primary Stressors to Dissolved Oxygen
Straight River (07010106-558)	Water temperature
Shell River (07010106-681)	Water temperature
Swan Creek (07010106-527)	Iron oxidation/ peatland-derived phosphorus Habitat alteration

1.4.4 Stream Macroinvertebrate Bioassessment

The aquatic life impairment in Swan Creek was characterized by a low IBI score for macroinvertebrates. The presence of a healthy, diverse, and reproducing aquatic community is a good indication that the aquatic life beneficial use is being supported by a lake, stream, or wetland. The aquatic community integrates the cumulative impacts of pollutants, habitat alteration, and hydrologic modification on a waterbody over time. Monitoring of the aquatic community is accomplished using an index of biological integrity (IBI) which incorporates multiple attributes of the aquatic community, called "metrics", to evaluate a complex biological systems. For further information regarding the development of stream IBIs, refer to the MPCA *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List*.

A stressor identification study was completed by MPCA (2013b) to determine the cause of low macroinvertebrate scores in Swan Creek. The following are excerpts from this report:

An overall analysis of the data strongly suggests that the biological impairments in Swan Creek are partly the result of localized human (animal husbandry related) physical alterations to the stream channel, and probably also partly due to natural factors influencing DO and iron concentrations. The majority of the Creek has very good, natural riparian condition, and a site in about the middle of the Creek's longitudinal course has the second highest habitat rating of all of the stream sites sampled in the Crow Wing River Watershed, and excellent fish and macroinvertebrate communities.

The two sites where the macroinvertebrates are impaired are reaches that currently have or historically had pastured riparian corridors. The third site is between these two sites, and has a natural riparian condition. It showed a very healthy fish and macroinvertebrate community. Cattle influence on stream channel geomorphology is evident at both of the impaired sites. Overwidening of stream channels is a common result of cattle having access to stream riparian areas and channels, and this has clearly occurred at the downstream site. As is also typical for unfenced stream channels, the upper pasture has bank erosion from animal trampling, and thus excess sediment in the stream. The MSHA metrics also substantiate the degraded habitat in these pastured reaches.

The levels of dissolved oxygen drop below the MN standard of 5.0 mg/l at several locations, particularly in July and August, which is a typical time of year for DO to be at its lowest annual levels. There are natural explanations that can account for much or all of this phenomenon. Tributaries to the Swan have significant groundwater inputs, as evidenced by their cold temperatures, orange color from iron oxide precipitation, and visual observance of many spring seeps along bank channels and within riparian meadows. Groundwater commonly has low dissolved oxygen due to numerous causes, the most obvious which is a lack of connection to the atmosphere. Chemical reactions with geological material and bacterial usage of oxygen in decomposition within certain soils also reduce oxygen levels in groundwater. All three of the Swan tributaries have very low DO. In addition to having low-DO water input from tributaries, the streams in this area have very low gradients (slow flow), and lack the rocky substrate (naturally) that form riffles in streams. The result is that the streams of this area are poor at re-aeration of their waters. So, this combination of landscape attributes join together to cause naturally-depleted stream waters. Addition of nutrients from animal waste can also lead to a reduction of DO, though nutrient water chemistry results do not suggest this is happening to a significant degree here.

Because evidence suggests that the anthropogenic impairment factors are quite local in both source and effect, and due more to physical issues, a TMDL is not the most efficient way to tackle the issues for improving biological community. As animal agriculture is the only evident stressor, and the fact that there is an *E. coli* (bacterial) impairment on this AUID, the implementation of practices to correct that impairment will likely also improve the physical condition of the stream channel and improve habitat for the macroinvertebrate community, since BMPs will likely involve keeping the animals at least somewhat more separated from the Creek than occurs currently.

Because phosphorus levels are elevated in Swan Creek and localized anthropogenic factors influencing this stream were observed during the stressor identification process, the aquatic life impairments in Swan Creek did not fulfill the MPCA criteria for natural background conditions (EPA Category 4D). Therefore, a TP TMDL was developed for this stream reach with the assumption that the best management practices (BMPs) put in place to meet the *E. coli* load reductions for the bacteria impairment (i.e., livestock exclusion) will also result in an improvement in dissolved oxygen levels and macroinvertebrate bioassessment scores. Therefore, no specific actions are recommended for TP reductions at this time but the TP loading goals developed for this stream can be used if anthropogenic influences increase on this stream in the future.

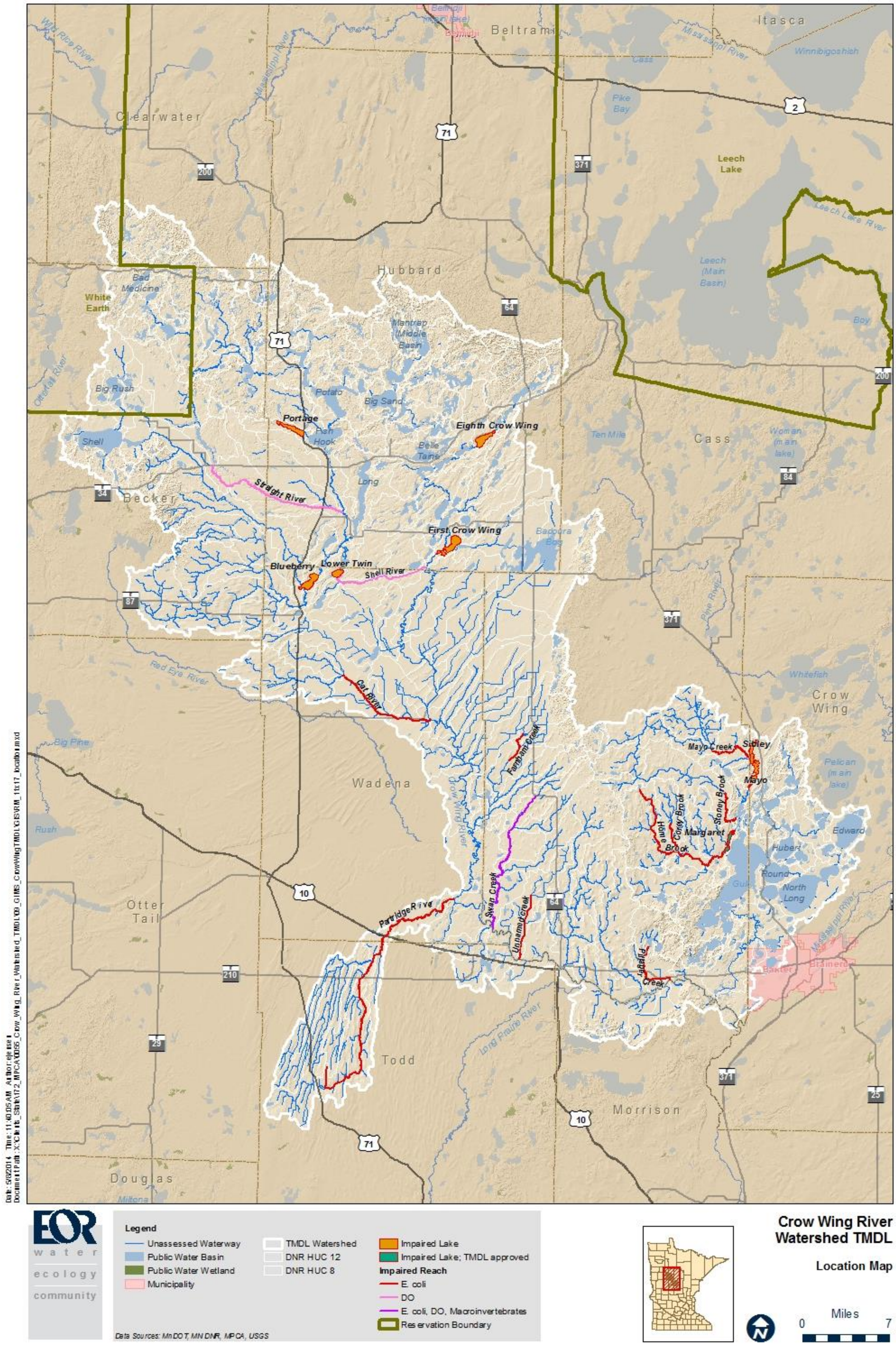


Figure 1. Crow Wing River Watershed Impaired Waters

2 APPLICABLE WATER QUALITY STANDARDS

2.1 Designated Use

Each stream reach and lake has a Designated Use Classification defined by the MPCA which defines the optimal purpose for that waterbody (see Table 1). The lakes and streams addressed by this TMDL fall into one of the following three designated use classifications:

1. 1B, 2A, 3B – drinking water use after approved disinfectant; a healthy cold water aquatic community; non-food industrial use with moderate treatment
2. 2B, 3C – a healthy warm water aquatic community; industrial cooling and materials transport without a high level of treatment
3. 2C – a healthy indigenous fish community

Class 1 waters are protected for aquatic consumption, Class 2 waters are protected for aquatic life and aquatic recreation, and Class 3 waters are protected for industrial consumption as defined by Minnesota Rules Chapter 7050.0140. The most protective of these classes is 1B, however water bodies are not currently being assessed by the MPCA for the beneficial use of domestic consumption; therefore water quality standards for the Class 1B waters are not presented here. The next most protective of these classes is 2A and 2B, for which water quality standards are provided below.

2.2 Lakes

Total phosphorus is often the limiting factor controlling primary production in freshwater lakes: as in-lake phosphorus concentrations increase, algal growth increases resulting in higher chlorophyll-a concentrations and lower water transparency. In addition to meeting phosphorus limits, chlorophyll-a and Secchi transparency depth standards must also be met. In developing the lake nutrient standards for Minnesota lakes (Minn. Rule 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson, 2005). Clear relationships were established between the causal factor total phosphorus and the response variables chlorophyll-a and Secchi transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the chlorophyll-a and Secchi standards will likewise be met. The impaired lakes within the Crow Wing River Watershed are located within the Northern Central Hardwood Forests Ecoregion or the Northern Lakes and Forests Ecoregion. The applicable water quality standards by ecoregion are listed in Table 3.

In the NCHF Ecoregion, a separate water quality standard was developed for shallow lakes which tend to have poorer water quality than deeper lakes in this ecoregion. According to the MPCA definition of shallow lakes, a lake is considered shallow if its maximum depth is less than 15 feet, or if the littoral zone (area where depth is less than 15 feet) covers at least 80% of the lake's surface area. Blueberry Lake and First Crow Wing Lake are shallow according to this definition.

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

Table 3. Lake Eutrophication Standards

Lake Type	TP (ppb)	Chl-a (ppb)	Secchi (m)
North Central Hardwood Forests: General Including: Lower Twin*	< 40	< 14	> 1.4
North Central Hardwood Forests: Shallow Lakes Including: Blueberry, First Crow Wing	< 60	< 20	> 1.0
Northern Lakes and Forests Including: Eighth Crow Wing, Mayo, Portage, Sibley	< 30	< 9	> 2.0

* Lower Twin Lake has a maximum depth of 20 feet and is at the threshold between general and shallow lake types

2.3 Streams

The Minnesota narrative water quality standard for all Class 2 waters (Rule 7050.0150 subp. 3) states that "the aquatic habitat, which includes the waters of the state and stream bed, shall not be degraded in any material manner, there shall be no material increase in undesirable slime growths or aquatic plants, including algae, nor shall there be any significant increase in harmful pesticide or other residues in the waters, sediments, and aquatic flora and fauna; the normal fishery and lower aquatic biota upon which it is dependent and the use thereof shall not be seriously impaired or endangered, the species composition shall not be altered materially, and the propagation or migration of the fish and other biota normally present shall not be prevented or hindered by the discharge of any sewage, industrial waste, or other wastes to the waters".

2.3.1 Numeric Targets

2.3.1.1 Phosphorus

Iron oxidation/ peatland-derived phosphorus and habitat alteration were identified as the key stressors to dissolved oxygen in Swan Creek through the stressor identification process. In addition, pasturing animals were observed in the stream which may be contributing to localized areas of stream trampling (habitat alteration) resulting in lost riparian shading, channel over-widening, siltation, and ultimate elevated plant growth that reduces dissolved oxygen levels at night. However, because phosphorus levels are elevated in Swan Creek and localized anthropogenic factors influencing this stream were observed during the stressor identification process, the aquatic life impairments in Swan Creek did not fulfill the MPCA criteria for natural background conditions (EPA Category 4D). Therefore, a TP TMDL was developed for this stream reach with the assumption that the best management practices (BMPs) put in place to meet the *E. coli* load reductions for the bacteria impairment (i.e., livestock exclusion) will also result in an improvement in dissolved oxygen levels and macroinvertebrate bioassessment scores. Therefore, no specific actions are recommended for TP reductions at this time but the TP loading goals developed for this stream can be used if anthropogenic influences increase on this stream in the future.

Stream eutrophication standards, and in particular phosphorus, are under development based on several studies and data collection efforts that have demonstrated significant and predictable relationships among summer nutrients, sestonic chlorophyll-a, and biochemical oxygen demand in several medium to large Minnesota rivers (Heiskary & Markus 2001, Heiskary & Markus 2003). Consistent with USEPA guidance, criteria are being developed for three "River Nutrient Regions (RNR)". The draft phosphorus standard for Central Region streams is 0.1 mg/L as a growing season (June-September) mean and will be used as the water quality target for the Swan Creek Phosphorus TMDL.

For more information, refer to the draft Minnesota Nutrient Criteria Development for Rivers report, available online:
http://www.pca.state.mn.us/index.php?option=com_k2&Itemid=131&id=3312&layout=item&view=item#draft-water-quality-standards-technical-support-documents)

2.3.1.2 Temperature

Through the dissolved oxygen stressor identification process conducted by EOR and described in Section 14, elevated stream water temperature was identified as the primary cause of low dissolved oxygen levels in the Straight and Shell Rivers. Patterns of DO in the Straight and Shell Rivers coincided strongly with seasonal variations in water temperature, with the lowest dissolved oxygen levels occurring at the warmest water temperatures during the summer months. Moreover, increased groundwater appropriations for surface crop irrigation since 1988 in the Straight River area have been linked to increased water temperatures in the Straight River according to a report by the Minnesota DNR[1].

A numeric water quality target was developed for temperature based on basic thermodynamic principles and observed relationships between dissolved oxygen saturation and water temperature in the impaired streams. The ability for water to dissolve oxygen is based on stream temperature, atmospheric pressure, and salinity with less oxygen dissolved as water temperature and salinity increase, and more oxygen dissolved as atmospheric pressure increases. These relationships were based on the following equations developed by the U.S. Geological Survey to predict the solubility of dissolved oxygen in water:

$$[DO] = DO_o \times F_S \times F_P \qquad (1)$$

$$DO_o = exp\left[-139.34411 + \frac{1.575701\times10^5}{T} - \frac{6.642308\times10^7}{T^2} + \frac{1.243800\times10^{10}}{T^3} - \frac{8.621949\times10^{11}}{T^4}\right] \qquad (2)$$

Where [*DO*] is the dissolved oxygen concentration in mg/L represented as a baseline dissolved oxygen concentration in freshwater (DO_o) multiplied by a salinity correction factor (F_S) and a pressure correction factor (F_P). T is the water temperature in Kelvin (T= t(°C) +273.15). For the

[1] Minnesota Department of Natural Resources – Division of Waters. July 2002. *Surface Water and Ground Water Interaction and Thermal Changes in the Straight River in North Central Minnesota.*

Straight and Shell rivers, which are freshwater (salinity ca. 0‰) and approximately at standard pressure (1 atm), the salinity and pressure factors are equal to 1.0.

The *dissolved oxygen saturation threshold* is the sum of the state water quality standard for dissolved oxygen (Table 4) and biochemical oxygen demand calculated from monitoring data (Table 5):

$$DO_{SAT} = DO_{STD} + BOD \qquad (3)$$

Where DO_{SAT} is the dissolved oxygen saturation threshold, DO_{STD} is the dissolved oxygen standard, and *BOD* is the in-stream biochemical oxygen demand. Monitoring data was available for biochemical oxygen demand in both the Straight and Shell rivers. Because low dissolved oxygen is a critical condition for aquatic life, the maximum monitored biochemical oxygen demand was chosen as a protective concentration for the calculation of the dissolved oxygen saturation threshold. The in-stream temperature target was set to maintain dissolved oxygen levels in the stream at or above the DO_{SAT} based on equations 1, 2, and 3 above (Table 6).

For the Straight River, the dissolved oxygen saturation threshold was set at 9.5 mg/L based on the Class 2A daily minimum dissolved oxygen standard of 7.0 mg/L plus the observed maximum BOD of 2.64 mg/L, rounded to the nearest 0.5 mg/L. The corresponding in-stream temperature target for the Straight River based on equations 1 and 2 is 18.5 °C. For the Shell River, the dissolved oxygen saturation threshold was set at 8.0 mg/L based on the Class 2B daily minimum dissolved oxygen standard of 5.0 mg/L plus the observed maximum BOD of 3.0 mg/L. The corresponding in-stream temperature target for the Shell River based on equations 1 and 2 is 26.5 °C.

Table 4. Stream dissolved oxygen standards (Minnesota Rule 7050.0220)

Stream Class	Daily Minimum Dissolved Oxygen (mg/L)
2A – Coldwater	7
2B – Coolwater or warmwater	5

Table 5. Average biochemical oxygen demand in the impaired streams
Monitoring stations are listed in order of upstream to downstream. Maximum BOD are bolded.

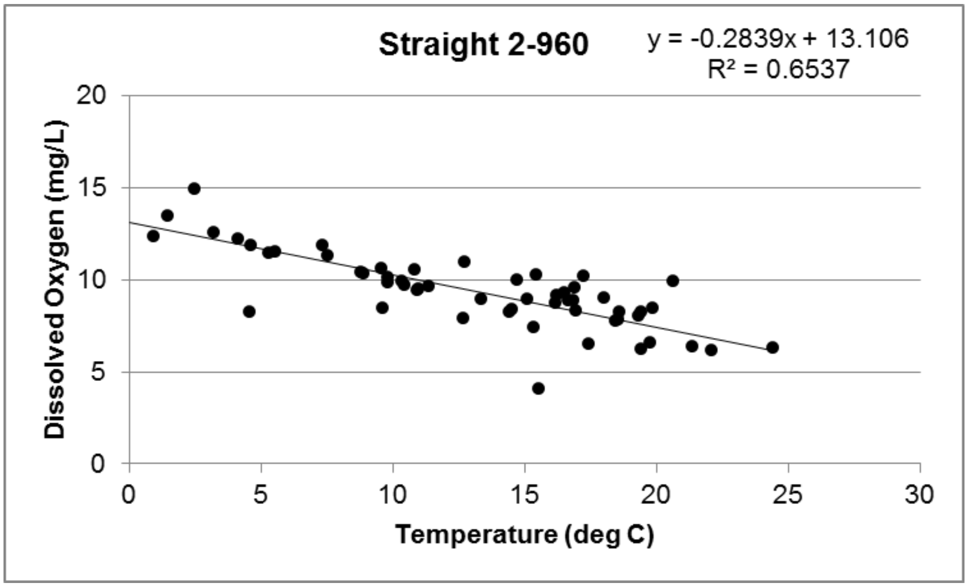
Impaired Stream (AUID)	Monitoring Station	Monitoring Period	Number of Samples	Average BOD (mg/L)	Min–Max BOD (mg/L)
Straight River (07010106-558)	S002-960	2004-2006	26	0.98	0.60 – 1.70
	S004-788	2007	2	2.52	2.40 – **2.64**
	S004-793	2007-2008	2	2.16	2.12 – 2.20
Shell River (07010106-681)	S002-962	2004	26	1.73	0.60 – **3.00**
	S003-833	2007-2008	3	2.11	2.00 – 2.30
	S003-442	2007	2	2.33	2.16 – 2.50

Table 6. Dissolved oxygen saturation threshold temperature

Impaired Stream (AUID)	Dissolved oxygen saturation threshold (mg/L)	Dissolved oxygen saturation threshold temperature (° C)
Straight River (07010106-558)	9.5	18.0
Shell River (07010106-681)	8.0	26.5

Figure 2. Relationship between temperature and dissolved oxygen in the Straight River. A) upstream station: S002-960; B) downstream station: S004-788. Note that these figures only included data collected on dates where both a temperature and a dissolved oxygen measurement were collected. The dissolved oxygen summary tables included in Section 14.2 include all dissolved oxygen measurements.

A.



B.

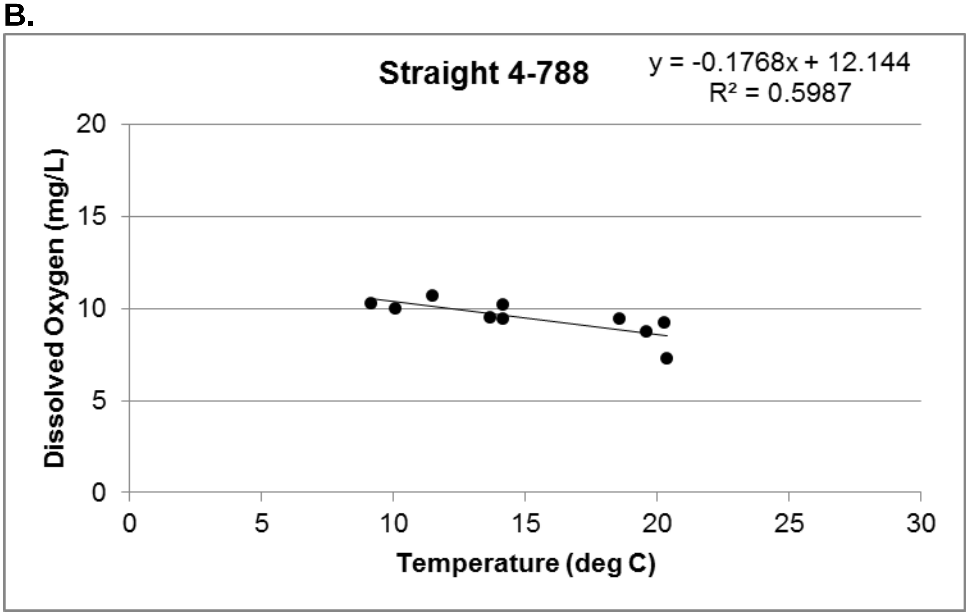
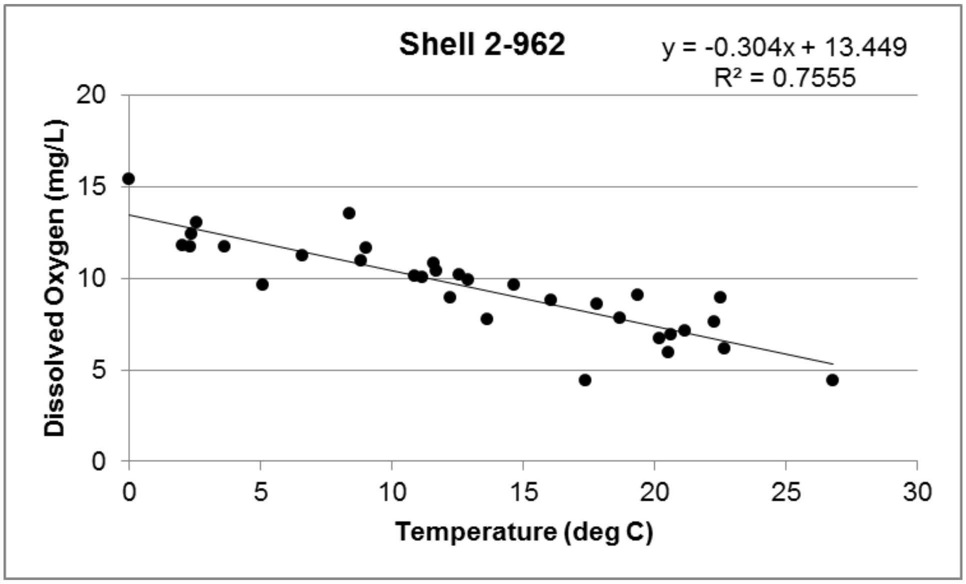


Figure 3. Relationship between temperature and dissolved oxygen in the Shell River.
A) **upstream station: S002-962; B) mid-stream station: S003-442; C) downstream station: S003-833. Note that these figures only included data collected on dates where both a temperature and a dissolved oxygen measurement were collected. The dissolved oxygen summary tables included in Section 14.3 include all dissolved oxygen measurements.**

A.



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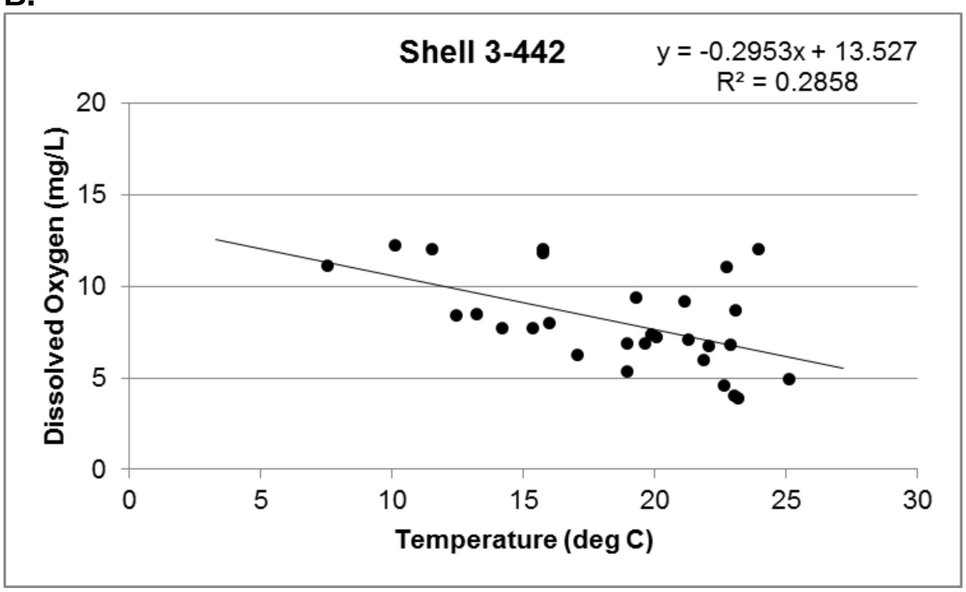
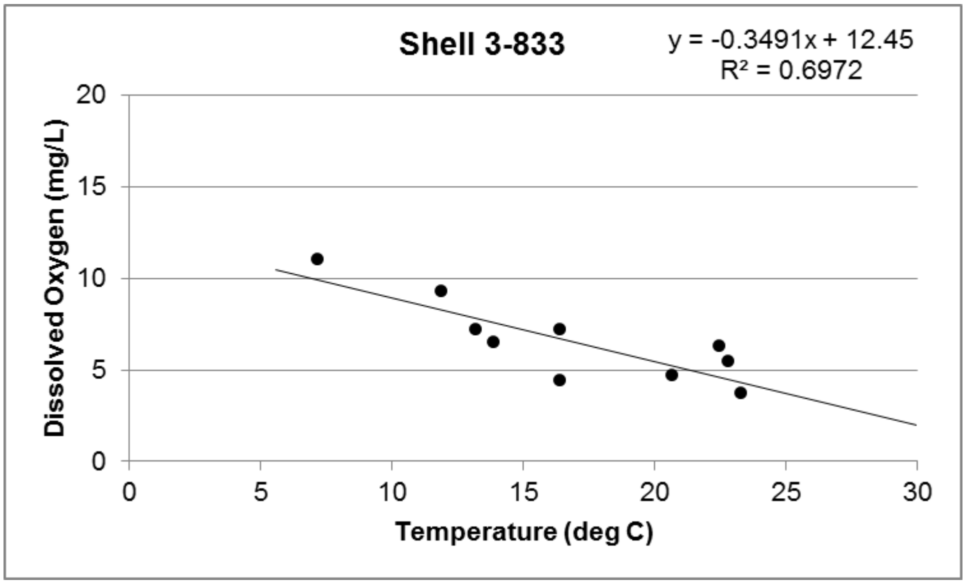


Figure 3 continued. Relationship between temperature and dissolved oxygen in the Shell River. A) upstream station: S002-962; B) mid-stream station: S003-442; C) downstream station: S003-833. Note that these figures only included data collected on dates where both a temperature and a dissolved oxygen measurement were collected. The dissolved oxygen summary tables included in Section 14.3 include all dissolved oxygen measurements.

C.



2.3.2 Numeric Standards

2.3.2.1 Bacteria

Numeric water quality standards have been developed for bacteria (Minnesota Rule 7050.0222), in this case Escherichia coli (*E. coli*), which are protective concentrations for short- and long-term exposure to pathogens in water. The past fecal coliform and current *E. coli* numeric water quality standards for Class 2 waters are shown in Table 7. *E. coli* and fecal coliform are fecal bacteria used as indicators for waterborne pathogens that have the potential to cause human illness. Although most are harmless themselves, fecal indicator bacteria are used as an easy-to-measure surrogate to evaluate the suitability of recreational and drinking waters, specifically, the presence of pathogens and probability of illness. Pathogenic bacteria, viruses, and protozoa pose a health risk to humans, potentially causing illnesses with gastrointestinal symptoms (nausea, vomiting, fever, headache, and diarrhea), skin irritations, or other symptoms. Pathogen types and quantities vary among fecal sources; therefore, human health risk varies based on the source of fecal contamination.

This Total Maximum Daily Load (TMDL) study will use the standard for *E. coli*. The change in the water quality standard from fecal coliform to *E. coli* is supported by an USEPA guidance document on bacteriological criteria (USEPA 1986). As of March 17, 2008, Minnesota Rules Chapter 7050 water quality standards for *E. coli* are:

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

Although surface water quality standards are now based on *E. coli*, wastewater treatment facilities are permitted based on fecal coliform (not *E. coli*) concentrations.

Geometric mean is used in place of arithmetic mean in order to measure the central tendency of the data, dampening the effect that very high or very low values have on arithmetic means. The MPCA's *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* provides details regarding how waters are assessed for conformance to the *E. coli* standard (MPCA 2012).

Table 7. Past and current numeric water quality standards of bacteria (fecal coliform and *E. coli*) for the beneficial use of aquatic recreation (primary and secondary body contact).

Past Standard	Units	Current Standard	Units	Notes
Fecal coliform	200 orgs per 100 ml	*E. coli*	126 orgs per 100 ml	Geometric mean of $\geq$5 samples per month (April - October)
Fecal coliform	2,000 orgs per 100 ml	*E. coli*	1,260 orgs per 100 ml	<10% of all samples per month (April - October) that individually exceed

3 WATERSHED DESCRIPTION

The impaired lakes and streams included in this study are located within the Crow Wing River Watershed (HUC 07010106), a tributary to the Mississippi River in the Upper Mississippi River Basin in central Minnesota (Figure 1). The Crow Wing River Watershed drains approximately 1,981 square miles (1,268,127 acres) in all or parts of Becker, Cass, Clearwater, Crow Wing, Hubbard, Morrison, Otter Tail, Todd, and Wadena Counties. The Crow Wing River begins in the Crow Wing Chain of Lakes and flows south and east and outlets to the Mississippi River.

White Earth Nation tribal lands are located within the Crow Wing River Watershed, including upstream portions of the Blueberry Lake, Lower Twin Lake, and Straight River subwatersheds (Figure 1).

3.1 Lakes

The physical characteristics of the impaired lakes are listed in Table 8. Lake surface areas were digitized from 2010 aerial photography; lake volumes, mean depths, and littoral areas (< 15 feet) were calculated using MN DNR 1992 depth contours and 2010 digitized surface areas; maximum depths were reported from the MN DNR Lake Finder website; and watershed areas and watershed to surface area ratios were calculated using MN DNR minor catchment GIS data.

Table 8. Impaired lake physical characteristics.
Note that the watershed area includes the surface area of the lake.

Lake	Surface area (ac)	Littoral area (% total area)	Volume (acre-feet)	Mean depth (feet)	Maximum depth (feet)	Watershed area (incl. lake area) (ac)	Watershed area : Surface area
Blueberry	533	100%	3,634	6.8	15	136,332	255: 1
Eighth Crow Wing	493	30%	9,050	18.4	30	25,086	50: 1
First Crow Wing	509	100%	2,926	5.8	15	166,458	326: 1
Lower Twin	252	53%	2,859	11.4	26	383,639	1,522: 1
Mayo	151	94%	1,141	7.6	22	35,941	237: 1
Portage	417	100%	3,004	7.2	17	2,999	7: 1
Sibley	426	60%	5,667	13.3	40	35,161	82: 1

3.2 Streams

The direct drainage and total watershed areas of the impaired stream reaches are listed in Table 9. Total watershed and direct drainage areas were delineated from HSPF subbasins (AquaTerra 2013) and USGS StreamStats (http://water.usgs.gov/osw/streamstats/). The direct drainage areas include only the area downstream of any monitored upstream lake or stream.

Table 9. Impaired stream reach direct drainage and total watershed areas

AUID	Name	Direct Drainage Area (ac)	Total Watershed Area (ac)	Upstream Water body
07010106-518	**Partridge River**	58,427	58,427	N/A
07010106-524	**Home Brook**	26,018	32,465	Corey Brook
07010106-527	**Swan Creek**	24,324	30,653	Iron Creek
07010106-544	**Cat River**	35,243	35,243	N/A
07010106-558	**Straight River**	29,745	52,765	Straight Lake
07010106-577	**Pillager Creek**	13,101	13,101	N/A
07010106-604	**Mayo Creek**	27,447	27,447	N/A
07010106-681	**Shell River**	19,938	406,364	Lower Twin Lake
07010106-684	**Unnamed creek**	9,593	9,593	N/A
07010106-698	**Stoney Brook**	23,495	23,495	N/A
07010106-700	**Corey Brook**	6,476	6,476	N/A
07010106-702	**Farnham Creek**	12,763	12,763	N/A

3.3 Subwatersheds

The individual impaired lake and stream subwatersheds are illustrated in Figure 4 through Figure 11 below.

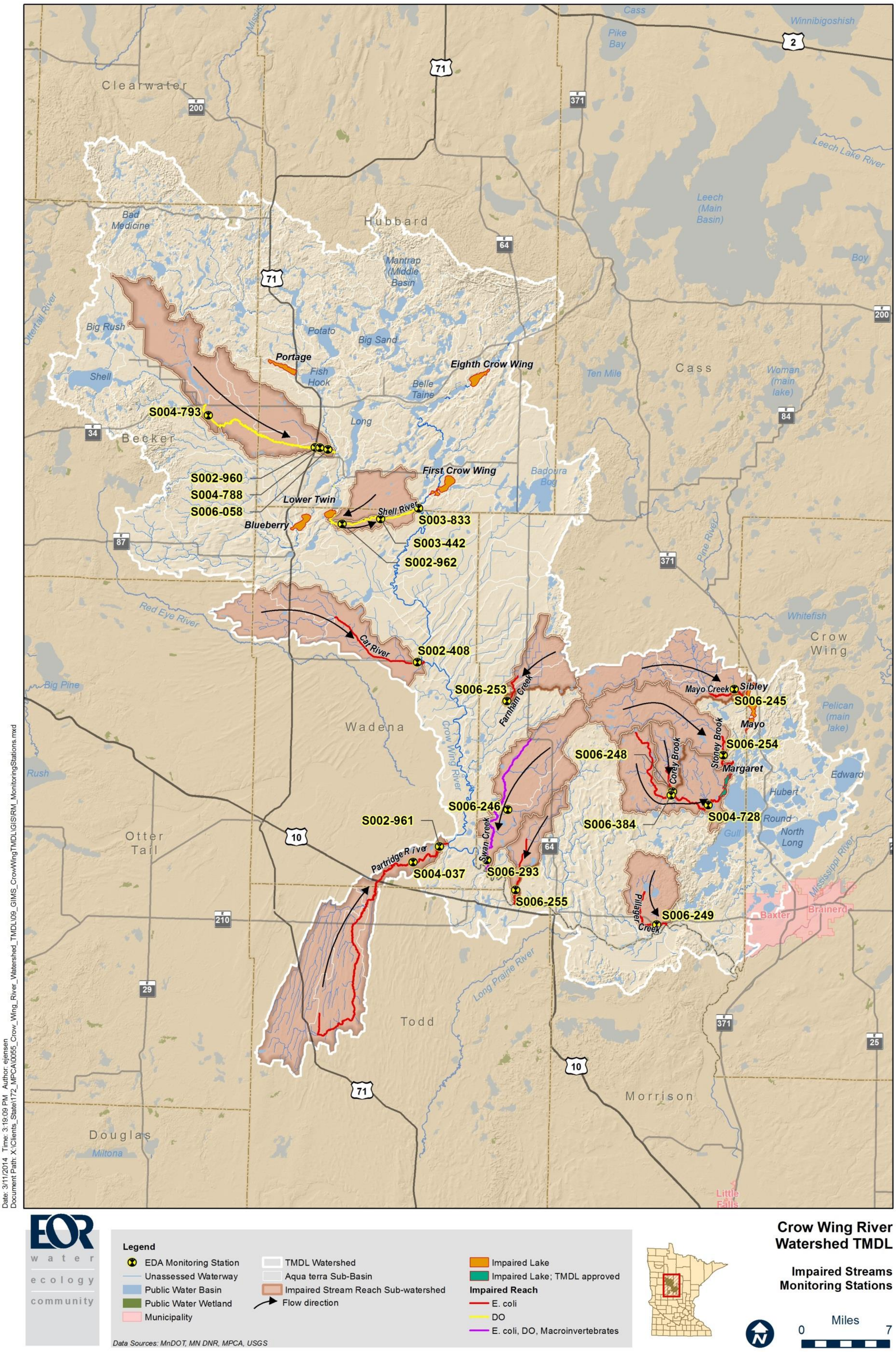


Figure 4. Crow Wing River Watershed impaired stream reach subwatersheds. Note that the Shell River subwatershed shown in this map only includes the area downstream of Lower Twin Lake.
Refer to Figure 8 for the boundary of the Lower Twin Lake subwatershed.

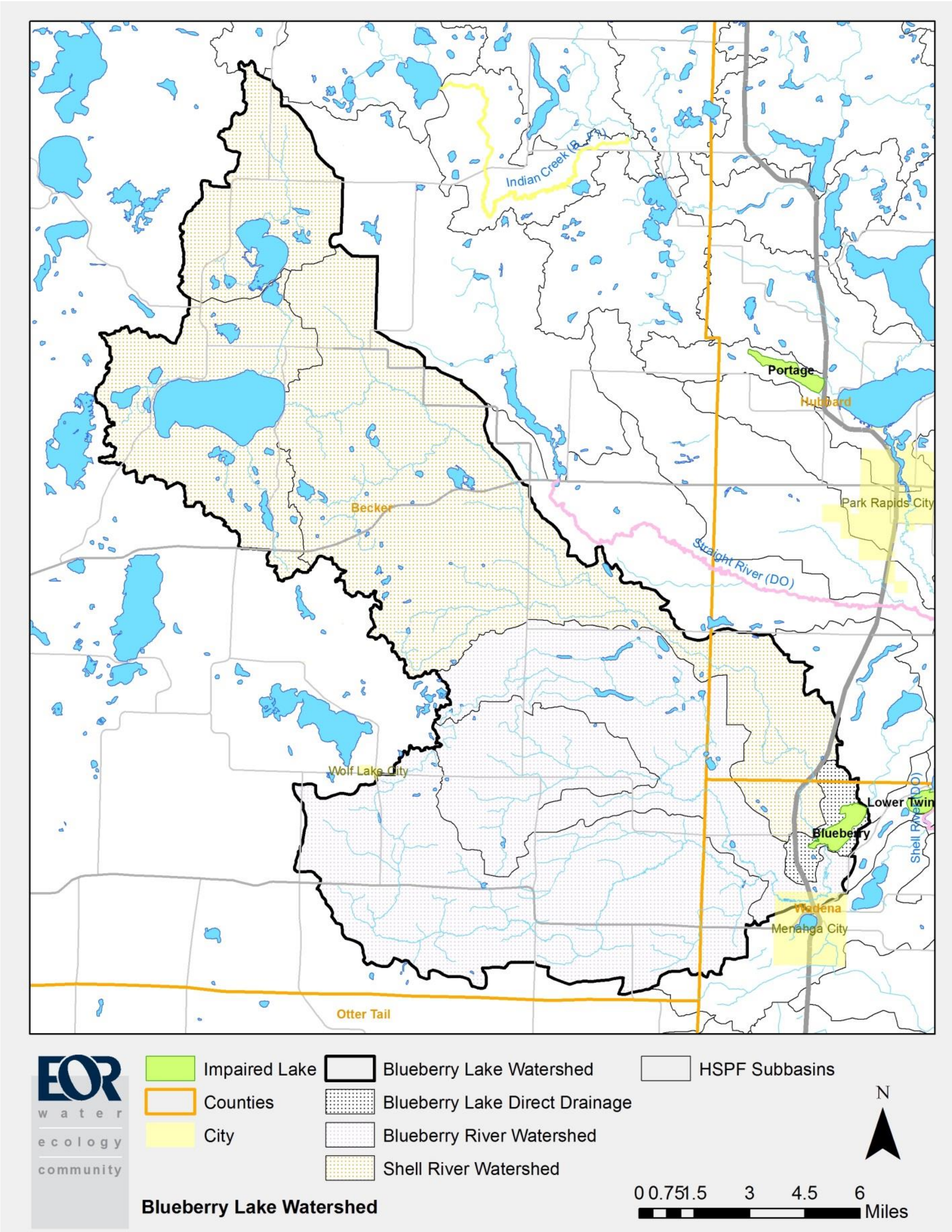


Figure 5. Blueberry Lake subwatershed

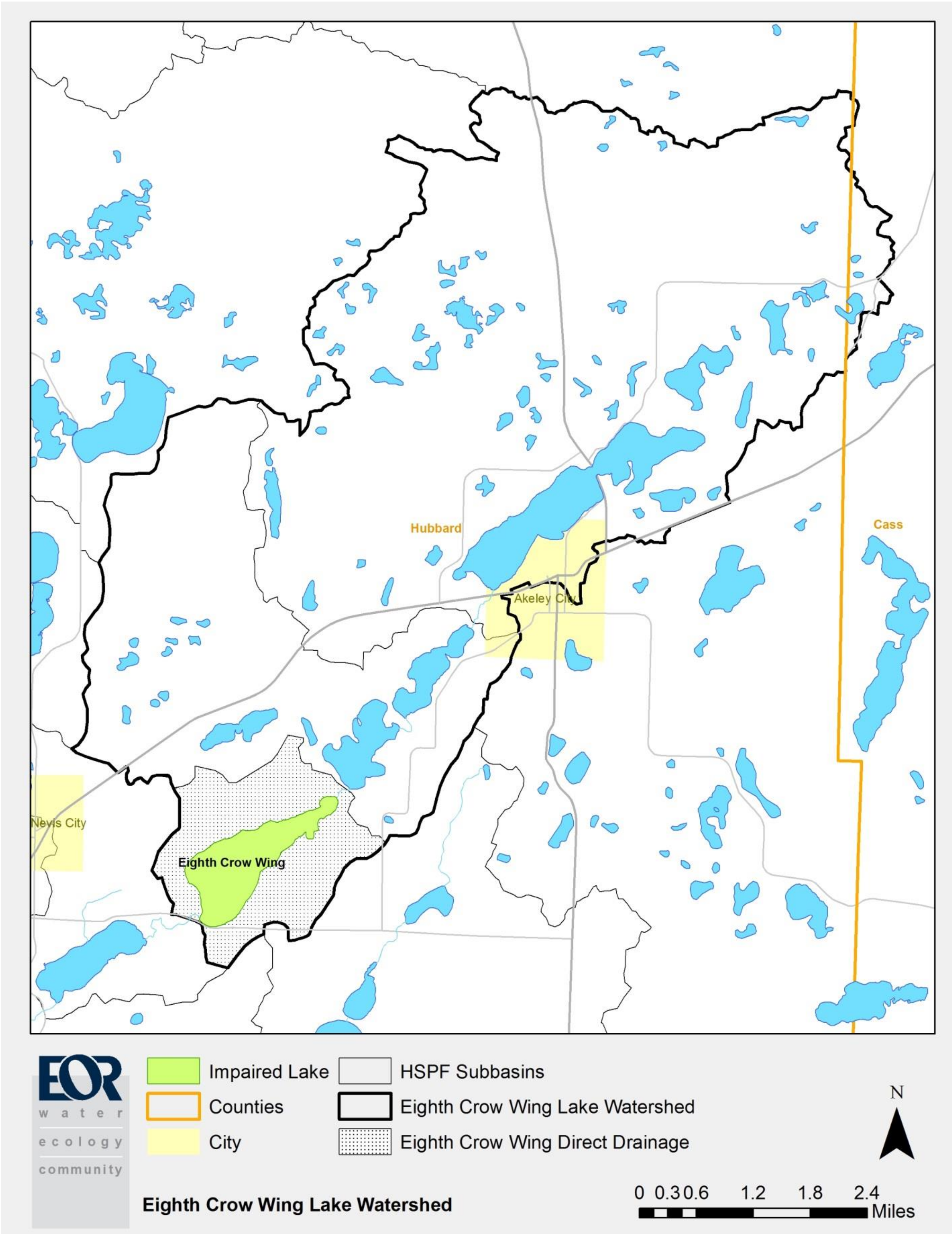


Figure 6. Eighth Crow Wing Lake subwatershed

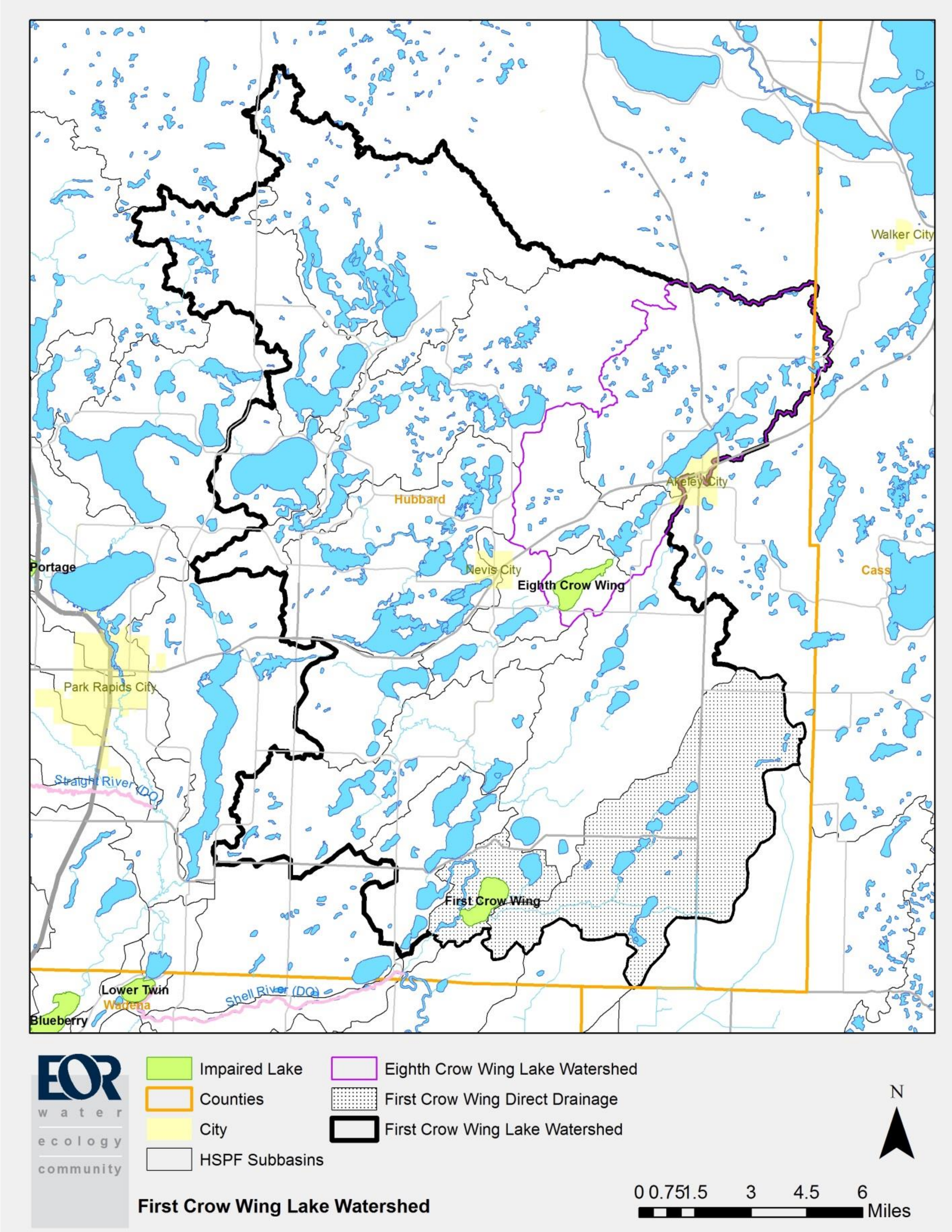


Figure 7. First Crow Wing Lake subwatershed

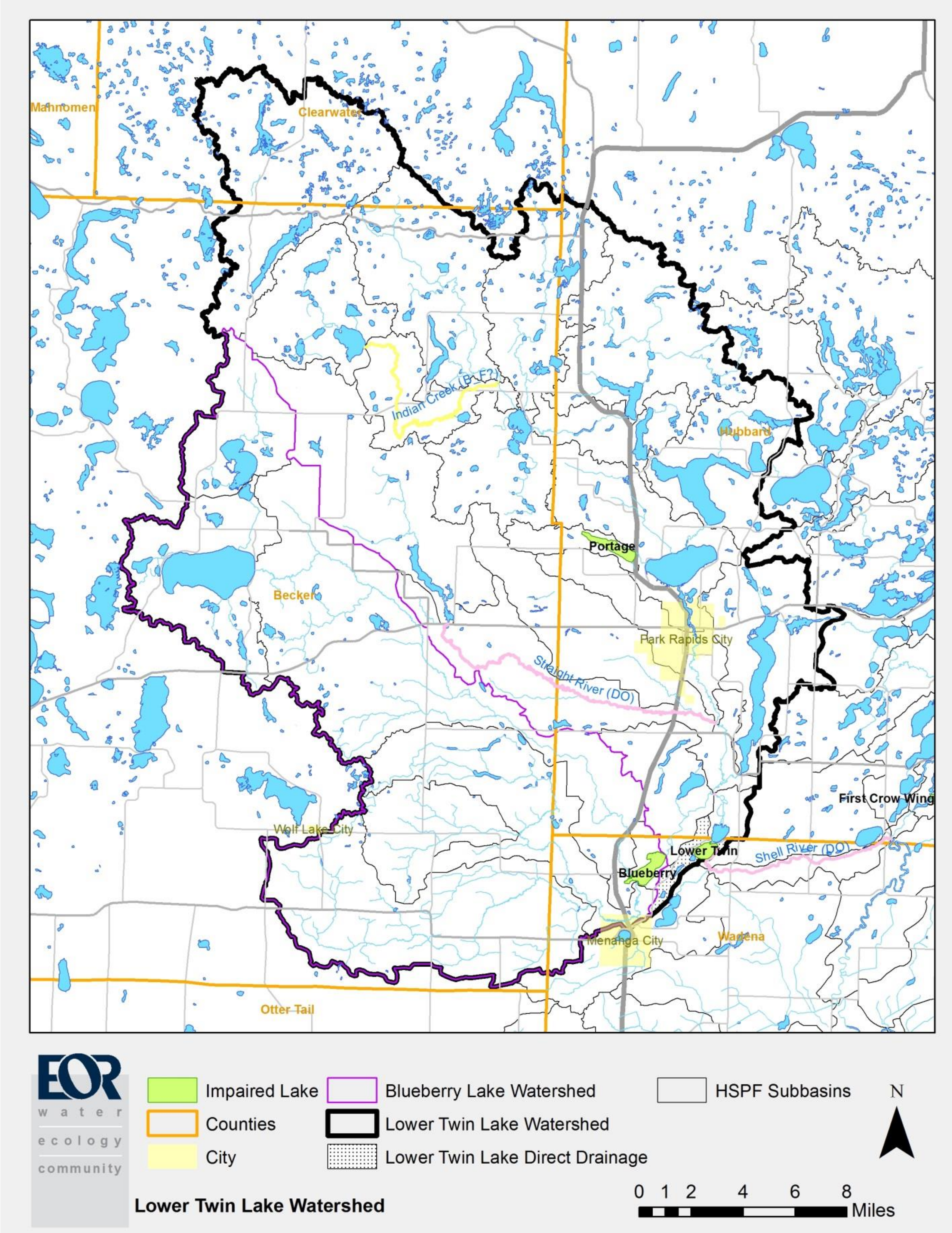


Figure 8. Lower Twin Lake subwatershed

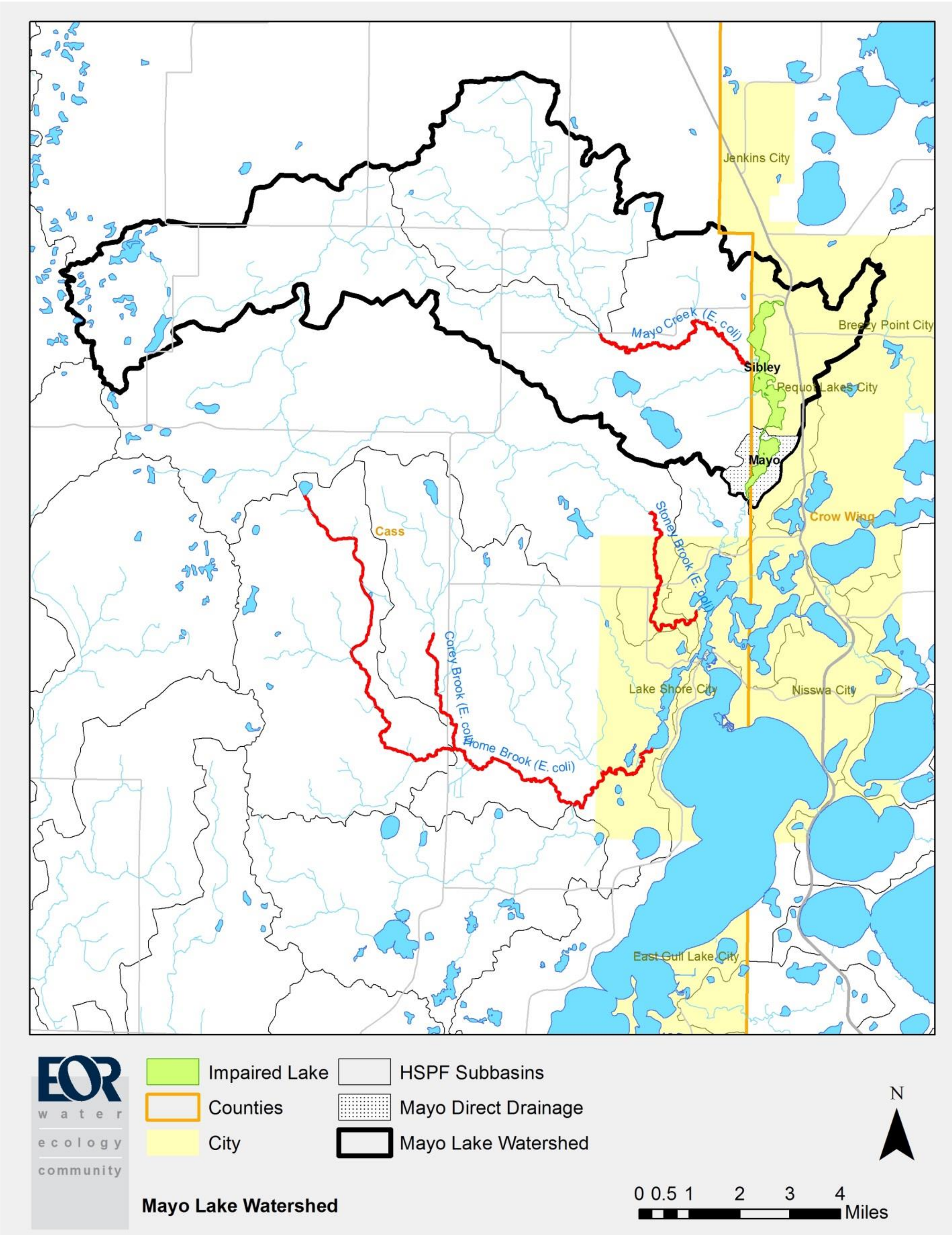


Figure 9. Mayo Lake subwatershed

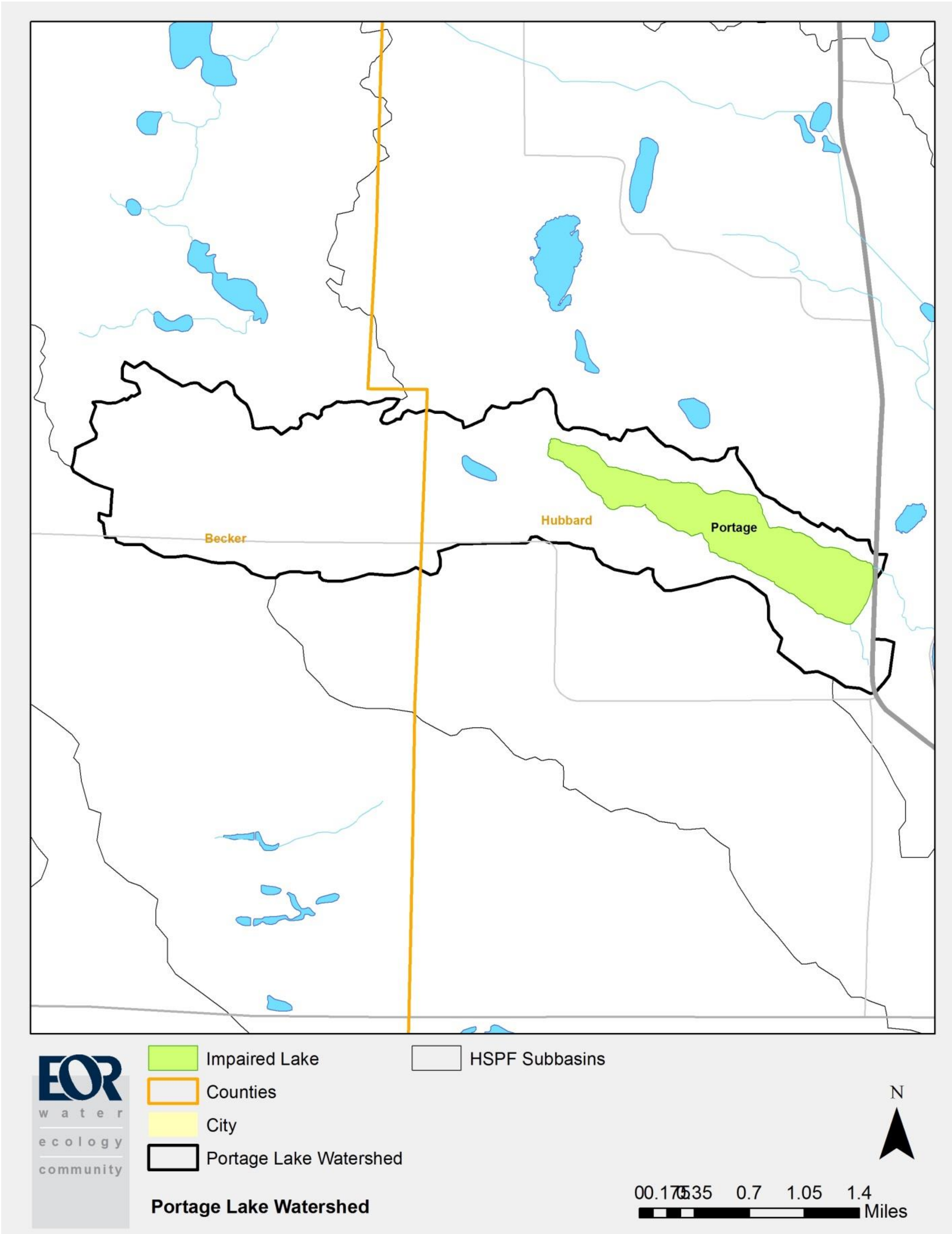


Figure 10. Portage Lake subwatershed

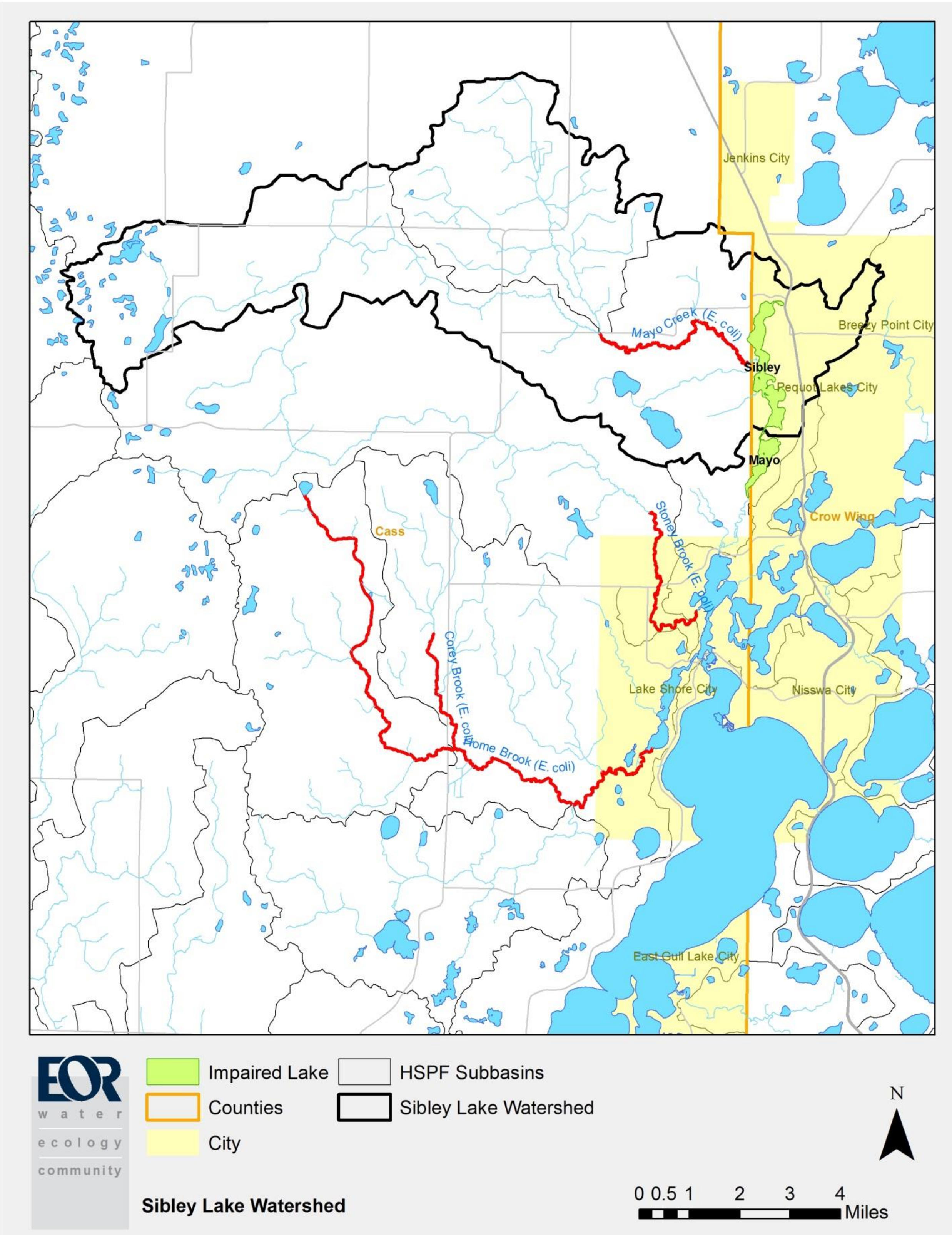


Figure 11. Sibley Lake subwatershed

3.4 Land Cover

Land cover in the Crow Wing River watershed was assessed using the Multi-Resolution Land Characteristics Consortium 2006 National Land Cover Dataset (http://www.mrlc.gov/nlcd2006.php). This information is necessary to draw conclusions about pollutant sources and best management practices that may be applicable within each subwatershed. The land cover distribution within impaired lake and stream watersheds is summarized in Table 10. This data was simplified to reduce the overall number of categories. Forest includes: evergreen forests, deciduous forests, mixed forests, and shrub/scrub. Developed includes: developed open space, and low, medium and high density developed areas. Grassland includes: native grass stands. Pasture includes: alfalfa, clover, long term hay, and pasture. Cropland includes: all annually planted row crops (corn, soybeans, wheat, oats, barley, etc.) and fallow crop fields. Wetland includes: wetlands and marshes. Open water includes: all lakes and rivers, and barren land.

The primary land covers within the Crow Wing River watershed are woodlands (48%) and wetlands (15%). Most of the impaired lake subwatersheds tend to have more woodlands than the Crow Wing River Watershed as a whole, except Mayo and Sibley lakes, which have more pasture/grasslands (Table 10). The impaired stream reaches also have high percentages of woodland, except Partridge, Straight, and Shell Rivers which have a larger percentage of cropland and pasture.

Table 10. Crow Wing River Watershed and Impaired Waterbody Subwatershed Land Cover (NLCD 2006)

Waterbody Name	Developed	Cropland	Pasture	Grassland	Woodland	Wetlands	Open Water	Total Area* (ac)
Blueberry Lake	3.5%	11.3%	11.7%	5.3%	53.2%	10.2%	4.7%	136,242
Eighth Crow Wing L.	3.7%	2.3%	10.9%	5.2%	66.6%	2.3%	9.0%	25,068
First Crow Wing L.	3.2%	8.6%	6.4%	5.5%	60.2%	4.7%	11.4%	166,385
Lower Twin Lake	3.6%	12.4%	8.6%	5.2%	55.8%	7.9%	6.5%	383,481
Mayo Lake	3.4%	3.2%	23.1%	9.3%	36.9%	20.5%	3.5%	35,877
Portage Lake	3.8%	4.2%	11.8%	6.1%	58.4%	1.3%	14.5%	2,997
Sibley Lake	3.5%	3.3%	23.5%	9.5%	36.6%	20.6%	3.2%	35,100
Partridge River	5.0%	29.5%	34.0%	8.3%	15.0%	8.0%	0.2%	58,345
Home Brook	1.5%	0.7%	12.5%	10.3%	58.1%	14.6%	2.2%	25,955
Swan Creek	2.7%	5.1%	22.1%	8.9%	29.1%	31.9%	0.2%	30,609
Cat River	3.9%	10.7%	16.8%	3.9%	44.6%	19.9%	0.2%	35,175
Pillager Creek	2.7%	5.6%	10.2%	8.9%	51.7%	17.7%	3.2%	13,073
Mayo Creek	2.7%	3.1%	28.5%	8.9%	40.1%	15.8%	0.9%	27,403
Unnamed Creek	2.5%	6.7%	21.0%	11.3%	30.2%	26.9%	1.3%	9,588
Stoney Brook	2.2%	1.2%	21.6%	9.7%	48.8%	15.9%	0.6%	23,479
Corey Brook	3.1%	0%	21.1%	9.1%	56.7%	9.3%	0.5%	6,476
Farnham Creek	1.6%	2.0%	4.6%	8.1%	69.8%	12.7%	1.1%	12,728
Straight River	3.9%	38.6%	10.3%	4.2%	36.4%	4.6%	1.9%	52,686
Shell River	3.6%	14.0%	8.4%	5.1%	55.0%	7.6%	6.3%	399,026
Crow Wing River Watershed	**3.5%**	**10.1%**	**11.4%**	**5.8%**	**47.8%**	**14.8%**	**6.6%**	**1,268,044**

* The total areas reported in this table are slightly less than the total watershed areas reported in Section 3.1 and 3.2 due to some small areas of unidentified land covers in the NLCD dataset.

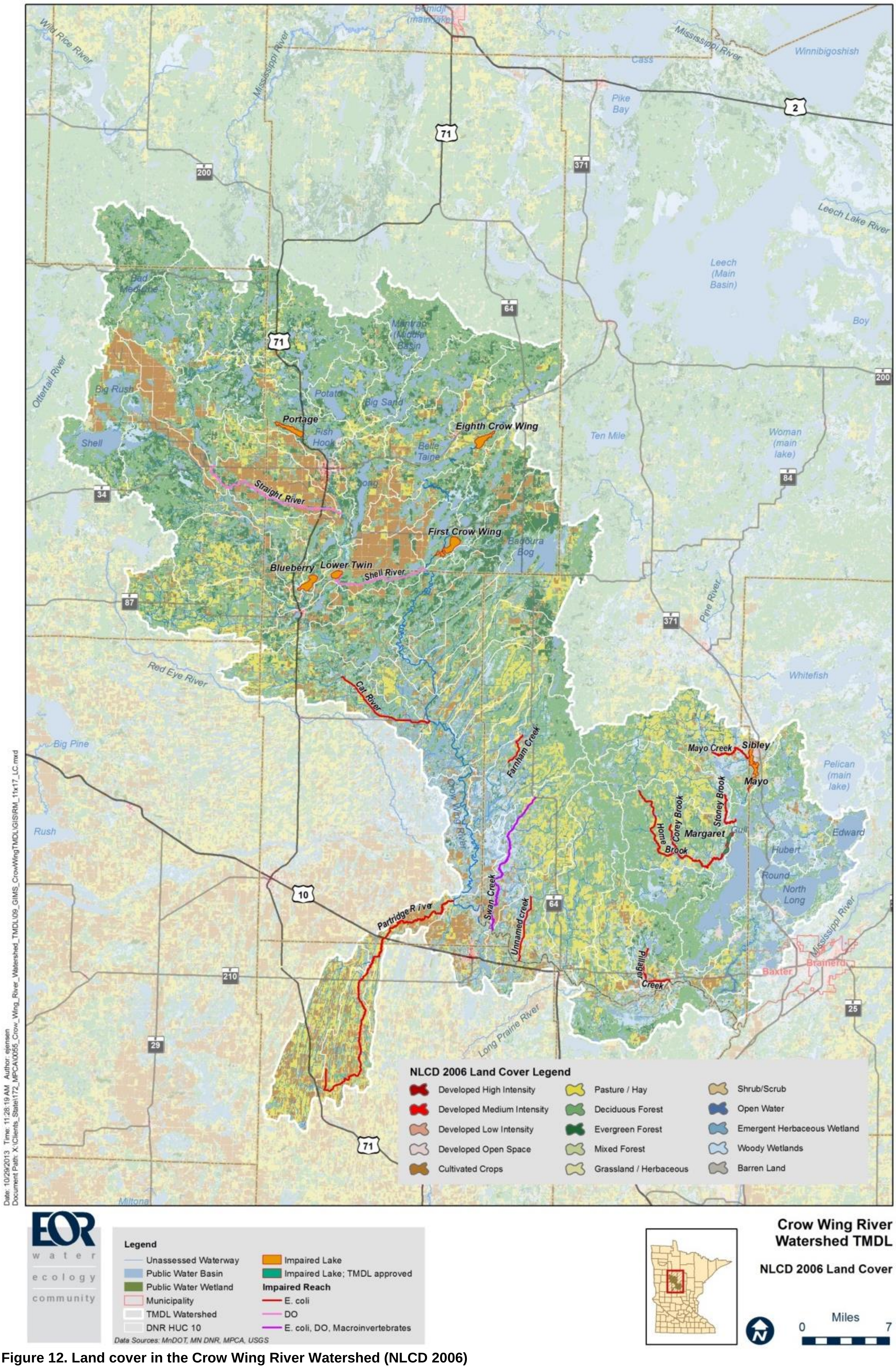


Figure 12. Land cover in the Crow Wing River Watershed (NLCD 2006)

3.5 Historic Water Quality Conditions

The existing in-lake and in-stream water quality conditions were quantified using data downloaded from the MPCA EQuIS database and available for the most recent ten year time period (2002-2011). This corresponds to the time period that the MPCA used to assess these lakes for nutrient impairments in the 2012 assessment cycle (MPCA, 2012a). Growing season means of total phosphorus, chlorophyll-*a*, and Secchi depth were calculated using monitoring data from June through September. Information on the species and abundance of macrophyte and fish present within the lakes was compiled from MN DNR fisheries surveys and information from volunteer lake monitors, and summarized in Section 11: Lake Summaries.

3.5.1 Lakes

Lake conditions were summarized for each lake based on available in-lake water quality, fisheries, and macrophyte data. Historic and recent (2002-2011) water quality trends and macrophyte and fish communities are summarized in the individual lake summary appendices at the end of this report. The 10-year growing season mean TP, Chl-*a*, and Secchi for each impaired lake is listed in Table 11.

Table 11. 10-year growing season mean TP, Chl-*a*, and Secchi, 2002-2011

	10-year Growing Season Mean (June – September)					
	TP		Chl-*a*		Secchi	
Lake Name	(µg/L)	CV	(µg/L)	CV	(m)	CV
NCHF – Shallow Lakes Standard	< 60	--	< 20	--	> 1.0	--
Blueberry	93	8%	52	10%	0.9	5%
First Crow Wing	59.5	8%	32	12%	1.1	5%
NCHF – General Standard	< 40	--	< 14	--	> 1.4	--
Lower Twin	40	5%	15	9%	1.9	3%
NLF - Standard	< 30	--	< 9	--	> 2.0	--
Eighth Crow Wing	29	8%	14	16%	2.7	6%
Mayo	36	4%	18	18%	2.0	6%
Portage	51	6%	22	8%	1.3	3%
Sibley	33	5%	20	8%	1.5	4%

CV = coefficient of variation, defined in BATHTUB as the standard error divided by the mean
* Lower Twin Lake has a maximum depth of 20 feet and is at the threshold between general and shallow lake types

3.5.2 Streams

3.5.2.1 Dissolved Oxygen

Ten-year (2002-2011) monthly mean and minimum dissolved oxygen concentrations were calculated by station for each of the three impaired reaches: Swan Creek (Table 12, Figure 13), Straight River (Table 13, Figure 14) and Shell River (Table 14, Figure 15). For each station, dissolved oxygen values generally decrease following spring, reach annual lows and sometimes drop below the water quality standard during the summer months, and then increase again into the fall.

Table 12. Dissolved oxygen (mg/L) by month in Swan Creek, 2002-2011.
Bold red font highlight samples below the water quality standard for 2B waters (5 mg/L).

Water body	Monitoring Station	Month	No. of Samples	Minimum DO (mg/L)	No. of Samples < 5 mg/L
Swan Creek (07010106-527)	S006-293	May	3	5.2	0
		June	4	5.3	0
		July	2	**4.0**	**1**
		August	5	**2.4**	**3**
		September	4	**4.3**	**1**

Figure 13. Dissolved oxygen (mg/L) by month in Swan Creek, 2002-2011.
Dashed red line shows the water quality standard for 2B waters (5 mg/L).

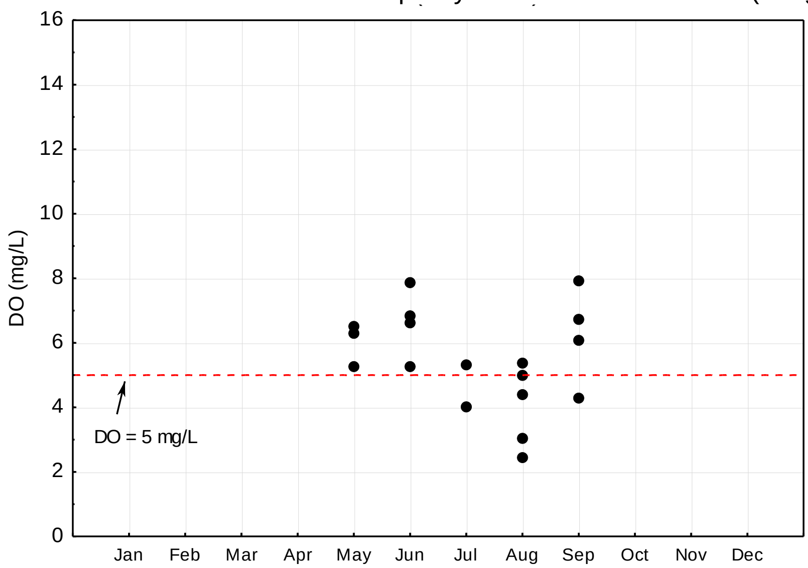


Table 13. Dissolved oxygen (mg/L) by month in the Straight River, 2002-2011.
Bold red font highlight samples below the water quality standard for 2A waters (7 mg/L).

Water body	Monitoring Station	Month	No. of Samples	Minimum DO (mg/L)	No. Samples < 7 mg/L
Straight River (07010106-558)	S004-793	April	1	10.2	0
		May	1	8.9	0
		June	1	**5.8**	**1**
		July	2	8.3	0
		August	1	12.3	0
	S002-960	January	1	14.9	0
		March	2	11.8	0
		April	6	9.9	0
		May	8	8.9	0
		June	11	7.4	0
		July	9	**6.2**	**4**
		August	7	**6.5**	**1**
		September	6	**4.1**	**1**
		October	2	8.3	0
		November	1	12.3	0
	S004-788	April	1	10.2	0
		May	1	10.0	0
		June	2	7.2	0
		July	2	8.7	0
		August	2	9.2	0
		September	2	9.5	0

Figure 14. Dissolved oxygen (mg/L) by month and monitoring station in the Straight River, 2002-2011.
Dashed red line shows the water quality standard for 2A waters (7 mg/L).

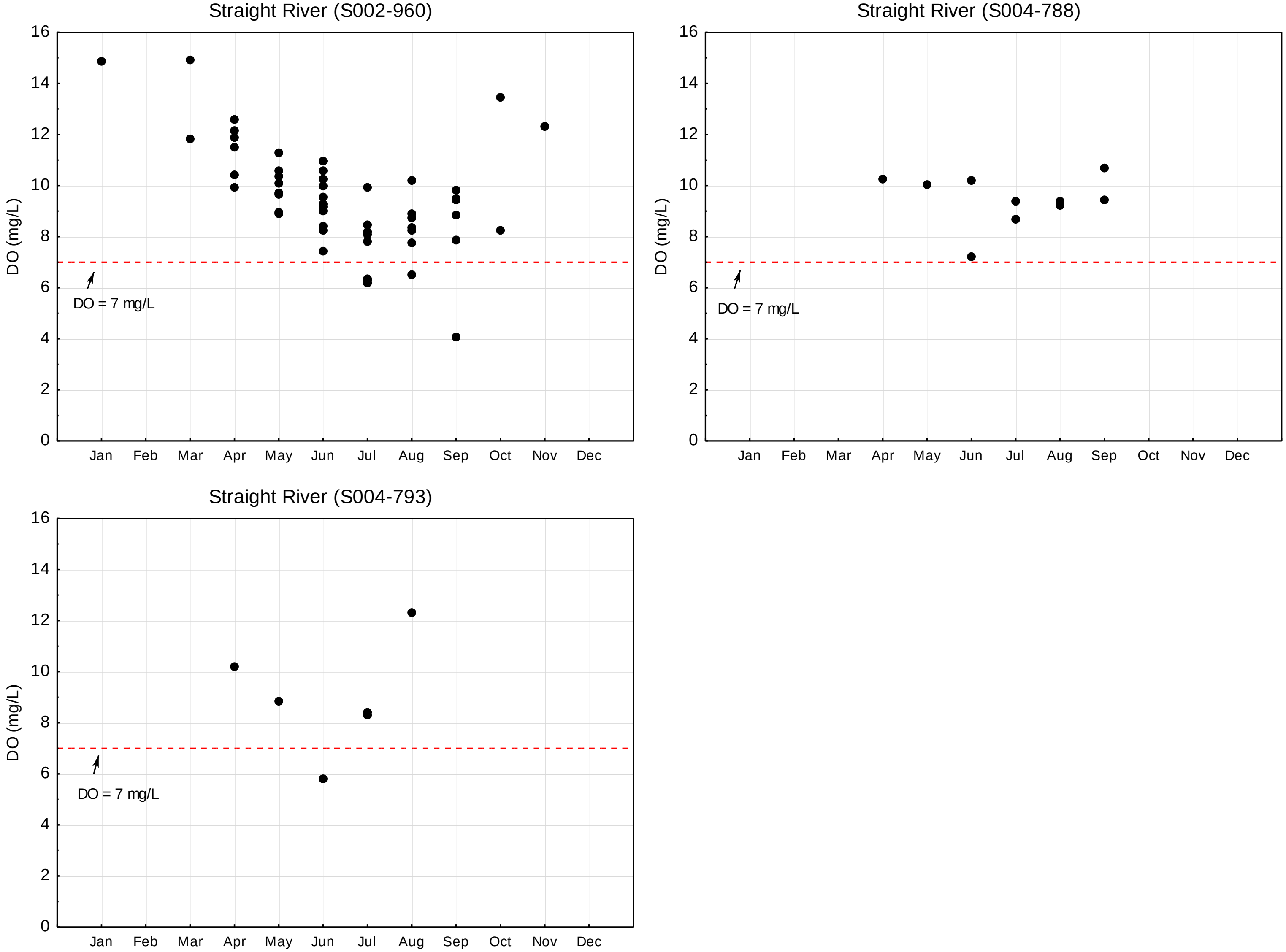
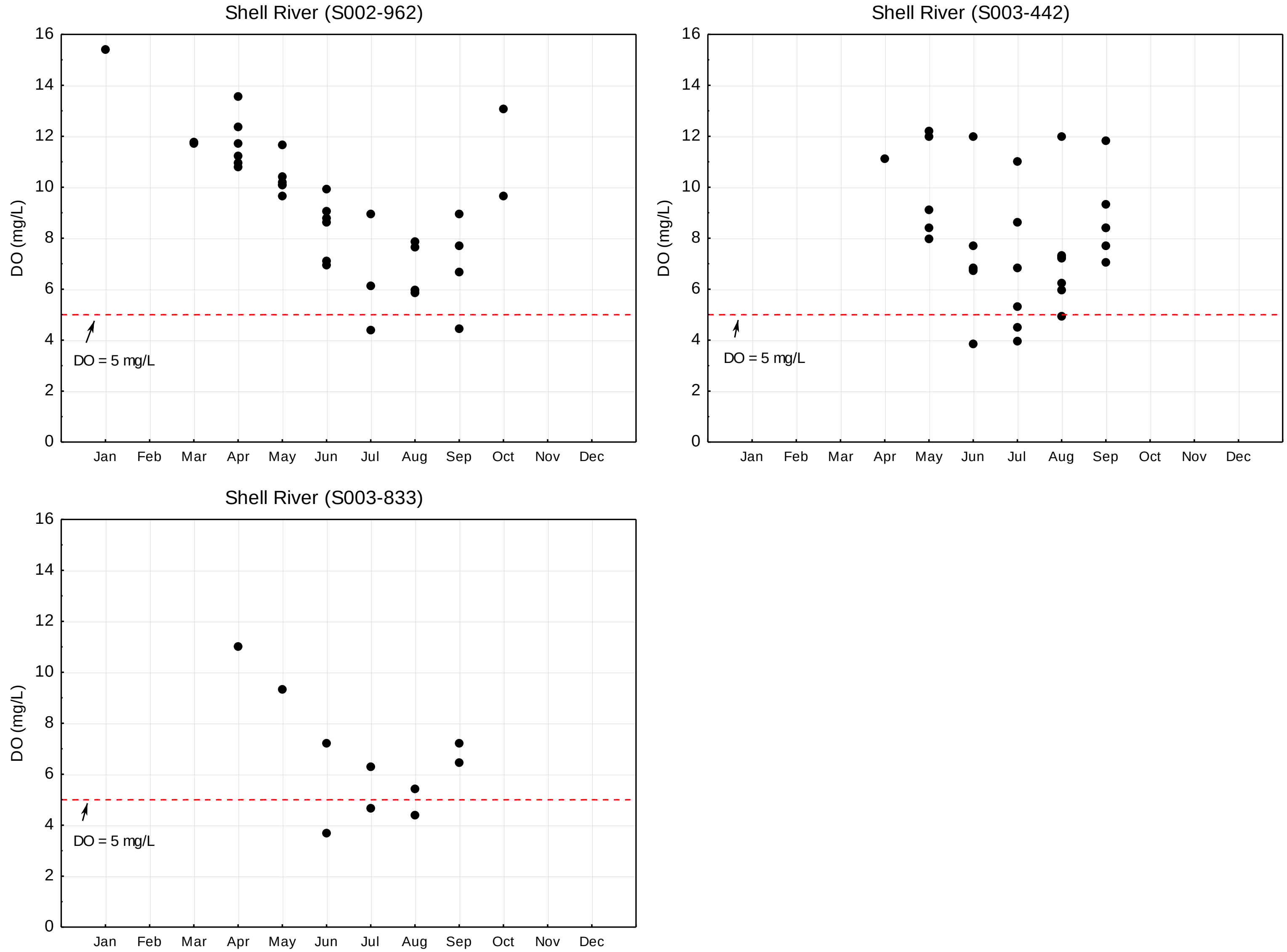


Table 14. Dissolved oxygen (mg/L) by month and monitoring station in the Shell River, 2002-2011. Bold red font highlight samples below the water quality standard for 2B waters (5 mg/L).

Water body	Monitoring Station	Month	No. of Samples	Minimum DO (mg/L)	No. Samples < 5mg/L
Shell River (07010106-681)	S002-962	January	1	15.4	0
		March	2	11.7	0
		April	6	10.8	0
		May	6	9.6	0
		June	6	6.9	0
		July	3	**4.4**	**1**
		August	4	5.9	0
		September	4	**4.4**	**1**
		October	2	9.6	0
	S003-442	April	1	11.1	0
		May	5	8.0	0
		June	6	**3.9**	**1**
		July	6	**4.0**	**2**
		August	7	**4.9**	**1**
		September	6	7.0	0
	S003-833	April	1	11.0	0
		May	1	9.3	0
		June	2	**3.7**	**1**
		July	2	**4.7**	**1**
		August	2	**4.4**	**1**
		September	2	6.5	0

Figure 15. Dissolved oxygen (mg/L) by month and monitoring station in the Shell River, 2002-2011.
Dashed red line shows the water quality standard for 2B waters (5 mg/L).



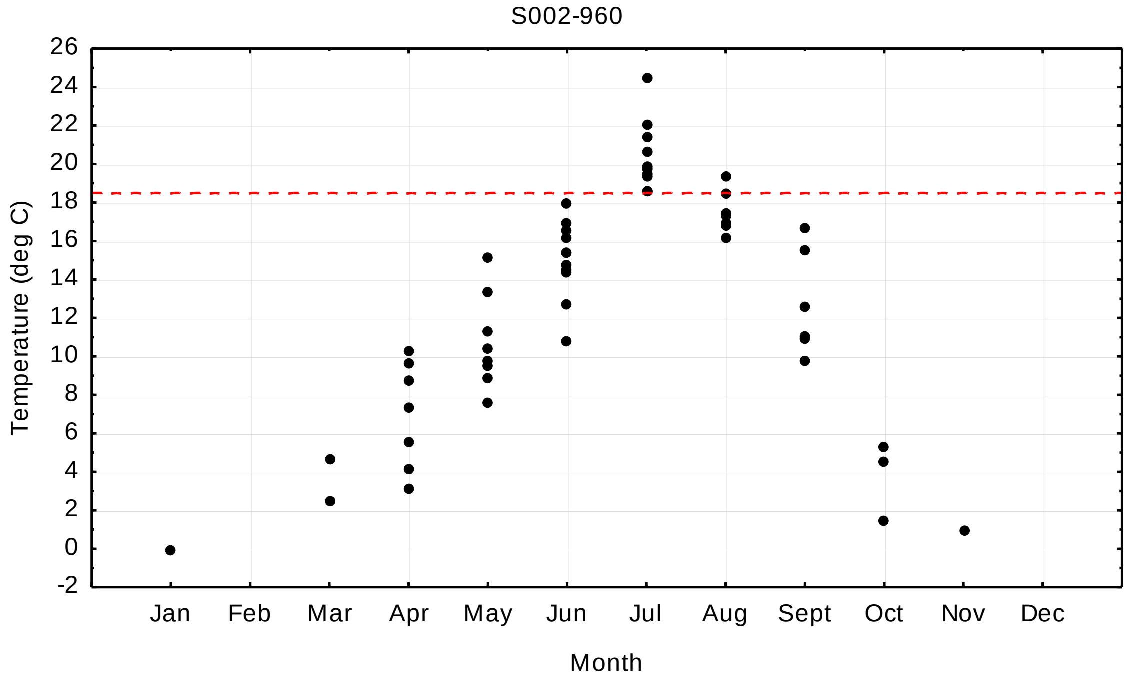
3.5.2.2 Temperature

Ten-year (2002-2011) monthly maximum water temperatures were calculated by station for the two impaired reaches with in-stream temperature targets to meet dissolved oxygen standards: the Straight River (Table 15) and the Shell River (Table 16). Also included in these tables are the number of temperature measurements that exceed the in-stream temperature targets of 18.5 °C and 26.5 °C for the Straight and Shell River, respectively.

Table 15. Temperature (deg C) by month and monitoring station in the Straight River, 2002-2011. Stations are listed in order from upstream to downstream. Temperature measurements exceeding the in-stream temperature target of 18.5 °C are in bold red font.

Waterbody	Monitoring Station	Month	No. of Samples	Max.Temp. (ºC)	No. > 18.5 ºC
Straight River (07010106-558)	S002-960	January	1	-0.01	0
		March	2	4.6	0
		April	7	10.4	0
		May	8	15.1	0
		June	11	18.0	0
		July	10	**24.4**	**10**
		August	7	**19.4**	**1**
		September	6	16.6	0
		October	3	5.3	0
		November	1	0.9	0
	S004-788	April	2	10.5	0
		May	2	11.8	0
		June	2	**20.4**	**1**
		July	2	**19.6**	**2**
		August	2	**20.3**	**1**
		September	2	13.7	0

Figure 16. Temperature (deg C) by month and monitoring station in the Straight River, 2002-2011. Dashed red line shows the Straight River temperature target (18.5 degrees C).



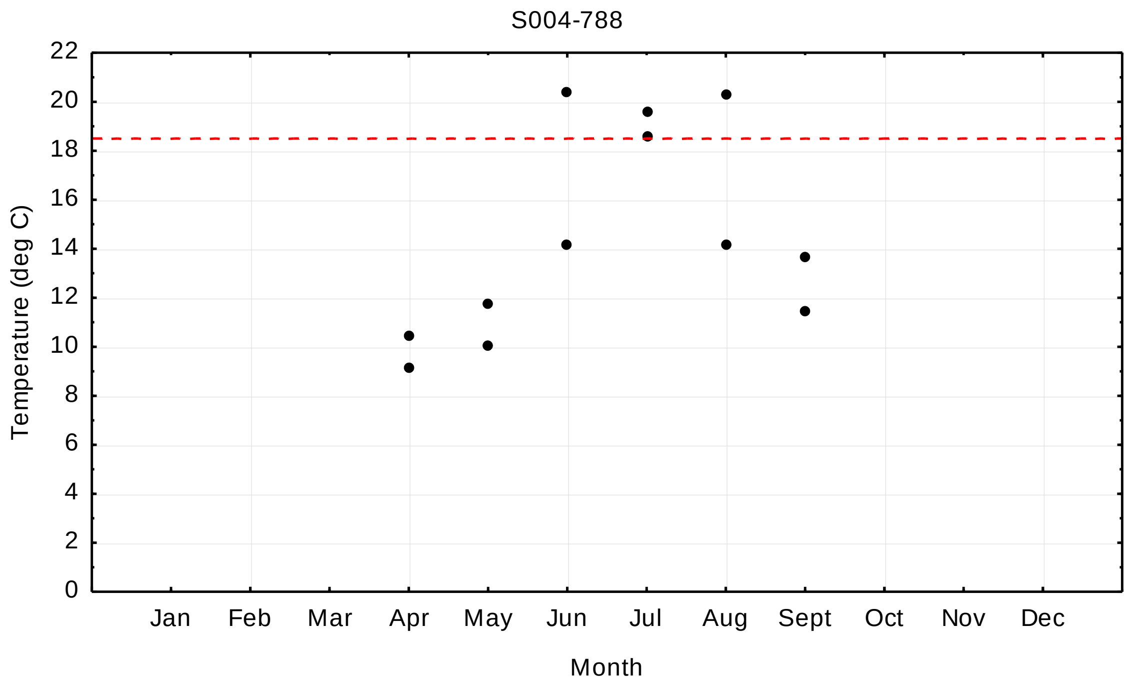
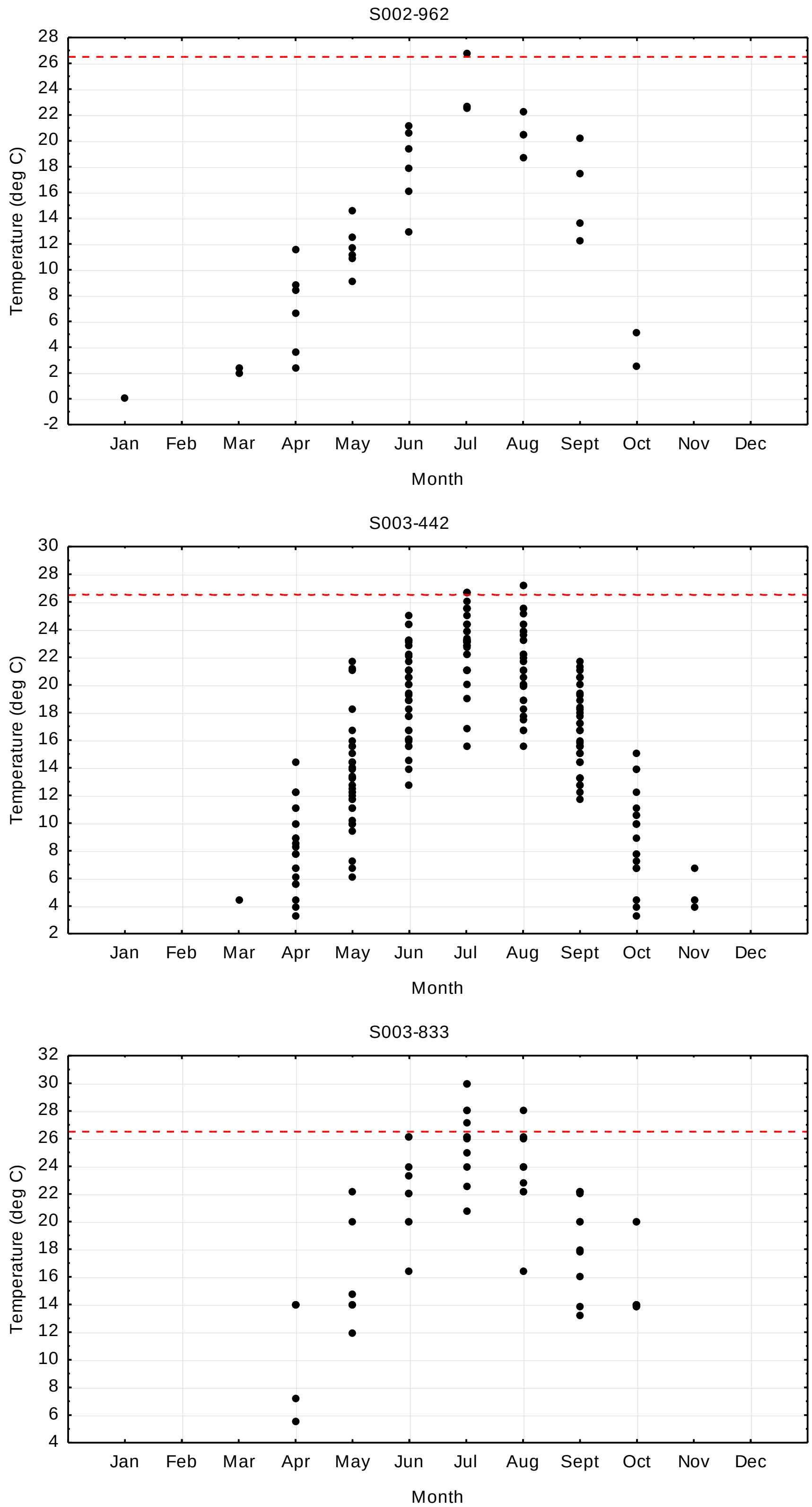


Table 16. Temperature (deg C) by month and monitoring station in the Shell River, 2002-2011.. Stations are listed in order from upstream to downstream. Temperature measurements exceeding the in-stream temperature target of 26.5 °C are in bold red font.

Waterbody	Monitoring Station	Month	No. of Samples	Max.Temp. (ºC)	No. > 26.5 ºC
Shell River (07010106-558)	S002-962	January	1	0.02	0
		March	5	2.35	0
		April	6	11.6	0
		May	6	14.6	0
		June	6	21.2	0
		July	3	**26.8**	**1**
		August	4	22.3	0
		September	4	20.2	0
		October	4	5	0
	S003-442	March	1	4.4	0
		April	23	14.4	0
		May	37	21.7	0
		June	42	25	0
		July	39	**26.7**	**3**
		August	37	**27.2**	**2**
		September	39	21.7	0
		October	21	15	0
		November	3	6.7	0
	S003-833	April	7	14.0	0
		May	7	22.2	0
		June	9	26.1	0
		July	12	**30.0**	**5**
		August	10	**28.0**	**1**
		September	11	22.2	0
		October	8	20	0

Figure 17. Temperature (deg C) by month and monitoring station in the Shell River, 2002-2011. Dashed red line shows the Shell River temperature target (26.5 degrees C).



3.5.2.1 Escherichia coli

Using data from the most recent ten year period (2002-2011), geometric mean *E. coli* concentrations were calculated by month for the ten stream reaches impaired for *E. coli* (Table 17; Figure 18). In general, *E. coli* concentrations in the impaired reaches were highest in July, with geometric means all exceeding the water quality standard (126 org/100 mL).

Table 17. 10-year geometric mean *E. coli* (org/100mL) concentrations by month, 2002-2011. Geometric means that exceed the water quality standard of 126 org/100mL for which there are at least 5 samples are highlighted in bold red font.

Waterbody	Monitoring Station	Month	Number of Samples	Geometric Mean (org/100mL)	Min – Max (org/100mL)
Cat River (07010106-544)	S002-408	May	2	36	29 – 44
		June	5	**206**	115 – 517
		July	5	**429**	308 – 649
		August	6	121	73 – 194
		September	4	80	43 – 148
Partridge River (07010106-518)	S002-961	May	2	65	22 – 196
		June	5	**237**	62 – 461
		July	5	**349**	166 – 866
		August	5	**178**	58 – 548
		September	5	**190**	96 – 548
Home Brook (07010106-524)	S004-728	June	6	121	28 – 108
		July	5	**434**	80 – 228
		August	5	**205**	26 – 249
	S006-384	June	5	70	23 – 345
		July	6	134	130 – 2420
		August	5	89	88 – 687
Mayo Creek (07010106-604)	S006-245	June	5	108	65 – 178
		July	5	**186**	114 – 309
		August	5	75	33 – 119
Corey Brook (07010106-700)	S006-248	June	5	103	57 – 166
		July	6	**315**	124 – 1553
		August	5	**280**	162 – 687
Pillager Creek (07010106-577)	S006-249	June	5	119	30 – 291
		July	6	**182**	82 – 549
		August	5	109	43 - 166
Farnham Creek (07010106-702)	S006-253	June	5	**477**	308 – 987
		July	5	**534**	228 – 2420
		August	5	84	50 – 259

Waterbody	Monitoring Station	Month	Number of Samples	Geometric Mean (org/100mL)	Min – Max (org/100mL)
Stoney Brook (07010106-698)	S006-254	June	7	**199**	93 – 365
		July	5	**550**	214 – 1203
		August	5	113	74 – 194
Unnamed Creek (07010106-684)	S006-255	June	6	**244**	42 – 1203
		July	5	**220**	98 – 2420
		August	5	121	57 – 583
Swan Creek (07010106-527)	S006-293	May	1	--	980
		June	4	307	185 – 548
		July	5	**778**	211 – 2420
		August	4	243	133 – 359

Figure 18. 10-year geometric mean *E. coli* (org/100mL) concentrations by month, 2002-2011. Number of samples are listed above each data bar. Dashed line represents the water quality standard (126 org/100mL).

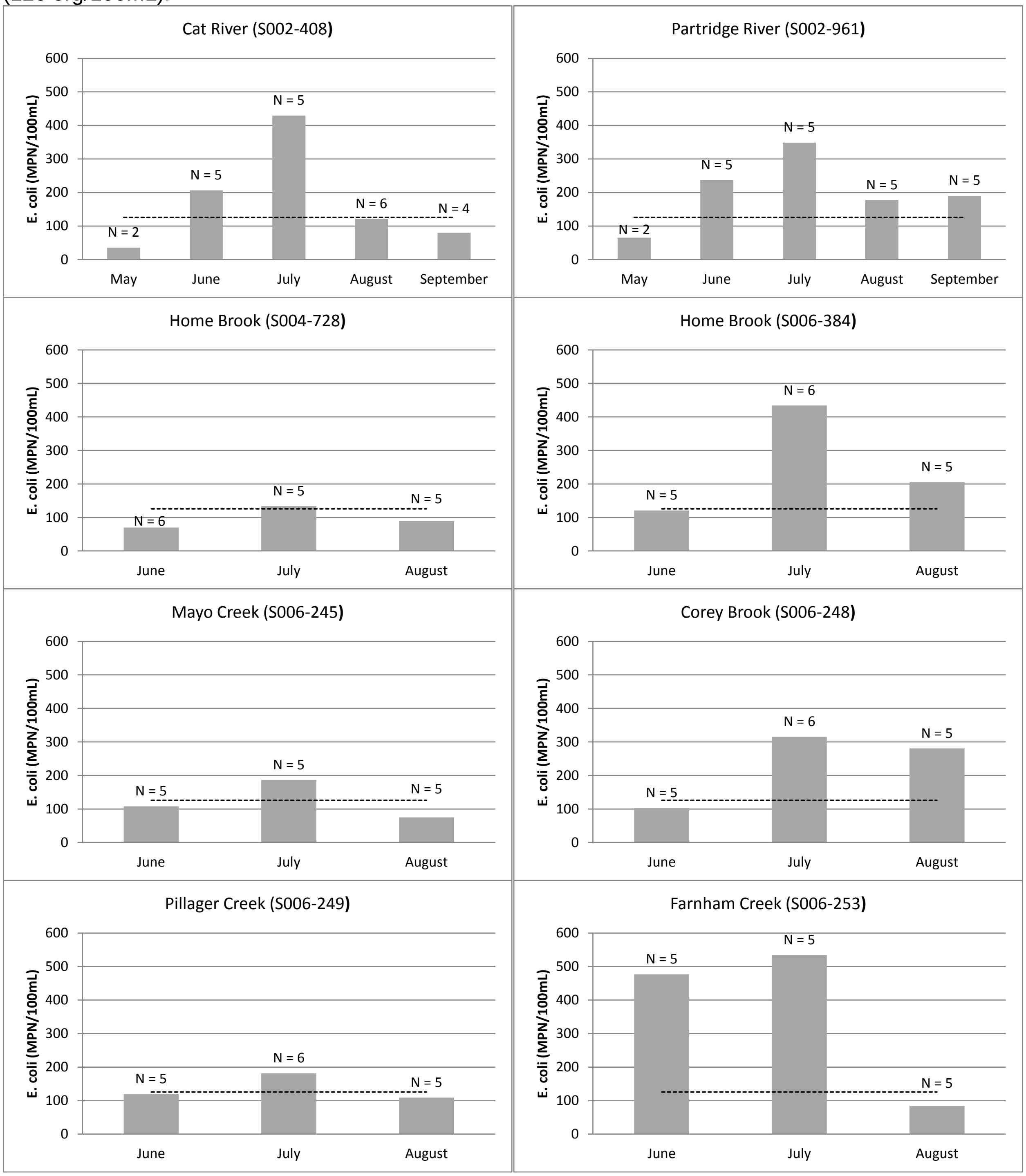
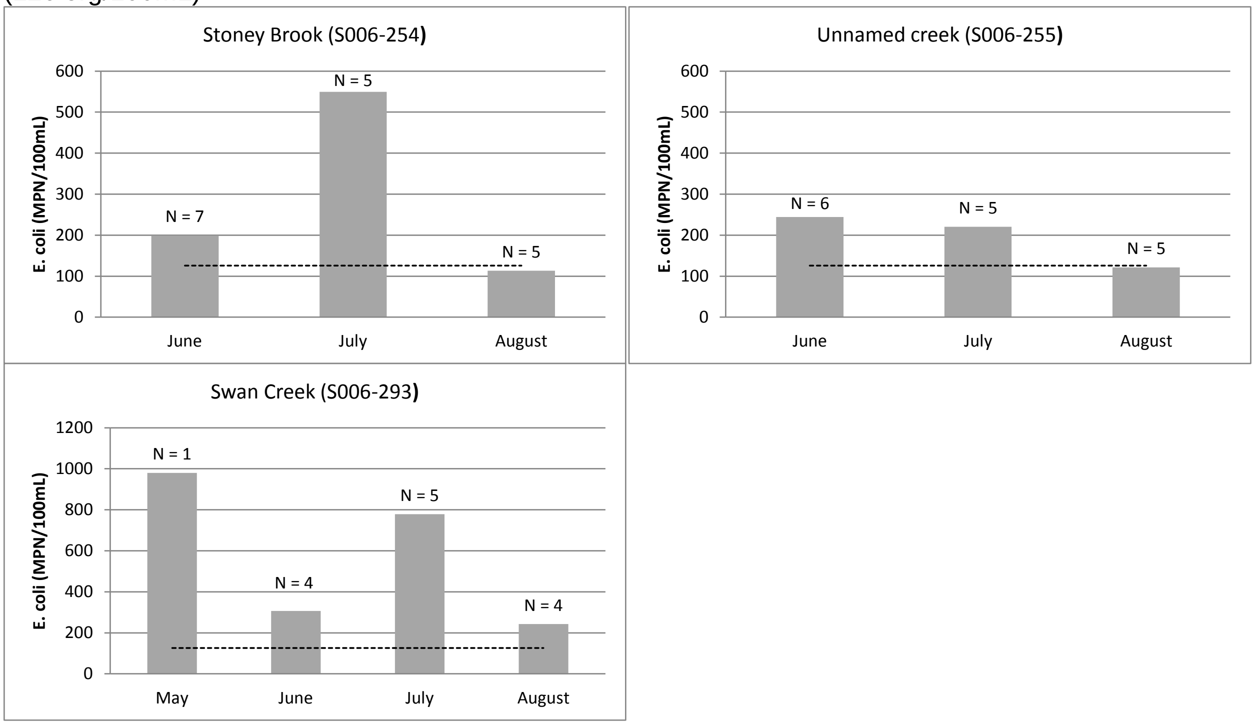


Figure 18 (cont'd). 10-year geometric mean *E. coli* (org/100mL) concentrations by month, 2002-2011.
Number of samples are listed above each data bar. Dashed line represents the water quality standard (126 org/100mL).



3.6 Pollutant Source Summary

3.6.1 Phosphorus

A key component to developing a nutrient TMDL is understanding the sources contributing to the impairment. This section provides a brief description of the potential sources in the watershed contributing to excess nutrients in the impaired lakes and Swan Creek addressed in this TMDL. The following sections discuss the major pollutant sources that have been quantified using collected monitoring data and water quality modeling to both assess the existing contributions of pollutant sources and target pollutant load reductions.

Phosphorus in lakes and streams often originates on land. Phosphorus from sources such as phosphorus-containing fertilizer, manure, and the decay of organic matter can adsorb to soil particles. Wind and water action erode the soil, detaching particles and conveying them in stormwater runoff to nearby waterbodies where the phosphorus becomes available for algal growth. Organic material such as leaves and grass clippings can leach dissolved phosphorus into standing water and runoff or be conveyed directly to waterbodies where biological action breaks down the organic matter and releases phosphorus.

3.6.1.1 Permitted Sources

The regulated sources of phosphorus within the watersheds of the eutrophication impairments addressed in this TMDL study include effluent from wastewater treatment plants, construction sites, and industrial sites. Phosphorus loads from WWTPs, construction, and industrial stormwater runoff were accounted for using the methods described in Section 4.1.1 below.

3.6.1.2 Non-permitted Sources

The following sources of phosphorus not requiring NPDES permit coverage were evaluated:

- Watershed runoff
- Loading from upstream waters
- Runoff from feedlots not requiring NPDES permit coverage
- Atmospheric deposition
- Septic systems
- Lake internal loading

Overland runoff

An Hydrologic Simulation Program Fortran (HSPF) model (AquaTerra 2013) was used to estimate watershed runoff volumes from the direct drainage area and upstream tributary watersheds of impaired lakes. The HSPF model generates overland runoff flows on a daily time step for 81 individual subwatersheds in the Crow Wing River Watershed based on land cover and soil type and was calibrated using meteorological data through 2009. A report containing calibration and validation details for the hydrology, sediment, and water quality constituents of the HSPF model will be available on the Crow Wing River Watershed webpage, as described in Section 16. A 10-year (2000-2009) average annual flow was calculated for lake BATHTUB models, and 10 years of daily flow (2000-2009) were summarized for stream load duration curves.

The Simple Method (Schueler 1987) was used to calculate watershed runoff TP loads. The Simple Method uses an equation that relates watershed pollutant load to watershed drainage area, rainfall depth, percent impervious cover, and event mean runoff pollutant concentration (EMC) based on land cover and soil type. Land cover data were obtained from the 2006 National Land Cover Dataset (http://www.mrlc.gov/nlcd2006.php) and soils data were obtained from the Natural Resources Conservation Service (NRCS) soil survey (http://soils.usda.gov/survey/). Unique combinations of land cover and soil types were generated in ArcGIS and assigned an EMC according to Table 19 below. Each land cover/soil combination was also assigned an estimated impervious percentage based on the NRCS curve number methodology and the Simple Method one-year, 24-hour rainfall event runoff calculation. The sum of all runoff generated by each land cover/soil combination was then calibrated to the average annual runoff modeled in HSPF and multiplied by a corresponding EMC to estimate the annual watershed TP load. The SIMPLE method summary tables for all impaired lake direct drainages and contributing tributaries are provided in Section 12 near the end of the report.

Phosphorus loads from specific sources within the watershed (upstream waters, feedlots not requiring NPDES permit coverage, and subsurface sewage treatment systems) were also independently estimated to determine their relative contributions, described below.

Table 18. HSPF 10 year (2000-2009) annual flow volumes and SIMPLE Method TP loads for direct drainages and contributing tributaries

Impaired lake direct drainage or contributing tributary	Area (ac)	Flow (ac-ft/yr)	TP Load (lb/yr)	TP Conc. (ppb)
Blueberry	1,798	976	257	97.97
Shell River	72,730	26,277	6,188	87.53
Blueberry River	61,271	27,092	6,766	92.83
Eighth Crow Wing	1,607	740	274	137.43
First Crow Wing	21,432	10,337	2,280	81.98
Lower Twin	1,614	693	260	139.65
Mayo	629	463	85	68.09
Portage	2,582	1,172	404	128.27
Sibley	34,735	21,496	4,452	76.99

* Based on daily mid-range flow loads converted to annual loads

Table 19. TP Event Mean Concentration (EMC) values by land cover and soil type

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

Upstream lakes

Upstream lakes can contribute significant phosphorus loads to downstream impaired lakes and streams. Because lakes remove phosphorus from its upstream contributing watershed load through sedimentation, watershed load models such as SIMPLE method that do not account for phosphorus removal of lakes overestimate watershed loads from upstream lakes. Therefore, water quality monitoring data and flow from upstream lakes were used to estimate their phosphorus loads to downstream impaired waters and are summarized in Table 20.

Table 20. Existing upstream phosphorus loads to impaired lakes and streams

Impaired Lake	Upstream Lake (Lake ID)	TP (ppb)	Flow (ac-ft/yr)	TP Load (kg/yr)
Eighth Crow Wing Lake	**Ninth Crow Wing Lake** (29-0025)	19	8,271	192
First Crow Wing Lake	**Second Crow Wing Lake** (29-0085)	22	52,929	1,424
Lower Twin Lake	**Upper Twin Lake** (29-0157)	41	174,078	8,750
Mayo Lake	**Sibley Lake** (18-0404)	33	21,496	880

Feedlots not requiring NPDES permit coverage

Runoff during precipitation and snow melt can carry phosphorus from uncovered feedlots to nearby surface waters. For the purpose of this study, non-permitted feedlots are defined as being all registered feedlots without an NPDES/SDS permit that house under 1,000 animal units. While these feedlots do not fall under NPDES regulation, other regulations still apply. Phosphorus loads from non-permitted registered feedlots were estimated based on assumptions described in the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004) and MPCA registered feedlot data listed in Table 21.

Table 21. Feedlot assumptions and phosphorus loads to impaired lakes and Swan Creek
Adapted from the method described in MPCA 2004

Parameter	Unit	Blueberry Lake	Eighth Crow Wing Lake	First Crow Wing Lake	Lower Twin Lake	Mayo Lake	Portage Lake	Sibley Lake	Swan Creek
Beef cattle	AU	1,600	0	0	651	505	0	505	316
	lb/ AU-yr	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5
Dairy cows	AU	2,599	0	945	99	1069	0	1069	82
	lb/ AU-yr	47.8	47.8	47.8	47.8	47.8	47.8	47.8	47.8
Swine	AU	13	0	3	972	0	0	0	0
	lb/ AU-yr	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6
Total P generated	lb/yr	178,178	0	45,251	302,012	68,016	0	68,016	14,491
Fraction of feedlots contributing to waters	%	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
P fraction lost to surface waters (average flow)	%	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044
Total Annual Feedlot Load	lb/yr	274	0	70	465	105	0	105	22
	kg/yr	**124**	**0**	**32**	**211**	**48**	**0**	**48**	**10**

Subsurface sewage treatment systems (SSTS)

Phosphorus loads from SSTS were estimated based on assumptions described in the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004) listed in Table 22. On average, 24.7% of all individual septic treatment systems are failing in the Upper Mississippi River Basin. Crow Wing County has inspected 3,498 individual septic systems per Minnesota Rules Chapter 7080 since 2008, representing approximately 14 percent of all systems in the County. Of the systems inspected, 140 tanks, or 4%, were found to be non-compliant. All of these systems were either abandoned or upgraded within 10 months to meet current standards. Crow Wing County also conducted 922 septic tank assessments on shoreline properties from 2009 to 2010. The results showed that over 90% of tanks had been recently pumped according to state standards. In addition, of the approximately 100 systems that were also inspected as part of the project, only 3 were non-compliant. Sibley and Mayo Lakes are located in Crow Wing County and were assigned a conservative failure rate of 4%. All other impaired lakes were assigned a failure rate or 24.7%.

Table 22. SSTS phosphorus loads to impaired lakes and assumptions (MPCA 2004)

Parameter	Unit	Blueberry Lake	Eighth Crow Wing Lake	First Crow Wing Lake	Lower Twin Lake	Mayo Lake	Portage Lake	Sibley Lake
Shoreline SSTS[a]	#	36	100	37	65	80	94	230
Seasonal Residence (4 mo/yr)	%	30%	30%	30%	30%	30%	30%	30%
Permanent Residence	%	70%	70%	70%	70%	70%	70%	70%
Conforming Systems	%	75.3%	75.3%	75.3%	75.3%	96%	75.3%	96%
Failing Systems[b]	%	24.7%	24.7%	24.7%	24.7%	4%	24.7%	4%
Capita per Residence[c]	#	2.37	2.33	2.33	2.36	2.18	2.35	2.18
P Production per Capita	lb/yr	1.95	1.95	1.95	1.95	1.95	1.95	1.95
Conforming SSTS %P “passing”	%	20%	20%	20%	20%	20%	20%	20%
Failing SSTS %P “passing”	%	43%	43%	43%	43%	43%	43%	43%
Conforming Systems	#	27	75	28	49	77	71	221
Failing Systems	#	9	25	9	16	3	23	9
P Load Conforming SSTS	lb/yr	20	55	20	36	52	52	150
P Load Failing SSTS	lb/yr	14	39	14	25	4	36	13
Total Shoreline SSTS P Load	lb/yr	34	94	34	61	57	88	163
	kg/yr	**15**	**43**	**15**	**28**	**26**	**40**	**74**
Total Shoreline SSTS P Load due to Failing	**kg/yr**	**3.5**	**9.5**	**3.4**	**6.1**	**1.1**	**8.8**	**3.2**

[a] 2011 Bing Aerial Photo; [b] 24.7% from p.12 of MPCA 2004
[c] 2007-2011, U.S. census bureau, http://quickfacts.census.gov/qfd/maps/minnesota_map.html

Atmospheric Deposition

Atmospheric deposition represents the phosphorus that is bound to particulates in the atmosphere and is deposited directly onto surface waters. Average phosphorus atmospheric deposition loading rates were ~0.24 lb/ac of TP per year for an average rainfall year for the Upper Mississippi River Basin (Barr 2007 addendum to MPCA 2004). This rate was applied to the lake and stream surface area to determine the total atmospheric deposition load per year to the impaired lakes. The surface area of Swan Creek was estimated based on an assumed average width of 30 feet and measured length of 102,998 feet (19.5 miles).

Table 23. Atmospheric deposition phosphorus loads to impaired lakes [MPCA 2004]

Parameter	Unit	Blueberry Lake	Eighth Crow Wing Lake	First Crow Wing Lake	Lower Twin Lake	Mayo Lake	Portage Lake	Sibley Lake	Swan Creek
Atmospheric deposition	lb/yr	128	121	122	60	36	100	102	17
	kg/yr	**58**	**55**	**55**	**27**	**16**	**45**	**46**	**7.7**

Internal Loading

Internal loading in lakes refers to the phosphorus load that originates in the bottom sediments or macrophytes and is released back into the water column. Internal loading can occur via:

1. *Chemical release from the sediments*
   Caused by anoxic (lack of oxygen) conditions in the overlying waters or high pH (>9). If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be mixed throughout the water column when the lake loses its stratification at the time of fall mixing. In shallow lakes, the periods of anoxia can last for short periods of time and occur frequently.

2. *Physical disturbance of the sediments*
   Caused by bottom-feeding fish behaviors (such as carp and bullhead), motorized boat activity, and wind mixing. This is more common in shallow lakes than in deeper lakes.

3. *Decaying plant matter*
   Specifically curly-leaf pondweed (Potamogeton crispus) which is an invasive plant that dies back mid-summer which is during the season to which the TMDL will apply and when water temperatures can accelerate algal growth.

Internal loading due to the anoxic release from the sediments of each lake was estimated in this study based on the expected release rate (RR) of phosphorus from the lakebed sediment, the lake anoxic factor (AF), and the lake area. Lake sediment samples were taken and tested for concentration of total phosphorus (TP) and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound phosphorus. Phosphorus release rates were calculated using statistical regression equations developed using measured release rates and sediment P concentrations from a large set of North American lakes (Nürnberg 1988; Nürnberg 1996). Internal loading due to physical disturbance and decaying curly-leaf pondweed is difficult to estimate reliably and was therefore not included in the lake phosphorus analyses. In lakes where internal loading due to these sources is believed to be substantial, the internal load estimates derived from lake sediment data presented here are likely an underestimate of the actual internal load.

Because some amount of internal loading is explicit in the BATHTUB lake water quality model and uncertainty exists around the amount of internal loading estimated by the Nurnberg regression equations, the estimated total sediment phosphorus release rates per anoxic day converted to a 365-calendar day were used as a reference point for calibrating each impaired lake BATHTUB model to observed in-lake phosphorus concentrations (see Section 4.1.1.1: Model Calibration). Moreover, the internal loading rates estimated by the Nurnberg regression equations represent the total potential sediment release rate while the calibrated internal loading rates from the BATHTUB model represents the excess sediment release rate beyond the average background release rate accounted for by the model development lake dataset. The estimated sediment phosphorus release rates using the Nurnberg regression equations are typically smaller than the calibrated BATHTUB release rates for shallow lakes because the BATHTUB model development lake dataset is less representative of this lake type and therefore accounts for less implicit internal loading in shallow lakes. This was the case for two shallow lakes in the Crow Wing River Watershed, Blueberry and First Crow Wing, where the calibrated BATHTUB release rates were slightly greater than the estimated sediment phosphorus release rates using the Nurnberg regression equations (Table 24). For all other lakes, the calibrated BATHTUB release rates were less than the estimated sediment phosphorus release rates using the Nurnberg regression equations or zero, indicating that some or all of the internal loading in these lakes was accounted for by average background release rates from the model development lake dataset.

Table 24. Internal phosphorus load assumptions and summary (Nurnberg 1988, 1996)

Lake	Lake Type	Sediment P Concentration (mg/kg dry)		Anoxic Factor	Estimated Total Sediment P Release Rate NA Lakes Dataset (mg/m^2-anoxic day)			Average Estimated Total Sediment P Release Rate NA Lakes Dataset	BATHTUB Calibrated Excess Release Rate	BATHTUB Calibrated Excess Internal Load
		Iron P (BD-P)	Total P (TP)	(days)	BD-P	TP	Average	(mg/m^2-calendar day)	(mg/m^2-calendar day)	(kg/yr)
Blueberry	Shallow	610	1,800	64	7.79	2.61	5.20	0.91	2.79	**2,196**
Eighth Crow Wing	General	290	2,200	40	3.40	4.11	3.76	0.41	0.41	**295**
First Crow Wing	Shallow	290	2,900	53	3.40	6.75	5.08	0.74	4.11	**3,094**
Lower Twin	General	1,100	3,200	47	14.51	7.88	11.20	1.44	1.28	**477**
Mayo	Shallow	1,900	7,200	44	25.49	22.96	24.23	2.92	0.89	**198**
Portage	Shallow	110	1,300	51	0.93	0.72	0.83	0.12	0.12	**73**
Sibley	General	950	7,800	42	12.45	25.23	18.84	2.17	0	**0**

3.6.2 Heating Capacity

Temperatures at some of the monitored sites on the Straight and Shell rivers exceeded the individual in-stream target temperatures necessary to maintain dissolved oxygen levels at or above the in-stream water quality standard plus monitored biochemical oxygen demands (see Section 2.3.1.2 for more information regarding the development of in-stream target temperatures).

The sources of high heat inputs to these rivers are linked to decreased groundwater flows, resulting primarily from increased groundwater appropriations for surface crop irrigation (Table 25, Figure 19). Since groundwater is cooler than surface water in summer months, the application of cool groundwater to the land surface lead to higher surface water temperatures. The interaction between surface water and groundwater and thermal changes in the Straight River have been investigated intensively by many local stakeholders, including the Minnesota DNR Hydrology Division, MN DNR Area Fisheries Division, RDO Lamb Weston, Trout Unlimited, the Minnesota Center for Environmental Advocacy, and the U.S. Geological Survey. The results from this investigation are publically available in the July 2002 report titled, "*Surface Water And Ground Water Interaction and Thermal Changes In The Straight River In North Central Minnesota*." In addition, the Minnesota DNR is currently working to implement a Straight River Groundwater Management Area (http://www.dnr.state.mn.us/gwmp/area-sr.html).

The following section is a summary provided by the Minnesota DNR for this TMDL report:

> The Straight River area is primarily and outwash area that is underlain by undifferentiated glacial till. The soils are sandy loam and till which are coarse textured and rapidly permeable (USDA, 2000). The glacial material (including the outwash and till) is several hundred feet thick and thickness increases from south to north (Stark et al, 1994.) The sandy outwash area under the majority of the area and directly beneath the City of Park Rapids (City) is of Wadena Lobe origin; produced during the formation of the Itasca Moraine. South of the city is the Wadena Lobe Alexandria Moraine. To the northwest is the Wadena Lobe Itasca End Moraine. To the northeast is the end moraine of the Bemis phase of the Des Moines Lobe. The bedrock geology beneath the city consists of late Archean metamorphic and igneous rocks that do not act as aquifers in this area.
>
> The glacial geology and area well logs indicate that two types of aquifers are available for use in this area, the quaternary unconfined water table aquifer (QWTA) and confined quaternary buried artesian aquifers (QBAA). The QWTA is a laterally extensive unconfined aquifer that is part of the Pinelands Sands aquifer (Helgesen, 1977) which extends through Becker, Cass, Hubbard, and Wadena counties.
>
> The aquifers designated as QBAA in this area consist of a number of confined sand/gravel aquifers found at varying depths that are generally separated by till layers of varying thickness. The till layers vary in composition from sandy clay to clayey materials and vary in their confining capability across the area. Locally, the QBAA layers can supply high capacity volumes of water. The first confined aquifer is a sand and gravel aquifer of varying thickness found at depths of approximately 100 feet intermittently throughout the study area. Locally, where the till thins to zero thickness, the aquifer is unconfined. The second confined aquifer is located at approximately 200 feet deep

intermittently throughout the study area and is also varying in thickness and composition. Test drilling, aquifer testing, and water level monitoring by MN DNR have demonstrated the tills separating these aquifers are discontinuous and hydraulically leaky. The USGS (Stark et al. 1994) also demonstrated this.

The surface water resources in this area are in the form of streams, lakes and wetlands. The primary river is the Straight River. The soils in this area are primarily outwash sands and gravels, which are excessively drained and have high to very high saturated hydraulic capacities[2]. Analyses by Stark et al. (1994), Helgesen (1977), LaBaugh et al. (1981), and Siegel (1980) have shown that shallow groundwater and surface water in this area is interconnected and heavily dependent on recharge from precipitation. Groundwater in the water table and first confined aquifer flows generally from the northwest to the southeast based on synoptic water level data collected by MN DNR in May and September of 2012 and May of 2013. Previous research by Stark et al. (1994) also showed this flow direction.

In the Straight River- Park Rapids area, the primary permitted water use is agricultural irrigation. Other permitted water users include municipal supply, non-crop irrigation, and industrial supply. As of 2012, there were 279 permits issued for water appropriation in this area. Of these permits, seven had been issued to appropriate directly from surface water bodies. The remaining permits were issued to appropriate groundwater from both the QWTA and the QBAA aquifers. Total use data from groundwater appropriation in this area since 1988 is shown in Figure 3. Total water use has been increasing since 1998, primarily because of increases in agricultural irrigation. Reported groundwater use by all permitted users in this area was 8.6 billion gallons per year in 2012 compared to 4.6 billion in 1988.

Domestic water use does not require permitting by MN DNR and therefore locations and numbers of domestic wells were not included in the projected water use analysis. Average household water use is 260 gallons of water per day according to the University of Minnesota (2008). There are 2322 wells reported as being domestic in the MDH well database County Well Index in this working area. The estimated total domestic use in this area would be approximately 603,720 gallons per day or 220.36 million gallons per year.

Water use in this area has changed over time in volume and distribution. Detailed records of water use reported by permit holders are available in an electronic database beginning with records from 1988. From 1988 to 2012 water use by Major crop irrigation has increased from 4.1 to 7.0 billion gallons per year. Non-crop irrigation increased from 48.8 million to 122 million gallons/year use. The primary increase was from nursery/orchard use.

The City of Park Rapids reported their average municipal groundwater use decreased from 214.7 to 160 million gallons/year from 1988 to 2012 respectively. The City reports on their website that their average demand is 500,000 gallons/day.

[2] http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

Straight River, Straight Lake (an impoundment of Straight River), and the two tributaries to Straight Lake are the primary surface water features in the area. Straight River and its tributaries are designated trout streams. These surface waters have a strong hydraulic connection to groundwater and health of these streams depends on the discharge of cold water from the groundwater system. Numerous springs, seeps and groundwater upwelling in the streams contribute cold water that keeps water temperatures suitable for trout. As a result, the Straight River supports a naturally reproducing population of brown trout. Upper Straight Creek supports a naturally reproducing population of brook trout that is stocked annually Straight Lake Creek supports both brook and brown trout.

Dissolved oxygen (DO) is also critical to many forms of aquatic life, but particularly those associated with cold water systems. The concentration of DO is inversely related to water temperature. As water temperature increases, the amount of DO the water can hold decreases. Reduction of groundwater discharge can result in decreases in flow or volume of water in a stream, which in turn can reduce the amount of habitat for fish and other aquatic organisms. Reduced groundwater discharge will also result in higher temperatures and lower DO holding capacity in the stream.

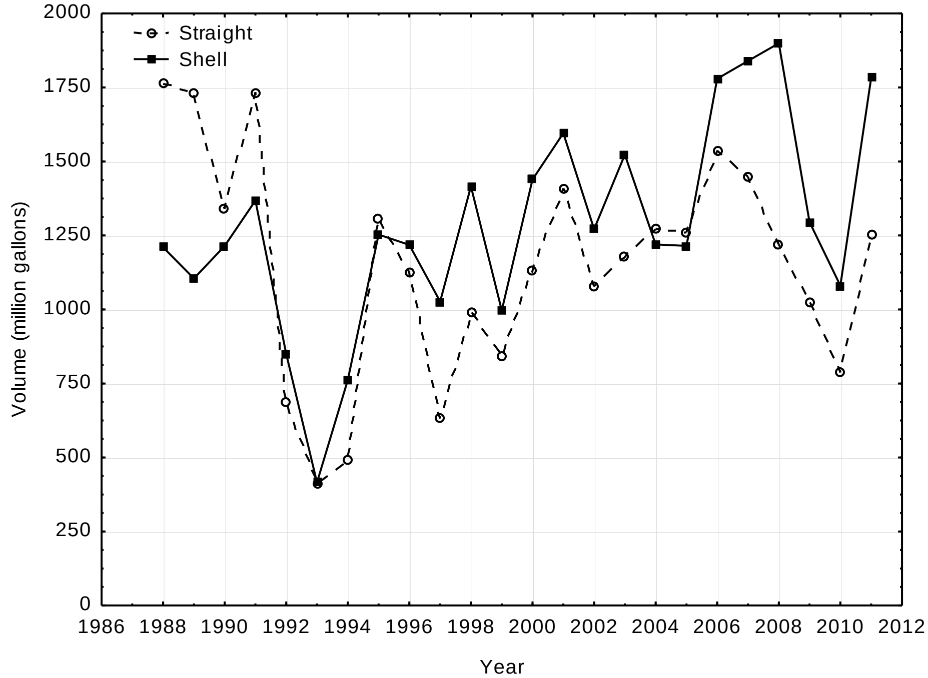
Water temperature monitoring in the Straight River by (DNR Fisheries) since 2003 has shown thermal stress ranges and even lethal temperatures for brown trout have frequently been exceeded. There has been an increasing trend over the last ten years in the average percentage of time that the thermal stress range for brown trout has been exceeded. In 2010 Minnesota Pollution Control Agency included the Straight River on the Minnesota List of Impaired Waters due to low DO levels. Minnesota statute prohibits issuing of non-temporary permits to appropriate water from trout streams.

Other surface water features in and around this area include many lakes and wetlands. As was demonstrated by Stark et al. (1994), Helgesen (1977), LaBaugh et al. (1981), Siegel (1980) and Walker et al. (2009), surface waters in this area have a strong hydraulic connection to the QWTA and their water levels are primarily affected by precipitation. Appropriation from the QWTA near these resources would have the most effect on these surface water resources.

Table 25: Groundwater appropriation uses located in the impaired stream direct drainage. Agricultural appropriations include major crop irrigation and nurseries while industrial appropriations include waterworks and industrial processing.

Impaired Stream	HSPF Basin	Time Period	Annual Average Groundwater Appropriation Uses				
			All Uses	Agricultural Uses		Industrial Uses	
			million gallons/ year	million gallons/ year	% total	million gallons/ year	% total
Straight River	515	1988-1989	966	966	100%	0	0%
		1990-1999	441	441	100%	0	0%
		2000-2009	648	648	100%	0	0%
		2010-2011	486	486	100%	0	0%
	516	1988-1989	781	776	99%	5	0.6%
		1990-1999	515	432	84%	83	16%
		2000-2009	608	604	99%	4	0.6%
		2010-2011	535	525	98%	10	1.9%
Shell River	528	1988-1989	1,157	1,157	100%	0	0%
		1990-1999	955	955	100%	0	0%
		2000-2009	1,395	1,395	100%	0	0%
		2010-2011	1,310	1,310	100%	0	0%
	530	1988-1989	0	0	-	0	-
		1990-1999	97	97	100%	0	0%
		2000-2009	113	113	100%	0	0%
		2010-2011	122	122	100%	0	0%

Figure 19. Annual groundwater appropriation uses within the Straight and Shell River watersheds.



3.6.3 *Escherichia coli*

Humans, companion animals, livestock, and wildlife all contribute bacteria to the environment. These bacteria, after appearing in animal waste, are dispersed throughout the environment by an array of natural and man-made mechanisms. Bacteria fate and transport is affected by disposal and treatment mechanisms, methods of manure reuse, imperviousness of land surfaces, and natural decay and die-off due to environmental factors such as ultraviolet (UV) exposure and detention time in the landscape. The following discussion highlights sources of bacteria in the environment and mechanisms that drive the delivery of bacteria to surface waters.

The fate and transport of bacteria after it leaves the animal is widely variable. The landscape onto which the bacteria is excreted, applied, stored, or discharged affects the level of risk of contamination of downstream surface waters. Mechanisms that drive the fate and transport of bacteria in pervious landscapes significantly differ from that of impervious landscapes.

Certainly agricultural activities and septic systems are unique to pervious, if not rural, landscapes. In addition, expansive pervious landscapes are characterized by natural and ditched drainage ways, agricultural draintile, and large tracts of natural landscapes. These factors affect the movement to surface waters of watershed runoff and its associated pollutants. Draintile can accelerate transport of pollutants, but pervious surfaces and natural landscapes can slow transport.

Absent of stormwater BMPs, fecal bacteria and associated pathogen loads in urban stormwater are directly conveyed to lakes, streams, and rivers via impervious surfaces, storm drains, and storm sewer system networks. As a result of aging infrastructure, impervious landscapes can also be characterized by chronic contamination of storm sewer systems that convey raw sewage originating from breeches in sanitary sewers (Sauer et al. 2011; Sercu et al. 2009; Sercu et al. 2011). Fecal bacteria concentrations in stormwater runoff from urban areas can be as great as or greater than those found in cropland runoff, grazed pasture runoff, and feedlot runoff (EPA 2001).

To evaluate the potential sources of bacteria to surface waters in the Crow Wing watershed a Bacteria Source Investigation was conducted. This investigation was conducted at two different scales due to limited data availability in some areas of the watershed. The two types of Bacteria Source Investigations conducted in the Crow Wing watershed are:

1. **Population Based Source Investigation**
2. **Population and Delivery Based Source Investigation**

The **Population Based Source Investigation** is less detailed than the Population and Delivery Based Source Investigation and generally provides guidance for protection planning to prevent future *E. coli* impairments. A Population Based Source Investigation includes the following steps:

1. Identify those population sources that are potentially contributing *E. coli* in the watershed. These populations may include humans, companion animals (horses, cats and

dogs), livestock (cattle, goats, hogs, sheep and poultry), and wildlife (deer, geese, ducks, raccoons, feral cats).

2. Once these population based sources have been identified, calculate the population using published estimates for each source on an individual subwatershed basis in the TMDL Project Area. This is typically a GIS exercise where population estimates are clipped to the individual subwatershed boundaries. In some cases, these population estimates are clipped to individual land uses (defined using the 2006 USGS National Land Cover Dataset, NLCD) within the individual subwatersheds. For example, estimated duck populations are assigned to open water land uses within individual subwatersheds.

3. Next, each source is assigned a bacteria production value (see Table 26). In some cases, overriding assumptions exist regarding the relative delivery potential (i.e. land application of biosolids having low delivery potential due to regulations) that are used in place of population estimates. These include:

    - Assumptions about relative delivery potential from humans are provided in Table 28;
    - Assumptions about relative delivery potential from livestock are provided in Table 33 (applies a percent reduction based upon assumptions made for grazing animals and animal feeding operations); and
    - Assumptions about relative delivery potential from companion animals are provided in Table 32 (based on assumptions made for waste collection).

In the case of the Crow Wing River Watershed TMDL a Population Based Source Investigation was conducted on six subwatersheds located in part in Crow Wing County due to a lack of inclusion in the state-wide GIS layers of Water Quality Risk.

The **Population and Delivery Based Source Investigation** takes the Population Based Source Investigation one step further and calculates the delivery potential for the sources by taking certain landscape features into account. The additional steps taken to conduct a Population and Delivery Based Source Investigation are as follows:

4. Develop and apply bacteria delivery factors for sources that end up on the land surface prior to discharge to surface waters but do not have overriding assumptions as to the relative delivery potential. The bacteria delivery factors account for fate and transport factors such as proximity to surface waters, watershed slope, imperviousness, and discharge to lakes prior to discharge to stream networks. A unique delivery factor is calculated for each bacteria source category and each subwatershed using the state-wide GIS layers of Water Quality Risk.

Figure 20 illustrates the portions of the watershed covered by the Population Based Source Investigation versus the Population and Delivery Based Source Investigation.

Bacteria production estimates are based on the bacteria content in feces and an average excretion rate (with units of colony forming units (cfu)/day-head; where *head* implies an individual animal). Bacteria content and excretion rates vary by animal type. The USEPA's *Protocol for Developing Pathogen TMDLs* provides estimates for bacteria production for most animals shown in Table 26 (USEPA 2001a). All production rates obtained from the literature are for fecal coliform rather than *E. coli* due to the lack of *E. coli* data. The fecal coliform production rate was multiplied by 0.5 to estimate the *E. coli* production rate, which is based on the rule of thumb that 50% of fecal coliform are *E. coli* (Doyle and Erikson 2006).

Table 26. Bacteria production by source

Source Category	Producer	*E. coli* Production Rate [cfu/day-head]	Literature Source[1]
Humans	Humans	1×10^{9}	Metcalf and Eddy 1991
Companion Animals	Dogs & Cats	2.5×10^{9}	Horsley and Witten 1996
Livestock	Horses	2.1×10^{8}	ASAE 1998
	Cattle	2.7×10^{9}	Metcalf and Eddy 1991
	Hogs	4.5×10^{9}	Metcalf and Eddy 1991
	Sheep & Goats	9×10^{9}	Metcalf and Eddy 1991
	Poultry	1.3×10^{8}	Metcalf and Eddy 1991
Wildlife	Deer	1.8×10^{8}	Zeckoski et al. 2005
	Geese	2.5×10^{10}	LIRPB 1978
	Breeding Ducks	5.5×10^{9}	Metcalf and Eddy 1991
	Raccoons	5.7×10^{7}	Yagow 1999
	Beavers	1.3×10^{8}	EPA Best Professional Judgment in Bacterial Indicator Tool
	Pigeons	8.0×10^{7}	Oshiro and Fujioka 1995

[1] Literature sources provide fecal coliform production rates, which were converted to *E. coli* by applying a conversion factor of 0.5 based on Doyle and Erikson (2006). Therefore, *E. coli* production rate = 0.5 x fecal coliform production rate

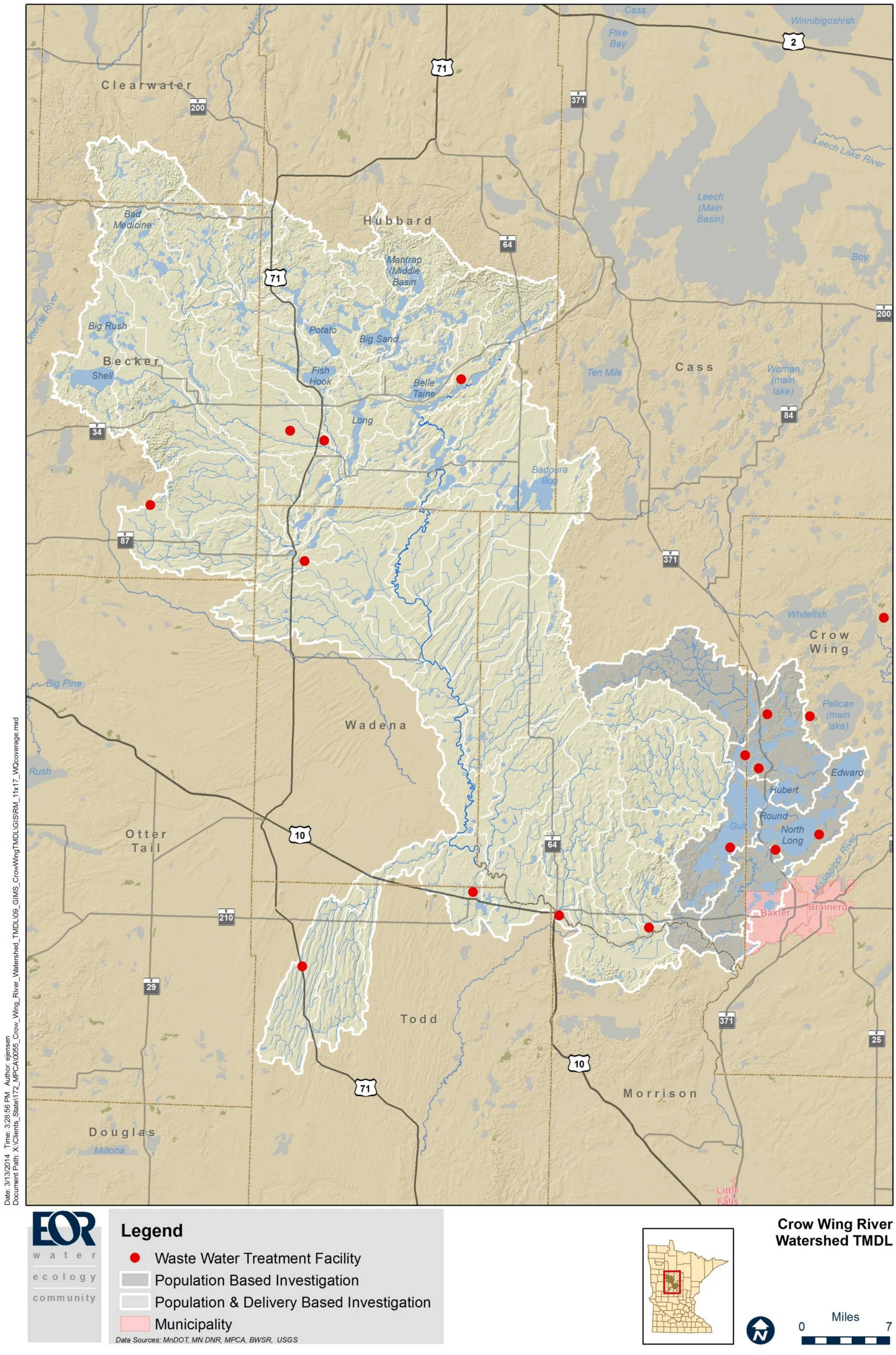


Figure 20. Population and Delivery Based Bacteria Source Investigation Areas & WWTFs

3.6.3.1 Permitted Sources of Escherichia Coli

Humans

Wastewater Treatment Facilities (WWTFs) and Collection Systems

WWTFs are required to test fecal coliform bacteria levels in effluent on a weekly basis. Dischargers to Class 2 waters are required to disinfect from April through October. Raw sewage *E. coli* concentration was estimated at 3.15×10^6 org/100 mL based on an approximate 2:1 relationship between fecal coliform and *E. coli* in waste [Doyle and Erickson (2006)]. Wastewater disinfection is required during all months for dischargers within 25 miles of a water intake for a potable water supply system (Min. Rules Ch. 7053.0215, subp. 1). The geometric mean for all samples collected in a month must not exceed 200 cfu/100 mL fecal coliform bacteria. The WWTFs located in the Crow Wing River Watershed with surface water discharges are summarized in Table 27 and shown in Figure 20.

Table 27. WWTF design flows and permitted bacteria loads

HUC 12 ID (07010106-XXXX)	Name of WWTF	Permit No.	Design Flow [mgd]	Permitted Bacteria Load as Fecal Coliform: 200 org/ 100 mL [billion org/day]	Equivalent Bacteria Load as *E. coli*: 126 org / 100 mL[1] [billion org/day]
1104	Motley WWTP	MN0024244	0.4300	3.25	2.05
0602	Nevis WWTP	MN0062855	0.0525	0.40	0.25
1101	Staples WWTP	MN0024988	0.3600	5.14	3.24
0301	Wolf Lake WWTP	MN0069205	0.0084	0.06	0.04
1106	Pillager WWTP	MNG580209	0.0732	0.56	0.35
0901	Bertha WWTP	MN0022799	0.6400	4.84	3.05
0102	Lamb Weston/RDO Frozen Industrial WWTP	MN0051454	9.5400	3.17	2.00
0801	Menagha WWTP	MNG580032	0.1950	1.48	0.93

[1] WWTF permits are regulated for fecal coliform, not *E. coli*. The MPCA surface water quality standard for *E. coli* (126 org / 100 ml) was used in place of the fecal coliform permitted limit of 200 org / 100 ml, which was also the MPCA surface water quality standard prior to the March 2008 revisions to Minnesota Rules Chapter 7050. Loads are reported with three significant figures.

Land Application of Biosolids

The application of biosolids from WWTFs is highly regulated, monitored, and tracked (see Minnesota Rules Chapter 7041 *Sewage Sludge Management*). Biosolids disposal methods that inject or incorporate within 24-hours of land application result in minimal possibility for mobilization of bacteria to downstream surface waters. While surface application could conceivably present a risk to surface waters, little to no runoff and bacteria transport is expected if permit restrictions are followed.

Data Sources and Assumptions

Human population data were obtained using block groups[3] from the 2010 Census data (U.S. Census Bureau 2011). The census block groups that overlap subwatershed boundaries were distributed between each applicable subwatershed on an area-weighted basis. Data sources and assumptions used for estimating the potential source of bacteria from humans are listed in Table 28.

Table 28. Data Sources & Assumptions for Estimates of Potential Bacteria Sources: Humans.

Bacteria Sources			Data Sources and Assumptions
Sewered Community	WWTF	WWTF Effluent	Based on WWTF design flow and NPDES permit limits
		Land Application of Biosolids	Delivery assumed to be low based on regulation.

[1] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g. a municipality or a portion of a large city).

3.6.3.2 Non-permitted Sources of Escherichia Coli

Humans

Combined Sewer Overflows

Combined sewer systems are designed to collect sanitary sewage and stormwater runoff in a single pipe system. These systems overflow occasionally when heavy rain or melting snow causes the wastewater volume to exceed the capacity of the sewer system or treatment plant. An overflow event is called a combined sewer overflow or CSO, which entails a mix of raw sewage and stormwater runoff (from buildings, parking lots, and streets) flowing untreated into surface waters. The occurrence of CSOs is not an issue in the Crow Wing River Watershed.

[3] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g. a municipality or a portion of a large city).

Illicit Discharges from Unsewered Communities

In many cases, onsite or small community cluster systems to treat wastewater are installed and forgotten until problems arise. Residential lots in small communities throughout Minnesota cannot accommodate modern septic systems that meet the requirements of current codes due to small lot size and/or inadequate soils. Development pressures in lake communities add to the problem as well as cabins that occupy a large footprint on small lake lots. In addition, many small communities are characterized by outdated, malfunctioning septic systems serving older residences. Small lots, poor soils, and inadequate septic system designs and installations may be implicated in bacterial contamination of groundwater but the link to surface water contamination is tenuous. Community septic systems that discharge greater than 10,000 gallons per day are required to obtain an NPDES discharge permit.

"Failing" subsurface sewage treatment systems (SSTS) are specifically defined as systems that are failing to protect groundwater from contamination, while those systems which discharge partially treated sewage to the ground surface, road ditches, tile lines, and directly into streams, rivers and lakes are considered an imminent threat to public health and safety (ITPHS). ITPHS systems also include illicit discharges from unsewered communities (sometimes called "straight-pipes"). Straight pipes are illegal and pose an imminent threat to public health as they convey raw sewage from homes and businesses directly to surface water. Community straight pipes are more commonly found in small rural communities.

MPCA's 2011 report to the legislature, *Recommendations and Planning for Statewide Inventories, Inspections of Subsurface Sewage Treatment System*, identifies percent of systems in unsewered communities that are ITPHS for each county in Minnesota (MPCA 2011). The following table identifies the percentage of systems in unsewered communities that are estimated to be ITPHS by county.

Table 29. 2000-09 Average Estimate of % Imminent Threat to Public Health & Safety Systems (ITPHSS) by County

County	%ITPHSS[1]
Becker	0%
Cass	7%
Clearwater	6%
Crow Wing	2%
Hubbard	6%
Morrison	13%
Ottertail	13%
Todd	10%
Wadena	6%

Source: MPCA (2011)
[1] Imminent Threat to Public Health & Safety (ITPHS) Septic System data are derived from surveys of County staff and County level Subsurface Sewage Treatment System (SSTS) status inventories. The specific location of ITPHS systems is not known. The table is not intended to suggest that ITPHS systems contribute excess bacteria to specific waterbodies addressed in this report, rather it suggests that, in general, failing septic systems are believed controllable sources of bacteria in the project area.

Land Application of Septage

A state subsurface sewage treatment system (SSTS) license applicable to the type of work being performed is required for any business that conducts work to design, install, repair, maintain, operate, or inspect all or part of an SSTS. A license is also required to land spread septage and operate a sewage collection system discharging to an SSTS. Disposal contractors are required to properly treat and disinfect septage through processing or lime stabilization. Treated septage may then be disposed of onto agricultural and forest lands. USEPA Standards Section 503 provides general requirements, pollutant limits, management practices, and operational standards for the final use or disposal of septage generated during the treatment of domestic sewage in a treatment works.

MPCA does not directly regulate the land application of septage, but management guidelines entail site suitability requirements with respect to soil conditions, slope, and minimum separation distances (MPCA 2002). Some cities and townships have SSTS septage ordinances (a list is available at http://www.pca.state.mn.us/index.php/view-document.html?gid=10139); these were not reviewed as a part of this study.

Data Sources and Assumptions

Data sources and assumptions used for estimating the potential source of bacteria from humans are listed in Table 30.

Table 30. Data Sources & Assumptions for Estimates of Potential Bacteria Sources: Humans.

Bacteria Sources			Data Sources and Assumptions
Unsewered Community	Compliant SSTS	SSTS Discharge to Groundwater	Not accounted for because discharge is not to surface water
		Land Application of Septage	Delivery assumed to be low based on regulations; refer to *Land Application of Septage* on Page 64.
	Non-Compliant SSTS	ITPHS SSTS, including Illicit Discharges	The population in unsewered communities was estimated based on 2010 Census block groups[1] (U.S. Census Bureau 2011) for those areas outside of the WWTF service area. The WWTF service area was estimated as applicable 2006 NLCD *Developed* land covers. SSTS flow was estimated to be 265 L/person-day (Metcalf and Eddy 1991). The estimated fraction of flow from unsewered communities that is classified as ITPHS was applied based on MPCA (2011) (refer to Table 2). Raw sewage *E. coli* concentration was estimated at 3.15 x 10^6 org/100ml, which is equal to half the fecal coliform concentration [(as suggested by Doyle and Erikson (2006)] provided in Overcash and Davidson (1980) as referenced in USEPA (2011).

[1] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g. a municipality or a portion of a large city).

Companion Animals

Companion animals (dogs and cats) can contribute bacteria to a watershed when their waste is not properly managed. When this occurs, bacteria can be introduced to waterways from:

- Dog parks
- Residential yard runoff (spring runoff after winter accumulation)
- Rural areas where there are no pet cleanup ordinances
- Animal elimination of excrement directly into waterbodies

Dog waste can be a significant source of pathogen contamination of water resources (Geldreich 1996). Dog waste in the immediate vicinity of a waterway could be a significant local source with local water quality impacts. However, it is generally thought that these sources may be only minor contributors of fecal contamination on a watershed scale because the estimated magnitude of this source is very small compared to other sources. Cats may contribute significantly to bacteria levels in urban streams and rivers (Ram et al. 2007). Feral cats are accounted for separately in this study as wildlife.

Data Sources and Assumptions

Numbers of households were used to estimate companion animal populations and were obtained using block groups[4] from the 2010 Census data (U.S. Census Bureau 2011). The census block groups that overlap subwatershed boundaries were distributed between each applicable sub watershed on an area-weighted basis. Data sources and assumptions used for estimating the potential source of bacteria from companion animals are listed in Table 31 and Table 32.

Table 31. Data Sources and Assumptions for Estimates of Companion Animal Populations

Animal	Basis for Estimates of Animal Population
Dogs	According to the American Veterinary Medical Association's (AVMA) 2006 data, 34.2% of Minnesota households own dogs with a mean number of 1.4 dogs in each of those households (AVMA 2007).
Cats	According to the American Veterinary Medical Association's (AVMA) 2006 data, 31.9% of Minnesota. households own cats with a mean number of 2.3 cats in each of those households (AVMA 2007)

Table 32. Data Sources & Assumptions for Estimates of Potential Bacteria Sources: Companion Animals

NOTE: In all cases, bacteria production by animal type was used based on references cited by USEPA (2001), refer to Table 26.

<table>
<tr><th colspan="2">Bacteria Source Categories
Data Sources and Assumptions</th><th>Delivery Factor</th></tr>
<tr><td rowspan="2">Waste Not Collected by Owners
- Dogs 38% (TBEP 2012)</td><td>Pervious Areas
Cats and dogs belonging to households within all 2006 NLCD land covers except Open Water and Developed.</td><td>Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters.</td></tr>
<tr><td>Impervious Areas
Cats and dogs belonging to households within 2006 NLCD Developed land covers.</td><td>Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters.</td></tr>
<tr><td colspan="2">Waste Collected by Owners
- Dogs 62%
- Cats 100%</td><td>Zero delivery to downstream surface waters.</td></tr>
</table>

[4] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g. a municipality or a portion of a large city).

Livestock

Animal Feeding Operations

Animal waste containing fecal bacteria can be transported in watershed runoff to surface waters. The MPCA regulates animal feedlots in Minnesota though counties may be delegated by the MPCA to administer the program for feedlots that are not under federal regulation. The primary goal of the state program for animal feeding operations is to ensure that surface waters are not contaminated by the runoff from feeding facilities, manure storage or stockpiles, and cropland with improperly applied manure. Livestock also occur at hobby farms, small-scale farms that are not large enough to require registration but may have small-scale feeding operations and associated manure application or stockpiles.

Land Application of Manure

Livestock manure is often either surface applied or incorporated into farm fields as a fertilizer and soil amendment. This land application of manure has the potential to be a substantial source of fecal contamination, entering waterways from overland runoff and drain tile intakes. Research being conducted in southern MN shows high concentrations of fecal bacteria leaving fields with incorporated manure and open tile intakes (Jamieson *et al.* 2002). MN Rules Chapter 7020 contains manure application setback requirements based on research related to phosphorus transport, and not bacterial transport, and the effectiveness of these current setbacks on bacterial transport to surface waters is not known.

Grazing

Pastured areas are those where grass or other growing plants are used for grazing and where the concentration of animals allows a vegetative cover to be maintained during the growing season. Pastures are neither permitted nor registered with the state. Technically, agricultural land uses adjacent to lakes, rivers, and streams require a buffer strip of permanent vegetation that is 50 feet wide unless the areas are part of a resource management system plan (MN Rule 6120.330 Subp. 7). Additionally, for any new ditches or ditch improvements, the land adjacent to public ditches must include a buffer strip of permanent vegetation that is usually 16.5 feet wide on each side (MN Statute 103E.021). These rules have limited enforcement statewide.

Data Sources and Assumptions

The Census of Agriculture is a complete count of U.S. farms and ranches. The Census definition of a farm is "any place from which $1,000 or more of agricultural products were produced and sold, or normally would have been sold, during the census year" (USDA 2009). The Census looks at data in many areas, including animal ownership and sales. The authority for the Census comes from federal law under the *Census of Agriculture Act of 1997* (Public Law 105-113, Title 7, United States Code, Section 2204g). The Census is taken every fifth year, covering the prior year. The most recent Census was completed for the year 2007. The USDA National Agricultural Statistics Service (NASS) conducts the survey. Livestock numbers, by county, are available for cattle, hogs, sheep, goats, and poultry.

Data for counties that overlap HUC 10 watershed boundaries were distributed between each applicable HUC 10 watershed on an area-weighted basis. For example, County A with

100 square miles and 100 heads of cattle would be treated as having 1 head of cattle per square mile; the HUC 10 watershed that includes 50 square miles of County A would be estimated to have 50 head of cattle. MPCA's geographic feedlot database developed for registration and NPDES permitting provides location data and related accounting. However, the numbers of animal units recorded in the database are the *allowable* numbers under the permit/registration and not the *actual* numbers on site; actual animal units are often lower and could be significantly lower. Therefore, USDA NASS data was used.

The fate and transport of manure is not considered in the project area estimates of potential bacteria sources. In addition, hobby farms, which do not produce $1,000 or more of agricultural products, are not included in the estimates.

Data sources and assumptions used for estimating the potential source of bacteria from livestock are listed in Table 35.

Table 33. Data sources and assumptions for estimates of potential bacteria sources: livestock. NOTE: This table is read from left-to-right, demonstrating the progressive breakdown into increasing numbers of categories of fate and transport mechanisms. For example, first livestock populations were categorized into grazing and AFO populations. The fate of bacteria from AFOs was further categorized into 'Partially Housed or Open Lot without Runoff Controls' or 'Land Application of Manure'.

<table>
<tr><th>Livestock Bacteria Sources</th><th colspan="2">Data Sources and Assumptions</th></tr>
<tr><td>Horses</td><td colspan="2">The AVMA's 2006 data (AVMA 2007) includes horses for the West North Central Region (Minnesota, North Dakota, South Dakota, Nebraska, Kansas, Missouri, and Iowa). The horse ownership rate among West North Central Region households is 2.6% with a mean number of 3.4 horses owned in each of those households.</td></tr>
<tr><td colspan="3">Grazing
Grazing populations were estimated for cattle, goats, and sheep based on the USDA 2007 Census of Agriculture (USDA NASS 2009).</td></tr>
<tr><td rowspan="3">Animal Feeding Operations (AFO)
AFO populations were estimated for cattle, poultry, goats, sheep and hogs based on the USDA 2007 Census of Agriculture (USDA NASS 2009).</td><td colspan="2">Partially Housed or Open Lot without Runoff Controls
The proportion of AFO animals that are partially housed or in open lots without runoff controls was based on Mulla et al. (2001)*:
- Cattle 50%
- Poultry 8%
- Goats 42%
- Sheep 42%
- Hogs 15%</td></tr>
<tr><td rowspan="2">Land Application of Manure
Mulla et al. (2001)*:
- Cattle 50%
- Poultry 92%
- Goats 58%
- Sheep 58%
- Hogs 85%</td><td>Surface Application without Incorporation
Mulla et al. (2001)*:
- Cattle 86%
- Poultry 91%
- Goats 89%
- Sheep 89%
- Hogs 65%</td></tr>
<tr><td>Incorporated or Injected
Mulla et al. (2001)*:
- Cattle 14%
- Poultry 9%
- Goats 11%
- Sheep 11%
- Hogs 35%</td></tr>
</table>

* Since publication of the Mulla et al. 2001 study, manure practices have improved in Minnesota. However, no other studies with updated estimates were known at the time this TMDL report was completed. Therefore, the Mulla et al. 2001 estimates were used but likely over-represent the bacteria load from manure application. If manure application is identified as a high ranking source of bacteria for a specific subwatershed, further investigation of local manure application practices will be conducted as part of the Watershed Restoration and Protection Strategy study to verify the results from this bacteria source summary.

Wildlife

Bacteria can be contributed to surface water by wildlife (e.g. raccoons, deer, geese, waterfowl, and feral cats) dwelling in waterbodies, within conveyances to waterbodies, or when their waste is carried to stormwater inlets, creeks, ditches, and lakes during stormwater runoff events. Areas such as MN DNR designated wildlife management areas, State Parks, National Parks, National Wildlife Refuges, golf courses, state forest, and for some animals, urban areas (e.g. raccoons) provide wildlife habitat encouraging congregation and could be potential sources of higher fecal coliform due to the high densities of animals. There are likely many other areas within the project area where wildlife congregates.

Data Sources and Assumptions

Permit areas or zones do not align with subwatershed boundaries. In order to distribute population data from permit areas or zones into multiple intersecting subwatershed boundaries, population data for any single permit area or zone was distributed between each intersecting sub watershed on an area-weighted basis. Populations of wildlife (breeding ducks, deer, geese, pigeons, and raccoons) were estimated as described in Table 34. Data sources and assumptions used for estimating the potential source of bacteria from wildlife are listed in Table 35.

Table 34. Data Sources and Assumptions for Estimates of Wildlife Populations

Animal	Basis for Estimates of Animal Population
Breeding Ducks	According to a presentation by Steve Cordts of the Minnesota DNR Wetland Wildlife Population and Research Group at the 2010 Minnesota DNR Roundtable reported on duck population status (http://files.dnr.state.mn.us/fish_wildlife/roundtable/2010/wildlife/wf_pop-harvest. pdf), Minnesota's annual breeding duck population between the years 2005-2009 averaged 550,000. While the breeding range of the canvasback and lesser scaup is typically outside of the project area, the majority of the breeding duck population (including blue-winged teal, mallards, ring-necked ducks, and wood ducks) has a state-wide breeding range. The statewide population estimate was distributed on an area-weighted basis among subwatersheds including only areas of open water. This population is assumed to be present in Minnesota from April through October; annual *E. coli* production estimates, therefore, include only a seven-month period.
Deer	The MN DNR report Status of Wildlife Populations, Fall 2009 includes a collection of studies that estimate wildlife populations of various species (Dexter 2009). These data enabled the estimation of deer populations throughout the project area. Deer population estimates are based on field surveys and modeling as reported in the following studies: Population Trends of White-Tailed Deer in Minnesota's Farmland/Transition Zone, 2009 by Marrett Grund and Population Trends Of White-Tailed Deer In The Forest Zone, 2009 by Mark Lenarz. Pre-fawn deer densities were reported by MN DNR deer permit area. Data for permit areas that overlap subwatershed boundaries were distributed between each applicable subwatershed on an area-weighted basis.
Feral Cats	Feral cat populations are unknown, but are suspected to be comparable to that of pet cats (AVMA 2010). Therefore, the household cat population was used (2.3 cats for each household that owns cats) in order to account for feral cats in the overall cat population estimate. Feral cat populations are assumed to be distributed throughout the project area in the same relative proportions as domestic cats.
Geese	The MN DNR report Status of Wildlife Populations, Fall 2009 also includes a collection of studies that estimate wildlife populations of various species (Dexter 2009). These data enabled the estimation of goose populations throughout the project area. Goose population estimates are based on a spring helicopter survey and modeling and are reported in the Minnesota Spring Canada Goose Survey, 2009 by David Rave. Counts were reported by Minnesota ecoregion: Prairie Parkland, Eastern Broadleaf Forest/Tallgrass Aspen Parklands, Laurentian Mixed Forest (less Lake and Cook Counties, the Boundary Waters Canoe Area, and the Northwest Angle).
Raccoons	Raccoon population data were provided by a state-wide MN DNR estimate of 800,000 to one million individuals (DNR 2011). An average value of 900,000 was used. Raccoon habitat is known to consist of prairie, woodland, and developed area (DNR 2011). Barding and Nelson (2008) document raccoon foraging in wetland, cropland, and forest. Therefore, the raccoon population was distributed among sub watersheds on an area-weighted basis including all land covers except open water (as classified by the 2006 National Land Cover Dataset).

Table 35. Data Sources and Assumptions for Estimates of Potential Bacteria Sources: Wildlife

NOTE: In all cases, bacteria production by animal type was used based on references cited by USEPA (2001), refer to Table 26.

Bacteria Source Categories: Data Sources & Assumptions	**Delivery Factor**
Open Water Areas Goose habitat is considered to be all open water areas, which includes the PWI basins, streams, ditches and rivers along with the 2006 NLCD *Open Water* features. All geese were considered to reside on and within a 100 foot buffer of this habitat. Duck habitat is considered to be a subset of the NWI polygons. All ducks were considered to reside on and within a 100 foot buffer of this habitat.	Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters.
Impervious Areas Deer, feral cats, and raccoons within 2006 NLCD *Developed* land covers.	
Pervious Areas Deer, feral cats, and raccoons within all 2006 NLCD land covers *except Open Water* and *Developed*.	
High Intensity Development Pigeons within 2006 NLCD *Developed, High Intensity* land covers.	

3.6.3.3 Bacteria Delivery Factor to Surface Waters

A bacteria delivery factor was applied to bacteria sources that do not directly discharge to surface waters (e.g. land application of manure or wildlife excrement) nor have overriding assumptions as to the relative delivery potential (e.g. land application of biosolids having low delivery potential). The bacteria delivery factor accounts for fate and transport factors such as proximity to surface waters, slope, imperviousness, and discharge to lakes prior to discharge to stream networks. The basis for the delivery factors was the state-wide GIS layers of Water Quality Risk, as recently developed by a Minnesota multi-Agency effort & published under the name Conservation Targeting Tools. The original Water Quality Risk GIS layer is a 30 meter gridded dataset. Each grid cell has a risk score on a 0-100 basis for its potential contribution to surface water quality degradation, 100 being the highest risk. Half (50 points) of the risk score was determined by Stream Power Index (SPI) values, which account for the likelihood of overland erosion based on slope and soil type. Half of the risk score was determined based on the proximity to the nearest surface water feature; the highest risk score was given to the grid cells closest to water features.

The original Water Quality Risk layer does not account for imperviousness. In addition lakes that are not part of a stream network (i.e. not flow-through lakes), are weighed equally with streams and flow-through lakes in the proximity scoring. Since imperviousness increases risk of surface water contamination of bacteria and since streams are the impaired surface waters of interest (not lakes), the 0-100 water quality risk layer was revised to account for these elements. Non-flow-through-lakes (including a quarter mile buffer) were reduced by 50 points, to a minimum possible value of zero as were all waterbodies located within 0.1 mile of developed land (assuming that these waterbodies would be stormwater management facilities). In addition, a third 50-point scale for imperviousness was added to the water quality risk score. Areas having imperviousness of 50% or more (2006 NLCD *Developed, Medium Intensity* and *Developed, High Intensity* land covers) were given an additional 50 points. Areas having imperviousness of 25 to 49% (2006 NLCD *Developed, Low Intensity* land cover) were given an additional 25 points. Finally, the project-wide GIS layer was re-scaled to a range of 0-100, resulting in the delivery factor GIS layer for use in the estimates of potential bacteria sources.

The delivery factor GIS layer was used wherever described in the tables in the previous sections which define bacteria source estimation approaches. The mean delivery factor across the applicable geographic areas for each of the subwatersheds was calculated. This value was interpreted and applied as the percent of the bacteria that ultimately reaches downstream surface waters. The delivery factor is not specific to the individual impaired reaches, but accounts for all stream reaches in the subwatershed.

3.6.3.4 Strengths and Limitations

The bacteria production estimates are provided at the subwatershed scale. The results inform stakeholders as to the types and relative magnitude of bacteria produced in their watershed. This information is a valuable tool for the planning and management of water bodies with respect to bacteria contamination. The project area potential bacteria source estimates use a GIS-based approach. However, available data sources are at different scales and have different boundaries than that of the study subwatersheds. A limitation to the estimation process is that populations must be distributed geographically (e.g. county to subwatersheds) using assumptions related to population density. There is a probable minimum scale at which bacteria production estimates are useful.

A significant portion of bacteria producers were accounted for in the potential bacteria sources. However, several animals were not included: birds other than geese and ducks (e.g. song birds and wading birds) and many wild animals (e.g. beavers, bear and wild turkey). Data, resource limitations, and consideration for the major bacteria producers in the project area led to the selected set of bacteria producers accounted for in these estimates. The project area estimates of potential bacteria sources is also limited by the fact that bacteria delivery is not addressed (e.g. treatment of human waste at wastewater treatment facilities prior to discharge to receiving waters, pet waste management, zero discharge feedlot facilities, incorporation of manure into soil, geese gathering directly on stormwater ponds). The subwatersheds included in the Level II Bacterial Source Investigation addresses bacteria delivery.

The potential bacteria source estimates also do not account for the relative risk among different types of bacteria. Instead, *E. coli* production is estimated as an indicator of the likelihood of pathogen contamination of our waterbodies.

3.6.3.5 Summary

This section presents the results of the Bacteria Source Investigation. These results are presented in a series of four tables. The first set of tables present the relative annual *E. coli* production ranked by source category *across the entire TMDL production area*. In the first of these two tables the source categories are general (i.e. Humans, Companion Animals, Livestock, and Wildlife) and in the second of these two tables the source categories are detailed (i.e., separated into specific source categories). The second set of tables present the relative *E. coli* production ranked by source category *within each individual subwatershed (HUC 12 unit),* by general source category first and then by detailed source category for each HUC 12 subwatershed

Please note that in some instances the ranking of the general source category is higher than the ranking of any of the individual components that make up the source category. For example, the ranking for Livestock in the Crow Wing River Subwatershed 070101061108 (Table 37) is high whereas the individual rankings for cattle, goats, sheep, hogs and poultry (Table 38) are low. This occurs because in some instances the individual *E. coli* production values in the detailed tables might be small, but the sum of these values may trigger the next ranking category in the general tables.

Table 36 lists the contributing HUC 12 subwatersheds to each impaired stream reach for all of the bacteria source inventory summary tables below.

Table 36. Contributing HUC 12 subwatersheds to the *E. coli* impaired stream reaches

Impaired stream reach (AUID)	Subwatershed Name	HUC-12 ID (07010106-XXXX)
Partridge River (07010106-518)	Little Partridge Creek	0901
	Edgy Creek-Partridge River	0902
	Partridge River	0903
Home Brook (07010106-524)	Home Brook	1004
Swan Creek (07010106-527)	Swan Creek	1102
Cat River (07010106-544)	Cat River	0804
Pillager Creek (07010106-577)	Pillager Creek	1107
Mayo Creek (07010106-604)	Mayo Creek	1001
Unnamed Creek (07010106-684)	City of Motley-Crow Wing River	1104
Stoney Brook (07010106-698)	Stony Brook	1002
Corey Brook (07010106-700)	Home Brook	1004
Farnham Creek (07010106-702)	Farnham Creek	0808

Population Based Summary Tables

Table 37 through Table 40 below present the results from the Population Based Bacteria Source Inventory for the 6 subwatersheds with part of their area located in Crow Wing County, which includes the impaired Mayo Creek subwatershed.

Population & Delivery Based Summary Tables

Table 41 through Table 44 below present the results from the Population & Delivery Based Bacteria Source Investigation for all of the remaining subwatersheds and nine impaired reaches.

Table 37. General Relative Annual *E. coli* Production Rank by Source Category across the TMDL Project Area (Population Based Source Investigation) – Shaded rows indicate a subwatershed containing an impaired reach

Subwatershed Name	HUC-12 ID (07010106-XXXX)	Area (sq. mi.)	Relative Annual *E. coli* Production Rank* (based on the number of *E. coli* organisms produced per year)				Estimated Total (billion org/ac-yr)
			Humans	Companion Animals	Livestock	Wildlife	
Crow Wing River	1108	18	⊙	⊙	●	⊙	10,026
Gull Lake	1007	41	⊙	⊙	⊙	⊙	2,838
Gull River	1008	31	⊙	●	⊙	●	7,143
Mayo Creek	1001	49	⊙	⊙	⊙	⊙	2,580
Round Lake	1006	38	⊙	⊙	⊙	⊙	2,637
Upper Gull Lake	1005	51	⊙	⊙	⊙	⊙	3,715

* ⊙ = “Low”, ◉ = “Medium-Low”, ○ = “Medium-High”, ● = “High”

Table 38. Detailed Relative Annual *E. coli* Production Rank by Source Category across the TMDL Project Area (Population Based Source Investigation) – Shaded rows indicate a subwatershed containing an impaired reach

Subwatershed Name	HUC-12 ID (07010106-XXXX)	Area (sq. mi.)	Relative Annual *E. coli* Production Rank* (based on the number of *E. coli* organisms produced per year)																		Est. Total (billion org/ ac-yr)
			Humans					Companion Animals			Livestock					Wildlife					
			WWTF Effluent	ITPHS Septics	% Area Having Sewers over 50 years old	Land Application of Biosolids	Land Application of Septage	Horses	Cats	Dogs	Cattle	Goats	Sheep	Hogs	Poultry	Feral Cats	Deer	Raccoons	Ducks	Geese	
Crow Wing R.	1108	18		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	◉	⊙	⊙	⊙	⊙	⊙	10,039
Gull Lake	1007	41	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,863
Gull River	1008	31	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	7,169
Mayo Creek	1001	49		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,618
Round Lake	1006	38	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,681
Upper Gull Lake	1005	51	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	3,771

* ⊙ = "Low", ◉ = "Medium-Low", ⭘ = "Medium-High", ● = "High"

Table 39. General Relative Annual *E. coli* Production Rank by Source Category within subwatersheds (Population Based Source Investigation) – Shaded rows indicate a subwatershed containing an impaired reach

Subwatershed Name	HUC-12 ID (07010106-XXXX)	Area (sq. mi.)	Relative Annual *E. coli* Production Rank* (based on the number of *E. coli* organisms produced per year)				Estimated Total (billion org/ac-yr)
			Humans	Companion Animals	Livestock	Wildlife	
Crow Wing River	1108	18	⊙	⊙	●	⊙	10,026
Gull Lake	1007	41	⊙	⊙	●	○	2,838
Gull River	1008	31	⊙	●	⊙	●	7,143
Mayo Creek	1001	49	⊙	◉	●	●	2,580
Round Lake	1006	38	⊙	◉	○	●	2,637
Upper Gull Lake	1005	51	⊙	●	○	●	3,715

* ⊙ = "Low", ◉ = "Medium-Low", ○ = "Medium-High", ● = "High"

Table 40. Detailed Relative Annual *E. coli* Production Rank by Source Category within Subwatersheds (Population Based Source Investigation) – Shaded rows indicate a subwatershed containing an impaired reach

Subwatershed Name	HUC-12 ID (07010106-XXXX)	Area (sq. mi.)	Relative Annual *E. coli* Production Rank* (based on the number of *E. coli* organisms produced per year)																		Estimated Total (billion org/ ac-yr)
			Humans					Companion Animals			Livestock					Wildlife					
			WWTF Effluent	ITPHS Septics	% Area Having Sewers > 50 yr	Land Application of Biosolids	Land Application of Septage	Horses	Cats	Dogs	Cattle	Goats	Sheep	Hogs	Poultry	Feral Cats	Deer	Raccoons	Ducks	Geese	
Crow Wing R.	1108	18		⊙	⊙		⊙	⊙	⊙	⊙	○	⊙	⊙	○	●	⊙	⊙	⊙	◉	⊙	10,039
Gull Lake	1007	41	⊙	⊙	⊙		⊙	⊙	⊙	⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	○	⊙	2,863
Gull River	1008	31	⊙	⊙	⊙		⊙	⊙	●	○	◉	⊙	⊙		⊙	●	⊙	⊙	◉	⊙	7,169
Mayo Creek	1001	49		⊙	⊙		⊙	⊙	◉	⊙	●	⊙	◉		⊙	◉	⊙	⊙	●	⊙	2,618
Round Lake	1006	38	⊙	⊙	⊙		⊙	⊙	◉	⊙	○	⊙	⊙		⊙	◉	⊙	⊙	●	⊙	2,681
Upper Gull Lake	1005	51	⊙	⊙	⊙		⊙	⊙	●	○	○	⊙	⊙		⊙	●	⊙	⊙	○	⊙	3,771

* ⊙ = "Low", ◉ = "Medium-Low", ○ = "Medium-High", ● = "High"

Table 41. General Relative Annual *E. coli* Production Rank by Source Category across TMDL Project Area (Population Delivery Based Source Investigation Results) – Shaded rows indicate a subwatershed containing an impaired reach

Subwatershed Name	HUC 12 ID (07010106-XXXX)	Area (sq. mi.)	Relative Annual *E. coli* Production Rank* (based on the number of *E. coli* organisms produced per year)				Estimated Total (billion org/ac-yr)
			Humans	Companion Animals	Livestock	Wildlife	
Basswood Creek	0202	31	⊙	⊙	⊙	⊙	2,860
Beaver Creek	0805	20	⊙	⊙	⊙	⊙	1,065
Belle Taine Lake	0504	24	⊙	⊙	⊙	⊙	1,076
Bender Creek	0605	29	⊙	⊙	⊙	⊙	555
Big Sand Lake	0502	25	⊙	⊙	⊙	⊙	587
Big Stony Lake-CWR	0603	21	⊙	⊙	⊙	⊙	685
Big Swamp Creek	0702	18	⊙	⊙	⊙	⊙	1,065
Blueberry Lake-Shell River	0403	16	⊙	⊙	⊙	⊙	497
Blueberry River	0302	47	⊙	⊙	⊙	⊙	5,101
Burgen Lake	0802	19	⊙	⊙	⊙	⊙	1,103
Cat River	0804	55	⊙	⊙	⊙	⊙	5,164
City of Motley-CWR	1104	41	⊙	⊙	⊙	⊙	6,516
City of Nimrod-CWR	0806	53	⊙	⊙	⊙	⊙	3,694
Dinner Creek	0204	25	⊙	⊙	⊙	⊙	1,785
Eagle Lake	0206	37	⊙	⊙	⊙	⊙	891
Edgy Creek-Partridge River	0902	31	⊙	⊙	◉	⊙	12,263
Eleventh Crow Wing Lake	0601	26	⊙	⊙	⊙	⊙	456
Farnham Creek	0808	53	⊙	⊙	⊙	⊙	2,230
Fifth Crow Wing Lake-CWR	0602	30	⊙	⊙	⊙	⊙	861
First Crow Wing Lake-CWR	0606	16	⊙	⊙	⊙	⊙	315
Fishhook Lake	0208	28	⊙	⊙	⊙	⊙	1,083
Fishhook River	0210	17	⊙	⊙	⊙	⊙	914
Goose Lake	0807	21	⊙	⊙	⊙	⊙	1,136
Goose L-Big Swamp Creek	0701	48	⊙	⊙	⊙	⊙	1,578
Hay Creek	0205	24	⊙	⊙	⊙	⊙	2,332
Hayden Creek-CWR	1101	29	⊙	⊙	⊙	⊙	6,073
Home Brook	1004	51	⊙	⊙	⊙	⊙	2,338
Indian Creek	0203	34	⊙	⊙	⊙	⊙	2,961
Kettle River	0301	49	⊙	⊙	⊙	⊙	6,544
Lake of the Valley	0201	43	⊙	⊙	⊙	⊙	4,021
Lake Placid-CWR	1106	42	⊙	⊙	●	⊙	47,526
Little Partridge Creek	0901	43	⊙	⊙	◉	⊙	18,357
Little Sand Lake	0503	32	⊙	⊙	⊙	⊙	1,305
Long Lake	0209	24	⊙	⊙	⊙	⊙	767
Mantrap Lake	0501	31	⊙	⊙	⊙	⊙	929
Mission Creek-Shell River	0402	68	⊙	⊙	⊙	⊙	6,103
Mosquito Creek	1103	54	⊙	⊙	⊙	⊙	2,200
Partridge River	0903	17	⊙	⊙	⊙	⊙	2,891
Pillager Creek	1107	20	⊙	⊙	⊙	⊙	790
Potato Lake	0207	23	⊙	⊙	⊙	⊙	631
Rush Brook	1003	20	⊙	⊙	⊙	⊙	978
Sevenmile Creek	1105	24	⊙	⊙	⊙	⊙	945
Shell Lake	0401	45	⊙	⊙	⊙	⊙	3,548
Shell River	0405	30	⊙	⊙	⊙	⊙	1,046
Simon Lake-CWR	0809	29	⊙	⊙	⊙	⊙	1,989
Stocking Lake	0404	15	⊙	⊙	⊙	⊙	1,913
Stony Brook	1002	37	⊙	⊙	⊙	⊙	1,113
Straight Lake	0101	36	⊙	⊙	⊙	⊙	2,721
Straight River	0102	46	⊙	⊙	⊙	⊙	3,518
Swan Creek	1102	56	⊙	⊙	⊙	⊙	2,574
Town of Huntersville-CWR	0803	41	⊙	⊙	⊙	⊙	2,731
Wallingford Creek	0604	34	⊙	⊙	⊙	⊙	532
Yaeger Lake	0801	33	⊙	⊙	⊙	⊙	1,929

* ⊙ = "Low", ◉ = "Medium-Low", ○ = "Medium-High", ● = "High", CWR = Crow Wing River, L = Lake

Table 42. Detailed Relative Annual *E. coli* Production Rank by Source Category across TMDL Project Area (Population Delivery Based Source Investigation Results) – Shaded rows indicate a subwatershed containing an impaired reach

Subwatershed	HUC 12 ID (07010106-XXXX)	Area (sq. mi.)	Relative Annual *E. coli* Production Rank* (based on the number of *E. coli* organisms produced per year)																		Estimated Total (billion org/ac-yr)
			Humans					Companion Animals			Livestock					Wildlife					
			WWTF Effluent	ITPHS Septics	% Area w/ Sewers > 50 yrs old	Land Application of Biosolids	Land Application of Septage	Horses	Cats	Dogs	Cattle	Goats	Sheep	Hogs	Poultry	Feral Cats	Deer	Raccoons	Ducks	Geese	
Basswood Creek	0202	31		⊙				⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	2,860
Beaver Creek	0805	20		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,066
Belle Taine Lake	0504	24		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,078
Bender Creek	0605	29		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	558
Big Sand Lake	0502	25		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	591
Big Stony Lake-CWR	0603	21		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	690
Big Swamp Creek	0702	18		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,071
Blueberry Lake-Shell River	0403	16		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	504
Blueberry River	0302	47		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	5,109
Burgen Lake	0802	19		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,112
Cat River	0804	55		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	5,174
City of Motley-CWR	1104	41	⊙	⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	6,527
City of Nimrod-CWR	0806	53		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	3,706
Dinner Creek	0204	25		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	1,799
Eagle Lake	0206	37		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	906
Edgy Creek-Partridge River	0902	31		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	12,279
Eleventh Crow Wing Lake	0601	26		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	473
Farnham Creek	0808	53		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,248
Fifth Crow Wing Lake-CWR	0602	30	⊙	⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	880
First Crow Wing Lake-CWR	0606	16		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	335
Fishhook Lake	0208	28		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	1,104
Fishhook River	0210	17		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	936
Goose Lake	0807	21		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,159
Goose L-Big Swamp Creek	0701	48		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,602
Hay Creek	0205	24		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	2,359
Hayden Creek-CWR	1101	29	⊙	⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	6,101
Home Brook	1004	51		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,367
Indian Creek	0203	34		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	2,991
Kettle River	0301	49	⊙	⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	6,575
Lake of the Valley	0201	43		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	4,053
Lake Placid-CWR	1106	42	⊙	⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	●	⊙	⊙	⊙	⊙	⊙	47,559
Little Partridge Creek	0901	43	⊙	⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	18,391
Little Sand Lake	0503	32		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,340
Long Lake	0209	24		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	803
Mantrap Lake	0501	31		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	966
Mission Creek-Shell River	0402	68		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	6,142
Mosquito Creek	1103	54		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,240
Partridge River	0903	17		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	2,932
Pillager Creek	1107	20		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	832
Potato Lake	0207	23		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	674
Rush Brook	1003	20		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,023
Sevenmile Creek	1105	24		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	991
Shell Lake	0401	45		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	3,595
Shell River	0405	30		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,094
Simon Lake-CWR	0809	29		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,038
Stocking Lake	0404	15		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	1,963
Stony Brook	1002	37		⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,164
Straight Lake	0101	36		⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	2,773
Straight River	0102	46	⊙	⊙			⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	3,571
Swan Creek	1102	56		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,628
Town of Huntersville-CWR	0803	41		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	2,786
Wallingford Creek	0604	34		⊙			⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	589
Yaeger Lake	0801	33	⊙	⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙	⊙	1,987

* ⊙ = "Low", ⦿ = "Medium-Low", **O** = "Medium-High", ● = "High", CWR = Crow Wing River, L = Lake

Table 43. General Relative Annual *E. coli* Production Rank by Source Category with Subwatersheds (Population Delivery Based Source Investigation Results) – Shaded rows indicate a subwatershed containing an impaired reach

Subwatershed	HUC 12 ID (07010106-XXXX)	Area (sq. mi.)	Relative Annual *E. coli* Production Rank* (based on the number of *E. coli* organisms produced per year)				Estimated Total (billion org/ac-yr)
			Humans	Companion Animals	Livestock	Wildlife	
Basswood Creek	0202	31	⊙	⊙	●	⊙	2,860
Beaver Creek	0805	20	⊙	⊙	●	○	1,065
Belle Taine Lake	0504	24	⊙	⊙	⦿	●	1,076
Bender Creek	0605	29	⊙	⊙	●	●	555
Big Sand Lake	0502	25	⊙	⊙	●	●	587
Big Stony Lake-CWR	0603	21	⊙	⊙	○	●	685
Big Swamp Creek	0702	18	⊙	⊙	●	●	1,065
Blueberry Lake-Shell River	0403	16	⊙	⊙	●	○	497
Blueberry River	0302	47	⊙	⊙	●	⊙	5,101
Burgen Lake	0802	19	⊙	⊙	●	○	1,103
Cat River	0804	55	⊙	⊙	●	⊙	5,164
City of Motley-CWR	1104	41	⊙	⊙	●	⊙	6,516
City of Nimrod-CWR	0806	53	⊙	⊙	●	⦿	3,694
Dinner Creek	0204	25	⊙	⊙	●	⦿	1,785
Eagle Lake	0206	37	⊙	⊙	●	●	891
Edgy Creek-Partridge River	0902	31	⊙	⊙	●	⊙	12,263
Eleventh Crow Wing Lake	0601	26	⊙	⊙	●	●	456
Farnham Creek	0808	53	⊙	⊙	●	●	2,230
Fifth Crow Wing Lake-CWR	0602	30	⊙	⊙	●	●	861
First Crow Wing Lake-CWR	0606	16	⊙	⊙	⦿	●	315
Fishhook Lake	0208	28	⊙	⊙	●	●	1,083
Fishhook River	0210	17	⊙	⊙	⦿	●	914
Goose Lake	0807	21	⊙	⊙	○	●	1,136
Goose L-Big Swamp Creek	0701	48	⊙	⊙	●	●	1,578
Hay Creek	0205	24	⊙	⊙	●	⦿	2,332
Hayden Creek-CWR	1101	29	⊙	⊙	●	⦿	6,073
Home Brook	1004	51	⊙	⊙	○	●	2,338
Indian Creek	0203	34	⊙	⊙	●	⊙	2,961
Kettle River	0301	49	⊙	⊙	●	⊙	6,544
Lake of the Valley	0201	43	⊙	⊙	●	⦿	4,021
Lake Placid-CWR	1106	42	⊙	⊙	●	⊙	47,526
Little Partridge Creek	0901	43	⊙	⊙	●	⊙	18,357
Little Sand Lake	0503	32	⊙	⊙	⦿	●	1,305
Long Lake	0209	24	⊙	⊙	○	●	767
Mantrap Lake	0501	31	⊙	⊙	●	●	929
Mission Creek-Shell River	0402	68	⊙	⊙	●	⊙	6,103
Mosquito Creek	1103	54	⊙	⊙	●	●	2,200
Partridge River	0903	17	⊙	⊙	●	⊙	2,891
Pillager Creek	1107	20	⊙	⊙	●	●	790
Potato Lake	0207	23	⊙	⊙	○	●	631
Rush Brook	1003	20	⊙	⊙	⦿	●	978
Sevenmile Creek	1105	24	⊙	⊙	●	●	945
Shell Lake	0401	45	⊙	⊙	●	⊙	3,548
Shell River	0405	30	⊙	⊙	●	⦿	1,046
Simon Lake-CWR	0809	29	⊙	⊙	●	○	1,989
Stocking Lake	0404	15	⊙	⊙	●	●	1,913
Stony Brook	1002	37	⊙	⊙	●	●	1,113
Straight Lake	0101	36	⊙	⊙	●	⊙	2,721
Straight River	0102	46	⊙	⊙	●	⦿	3,518
Swan Creek	1102	56	⊙	⊙	○	●	2,574
Town of Huntersville-CWR	0803	41	⊙	⊙	●	⦿	2,731
Wallingford Creek	0604	34	⊙	⊙	●	○	532
Yaeger Lake	0801	33	⊙	⊙	●	⦿	1,929

* ⊙ = "Low", ⦿ = "Medium-Low", ○ = "Medium-High", ● = "High", CWR = Crow Wing River, L = Lake

Table 44. Detailed Relative Annual *E. coli* Production Rank by Source Category with Subwatersheds (Population Delivery Based Source Investigation Results) – Shaded rows indicate a subwatershed containing an impaired reach

Subwatershed	HUC 12 ID (07010106-XXXX)	Area (sq. mi.)	Relative Annual *E. coli* Production Rank* (based on the number of *E. coli* organisms produced per year)																		Estimated Total (billion org/ac-yr)
			Humans					Companion Animals			Livestock					Wildlife					
			WWTF Effluent	ITPHS Septics	% Area w/ Sewers > 50 yrs old	Land Application of Biosolids	Land Application of Septage	Horses	Cats	Dogs	Cattle	Goats	Sheep	Hogs	Poultry	Feral Cats	Deer	Raccoons	Ducks	Geese	
Basswood Creek	0202	31		⊙				⊙		⊙	○	⊙	⊙	○	●	⊙	⊙	⊙	◉	⊙	2,860
Beaver Creek	0805	20		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	○	⊙	1,066
Belle Taine Lake	0504	24		⊙	⊙		⊙	⊙		⊙	◉	⊙	⊙		⊙	●	⊙	⊙	◉	⊙	1,078
Bender Creek	0605	29		⊙			⊙	⊙		⊙	●	⊙	◉		⊙	◉	⊙	⊙	●	⊙	558
Big Sand Lake	0502	25		⊙			⊙	⊙		⊙	●	⊙	◉		⊙	◉	⊙	⊙	●	⊙	591
Big Stony Lake-CWR	0603	21		⊙			⊙	⊙		⊙	○	⊙	⊙		⊙	●	⊙	⊙	◉	⊙	690
Big Swamp Creek	0702	18		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	◉	⊙	⊙	○	⊙	1,071
Blueberry Lake-Shell River	0403	16		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	○	⊙	504
Blueberry River	0302	47		⊙	⊙		⊙	⊙		⊙	●	⊙	⊙	○	●	⊙	⊙	⊙	◉	⊙	5,109
Burgen Lake	0802	19		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	◉	⊙	⊙	◉	⊙	1,112
Cat River	0804	55		⊙			⊙	⊙		⊙	●	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	5,174
City of Motley-CWR	1104	41	⊙	⊙	⊙		⊙	⊙		⊙	○	⊙	⊙	◉	●	⊙	⊙	⊙	⊙	⊙	6,527
City of Nimrod-CWR	0806	53		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	◉	⊙	3,706
Dinner Creek	0204	25		⊙			⊙	⊙		⊙	●	⊙	⊙	○	●	⊙	⊙	⊙	◉	⊙	1,799
Eagle Lake	0206	37		⊙			⊙	⊙		⊙	●	⊙	◉	⊙	⊙	◉	⊙	⊙	●	⊙	906
Edgy Creek-Partridge River	0902	31		⊙			⊙	⊙		⊙	○	⊙	⊙	◉	●	⊙	⊙	⊙	⊙	⊙	12,279
Eleventh Crow Wing Lake	0601	26		⊙			⊙	⊙		⊙	●	⊙	◉		⊙	⊙	⊙	⊙	●	⊙	473
Farnham Creek	0808	53		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	●	⊙	2,248
Fifth Crow Wing Lake-CWR	0602	30	⊙	⊙	⊙		⊙	⊙		⊙	●	⊙	◉		⊙	●	⊙	⊙	○	⊙	880
First Crow Wing Lake-CWR	0606	16		⊙			⊙	⊙		⊙	○	⊙	⊙		⊙	◉	⊙	⊙	●	⊙	335
Fishhook Lake	0208	28		⊙	⊙		⊙	⊙		⊙	●	⊙	⊙	⊙	◉	●	⊙	⊙	●	⊙	1,104
Fishhook River	0210	17		⊙	⊙		⊙	⊙		⊙	◉	⊙	⊙	⊙	⊙	●	⊙	⊙	⊙	⊙	936
Goose Lake	0807	21		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	●	⊙	⊙	○	⊙	1,159
Goose L-Big Swamp Creek	0701	48		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	●	⊙	1,602
Hay Creek	0205	24		⊙			⊙	⊙		⊙	○	⊙	⊙	○	●	○	⊙	⊙	⊙	⊙	2,359
Hayden Creek-CWR	1101	29	⊙	⊙	⊙		⊙	⊙		⊙	●	⊙	⊙	◉	●	○	⊙	⊙	⊙	⊙	6,101
Home Brook	1004	51		⊙	⊙		⊙	⊙		⊙	●	⊙	⊙		⊙	●	⊙	⊙	○	⊙	2,367
Indian Creek	0203	34		⊙			⊙	⊙		⊙	○	⊙	⊙	○	●	⊙	⊙	⊙	⊙	⊙	2,991
Kettle River	0301	49	⊙	⊙	⊙		⊙	⊙		⊙	○	⊙	⊙	○	●	◉	⊙	⊙	⊙	⊙	6,575
Lake of the Valley	0201	43		⊙			⊙	⊙		⊙	●	⊙	⊙	○	○	○	⊙	⊙	◉	⊙	4,053
Lake Placid-CWR	1106	42	⊙	⊙	⊙		⊙	⊙		⊙	⊙	⊙	⊙	⊙	●	⊙	⊙	⊙	⊙	⊙	47,559
Little Partridge Creek	0901	43	⊙	⊙	⊙		⊙	⊙		⊙	○	⊙	⊙	◉	●	⊙	⊙	⊙	⊙	⊙	18,391
Little Sand Lake	0503	32		⊙			⊙	⊙		⊙	◉	⊙	⊙		⊙	●	⊙	⊙	◉	⊙	1,340
Long Lake	0209	24		⊙	⊙		⊙	⊙		⊙	○	⊙	⊙		⊙	●	⊙	⊙	○	⊙	803
Mantrap Lake	0501	31		⊙			⊙	⊙		⊙	●	⊙	◉		⊙	●	⊙	⊙	○	⊙	966
Mission Creek-Shell River	0402	68		⊙			⊙	⊙		⊙	○	⊙	⊙	○	●	⊙	⊙	⊙	◉	⊙	6,142
Mosquito Creek	1103	54		⊙	⊙		⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	○	⊙	2,240
Partridge River	0903	17		⊙			⊙	⊙		⊙	●	⊙	⊙	◉	●	⊙	⊙	⊙	⊙	⊙	2,932
Pillager Creek	1107	20		⊙	⊙		⊙	⊙		⊙	●	⊙	⊙		⊙	○	⊙	⊙	○	⊙	832
Potato Lake	0207	23		⊙			⊙	⊙		⊙	○	⊙	⊙		⊙	◉	⊙	⊙	●	⊙	674
Rush Brook	1003	20		⊙	⊙		⊙	⊙		⊙	○	⊙	⊙		⊙	●	⊙	⊙	○	⊙	1,023
Sevenmile Creek	1105	24		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	◉	⊙	⊙	◉	⊙	991
Shell Lake	0401	45		⊙			⊙	⊙		⊙	◉	⊙	⊙	○	●	⊙	⊙	⊙	⊙	⊙	3,595
Shell River	0405	30		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	◉	⊙	1,094
Simon Lake-CWR	0809	29		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	◉	⊙	⊙	◉	⊙	2,038
Stocking Lake	0404	15		⊙	⊙		⊙	⊙		⊙	●	⊙	⊙	⊙	⊙	●	⊙	⊙	⊙	⊙	1,963
Stony Brook	1002	37		⊙	⊙		⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	○	⊙	1,164
Straight Lake	0101	36		⊙			⊙	⊙		⊙	○	⊙	⊙	○	●	⊙	⊙	⊙	⊙	⊙	2,773
Straight River	0102	46	⊙	⊙			⊙	⊙		⊙	●	⊙	⊙	○	●	●	⊙	⊙	⊙	⊙	3,571
Swan Creek	1102	56		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	●	⊙	⊙	●	⊙	2,628
Town of Huntersville-CWR	0803	41		⊙			⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	◉	⊙	2,786
Wallingford Creek	0604	34		⊙			⊙	⊙		⊙	●	⊙	◉		⊙	⊙	⊙	⊙	○	⊙	589
Yaeger Lake	0801	33	⊙	⊙	⊙		⊙	⊙		⊙	●	⊙	⊙		⊙	⊙	⊙	⊙	◉	⊙	1,987

* ⊙ = "Low", ◉ = "Medium-Low", ○ = "Medium-High", ● = "High", CWR = Crow Wing River, L = Lake

4 TMDL DEVELOPMENT

This section presents the overall approach to estimating the components of the TMDL. The pollutant sources were first identified and estimated in the pollutant source assessment. The loading capacity (TMDL) of each lake or stream was then estimated using an in-lake water quality response model or stream load duration curve and was divided among wasteload allocations (WLAs) and load allocations (LAs). A TMDL for a waterbody that is impaired as the result of excessive loading of a particular pollutant can be described by the following equation:

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

Where:

Loading capacity (LC): the greatest pollutant load a waterbody can receive without violating water quality standards;

Wasteload allocation (WLA): the pollutant load that is allocated to point sources, including wastewater treatment facilities, regulated construction stormwater, and regulated industrial stormwater, all covered under NPDES permits for a current or future permitted pollutant source;

Load allocation (LA): the pollutant load that is allocated to sources not requiring NPDES permit coverage, including non-regulated stormwater runoff, atmospheric deposition, and internal loading;

Margin of Safety (MOS): an accounting of uncertainty about the relationship between pollutant loads and receiving water quality;

Reserve Capacity (RC): the portion of the loading capacity attributed to the growth of existing and future load sources.

4.1 Phosphorus

4.1.1 Loading Capacity

4.1.1.1 Lake Response Model

Summary of Model Applications

For the lake TMDL derivations, flows from the HSPF model (AquaTerra 2013) and land cover Event Mean Concentrations (EMCs) were combined using the Simple Method to estimate existing watershed phosphorus loading to the impaired lakes. The watershed phosphorus loads served as input to BATHTUB models, which were used to estimate in-lake water quality. The BATHTUB models were calibrated to existing in-lake water quality data (10-year growing season means) and were then used to identify the phosphorus load reductions needed to meet State in-lake water quality standards.

The modeling software Bathtub (Version 6.1) was selected to link phosphorus 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). It 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 phosphorus 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 phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and groundwater; and outputs through the lake outlet, water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

Long-term averages were used as input data to the models, due to the lack of detailed annual loading and water balance data for each of the lakes. The outputs from the phosphorus source assessment (*Section 3.6.1.2*) were used as inputs to the Bathtub lake models. The models were calibrated to existing phosphorus concentrations (2002-2011), and then were used to determine the phosphorus reductions needed to meet each lake's phosphorus standard. The phosphorus reduction needed to meet the phosphorus standard, calculated from the Bathtub model, was subtracted from the total existing phosphorus load to determine each lake's loading capacity. The loading capacity of each lake is the TMDL; the TMDL is then split into Wasteload Allocations (WLAs), Load Allocations (LAs), and a margin of safety (MOS). Regression equations developed by the MPCA (Heiskary and Wilson 2005) suggest that the two response variables, Secchi depth and chlorophyll-a, should also meet state standards when the necessary phosphorus reductions are made.

The TMDL (or loading capacity) was first determined in terms of annual loads. In-lake water quality models predict annual averages of water quality parameters based on annual loads. Symptoms of nutrient enrichment normally are the most severe during the summer months; the state eutrophication standards (and, therefore, the TMDL goals) were established with this seasonal variability in mind. The annual loads were then converted to daily loads by dividing the annual loads by 365 days. Section 13 contains for all lakes Bathtub modeling case data (inputs), diagnostics (results), and segment balances (water and phosphorus budgets) for both the calibrated (benchmark/existing) models and the TMDL scenarios.

System Representation in Model

In typical applications of Bathtub, lake and reservoir systems are represented by a set of segments and tributaries. Segments are the basins (lakes, reservoirs, etc.) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined inputs of flow and pollutant loading to a particular segment. For this study, the direct drainage area, upstream lakes, and major contributing tributaries were modeled as separate tributaries to each lake (i.e., segment).

Model Inputs

The input required to run the Bathtub model includes lake geometry, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data are also entered into the Bathtub program in order to facilitate model verification and calibration. The availability of observed lake water quality data is summarized for each lake in Section 11:

Lake Summaries. Lake segment inputs are listed in Table 45, and tributary inputs are listed in Table 18 and Table 20 from Section 3.6.1.2. Precipitation rates were estimated at 0.69 m per year and evaporation rates were estimated to be 0.81 m per year based on data from the MN Hydrology Guide (SCS 1992). Precipitation and evaporation rates apply only to the lake surface areas. Average phosphorus atmospheric deposition loading rates were estimated to be 0.24 lb/ac-yr for the Upper Mississippi River Basin (Barr 2007), applied over each lake's surface area. See discussion titled *Atmospheric Deposition* in *Section 3.6.1.2* for more details.

Table 45. Bathtub segment input data

Impaired Lake	Surface area (sq km)	Lake fetch (km)	Mean depth (m)	Total Phosphorus	
				(ppb)	CV (%)
Blueberry	2.1551	2.4140	2.08	92.6	8%
Eighth Crow Wing	1.9959	3.0861	5.59	29.2	8%
First Crow Wing	2.0611	2.4171	1.75	59.5	8%
Lower Twin	1.0194	1.5316	3.46	39.9	5%
Mayo	0.6101	1.8867	2.31	35.7	4%
Portage	1.6873	3.6195	2.20	50.9	6%
Sibley	1.7229	3.9563	4.06	33.5	5%

Model Equations

Bathtub allows a choice among several different phosphorus sedimentation models. The Canfield-Bachmann phosphorus sedimentation model (Canfield and Bachmann 1981) best represents the lake water quality response of Minnesota lakes, and is the model used by the majority of lake TMDLs in Minnesota. In order to perform a uniform analysis it was selected as the standard equation for the study. However, the Canfield-Bachmann phosphorus sedimentation model tends to underpredict the amount of internal loading in shallow, frequently mixing lakes. Therefore, an explicit internal load is added to shallow lakes to improve the lake water quality response of the Canfield-Bachmann phosphorus sedimentation model.

Model Calibration

The models were calibrated to existing water quality data according to Table 46, and then were used to determine the phosphorus loading capacity (TMDL) of each lake. When the predicted in-lake total phosphorus concentration was *lower* than the average observed (monitored) concentration, an explicit additional load was added to calibrate the model. It is widely recognized that Minnesota lakes in agricultural and urban regions have histories of high phosphorus loading and/or very poor water quality. For this reason, it is reasonable that internal loading may be higher than that of the lakes in the data set used to derive the Canfield-Bachmann lakes formulation. It is also possible that the watershed model loading estimates did not account for certain hot spots of phosphorus loading such as above average application of lawn fertilizer runoff and/or pet waste. When the predicted in-lake total phosphorus concentration was *higher* than the average monitored concentration; the phosphorus calibration coefficient was increased to calibrate the model.

Table 46. Model calibration summary for the impaired lakes

Impaired Lake	P Sedimentation Model	Calibration Mode	Calibration Value
Blueberry	Canfield & Bachmann, Lakes	Added Internal Load	2.79 mg/m^2-day
Eighth Crow Wing	Canfield & Bachmann, Lakes	Added Internal Load	0.405 mg/m^2-day
First Crow Wing	Canfield & Bachmann, Lakes	Added Internal Load	4.11 mg/m^2-day
Lower Twin	Canfield & Bachmann, Lakes	Added Internal Load	1.28 mg/m^2-day
Mayo	Canfield & Bachmann, Lakes	Added Internal Load	0.89 mg/m^2-day
Portage	Canfield & Bachmann, Lakes	Added Internal Load	0.119 mg/m^2-day
Sibley	Canfield & Bachmann, Lakes	TP Calibration Factor	2.31

Determination of Lake Loading Capacity (TMDL)

Using the calibrated existing conditions model as a starting point, the phosphorus concentrations associated with tributaries were reduced until the model indicated that the total phosphorus state standard was met, to the nearest whole number. Minnesota lake water quality standards assume that once the total phosphorus goals are met, the chlorophyll-*a* and Secchi transparency standards will likewise be met (see *Section 2: Applicable Water Quality Standards*). With this process, a series of models were developed that included a level of phosphorus loading consistent with lake water quality state standards, or the TMDL goal. Actual load values are calculated within the Bathtub software, so loads from the TMDL goal models could be compared to the loads from the existing conditions models to determine the amount of load reduction required.

Several lakes (First Crow Wing, Eighth Crow Wing, and Lower Twin) were listed as impaired due to declining trends in water quality or historically lower water quality, although the most recent 10-year growing season mean phosphorus concentrations were just below the state water quality standard. In this case, the TMDL goal was based on the achieving a 10% margin of safety reduction in total load to the lake. This reduction is necessary to maintain or improve current water quality conditions.

4.1.1.2 Stream Load Duration Curves

The loading capacity for Swan Creek receiving a TP TMDL as a part of this study were determined using load duration curves. Flow and load duration curves (LDCs) are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. LDCs take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (loading capacity) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

For the stream TMDL derivation, HSPF modeled daily stream flows for the period 2000-2009 were used to develop flow and phosphorus load duration curves. However, for Swan Creek and its tributary Iron Creek, phosphorus monitoring data was only available from 2010 and 2011. To estimate the missing flow records from 2010 and 2011, regression equations were developed using 2000-2009 mean daily flow records for USGS gage #05347500 (Sylvan Dam outlet), and the corresponding HSPF modeled flows. Regression equations where then used to predict missing flow records using the 2010-2011 record at USGS gage #05347500. The sources of all water quality and stream flow data used in the development of load duration curves are described in Section 15 at the end of this report.

The loading capacities were determined by applying the in-stream phosphorus target (100 µg/L) to the flow duration curve to produce a phosphorus standard curve. Loading capacities were calculated as the median value of the phosphorus load (in kg/day) along the phosphorus standard curve within each flow regime. A phosphorus load duration curve with monitored data and a TMDL summary table are provided for Swan Creek in Section 4.1.7.8.

The loading capacities for impaired stream reaches receiving a TMDL as a part of this study were determined using load duration curves. Flow and load duration curves (LDCs) are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. LDCs take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (loading capacity) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

The load duration curve method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by USEPA.

4.1.2 Load Allocations

The LA includes all sources of phosphorus that do not require NPDES permit coverage: watershed runoff, internal loading, atmospheric deposition, and any other identified loads described in Section 3.6.1.2. The remainder of the loading capacity (TMDL) after subtraction of the MOS and calculation of the WLA was used to determine the LA for each impaired lake or stream, on an areal basis.

4.1.3 Wasteload Allocations

4.1.3.1 Regulated Construction Stormwater

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

A categorical WLA was assigned to all construction activity in the each impaired lake or stream subwatershed. First, the median annual fraction of the impaired lake subwatershed area under construction activity over the past 5 years was calculated based on MPCA Construction Stormwater Permit data from January 1, 2007 to October 6, 2012 (Table 47), area weighted based on the fraction of the subwatershed located in each county. This percentage was multiplied by the watershed runoff load which is equal to the total TMDL (loading capacity) minus the sum of the atmospheric load, sediment load, and MOS to determine the construction stormwater WLA.

Table 47. Median Annual NPDES/SDS Construction Stormwater Permit Activity by County (1/1/2007-10/6/2012)

County	Total Area (ac)	Median Annual Construction Activity (% Total Area)
Becker	838,676	0.01%
Cass	1,291,373	0.78%
Clearwater	636,544	0.01%
Crow Wing	637,779	0.05%
Hubbard	590,335	0.02%
Morrison	719,571	0.03%
Otter Tail	1,266,909	0.04%
Todd	602,937	0.01%
Wadena	342,488	0.02%

4.1.3.2 Regulated Industrial Stormwater

Industrial stormwater is regulated by NPDES permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in an impaired lake subwatershed for which NPDES industrial stormwater permit coverage is required.

A categorical WLA was assigned to all industrial activity in each impaired lake or stream subwatershed. The industrial stormwater WLA was set equal to the construction stormwater WLA because industrial activities make up a very small fraction of the watershed area.

4.1.3.3 MS4 Regulated Stormwater

There is no regulated MS4 stormwater in any of the impaired lake or stream subwatersheds.

If MS4 communities come under permit coverage in the future, a portion of the LA will be shifted to the WLA to account for the regulated MS4 stormwater. MS4 permits for state (MnDOT) and county road authorities apply to roads within the U.S. Census Bureau Urban Area. None of the impaired lake subwatersheds are located within the U.S. Census Bureau Urban Area. Therefore, no roads are currently under permit coverage and no WLAs were assigned to the corresponding road authorities. If, in the future, the U.S. Census Bureau Urban Area extends into an impaired lake subwatershed and these roads come under permit coverage, a portion of the LA will be shifted to the WLA.

4.1.3.4 Feedlots Requiring NPDES/SDS Permit Coverage

Animal waste containing phosphorus can be transported in watershed runoff to surface waters. The primary goal of the state feedlot program is to ensure that surface waters are not contaminated by runoff from feedlots, manure storage or stockpiles, and cropland with improperly applied manure. Feedlots that either (a) have a capacity of 1,000 animal units or more, or (b) meet or exceed the USEPA's Concentrated Animal Feeding Operation (CAFO) threshold, are required to apply for coverage under an NPDES/SDS permit for livestock production from the MPCA.

One large animal feedlot is located in the Lower Twin Lake subwatershed. The Jennie-O Turkey Store – Menahga Farm (MNG440421) is permitted for 8,968 animal units and has a general NPDES permit. This facility has no surface discharge of effluent and therefore does not receive a WLA.

4.1.3.5 Municipal and Industrial Waste Water Treatment Systems

An individual WLA was provided for all NPDES-permitted waste-water treatment facilities (WWTFs) that have pollutant discharge limits (for phosphorus) and a surface discharge station within an impaired lake or stream subwatershed. The WLA was calculated as the pollutant effluent limit multiplied by the permitted facility design flow. Continuously discharging municipal WWTF WLAs were calculated based on the average wet weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. Municipal controlled (pond) discharge WWTF WLAs were calculated based on the maximum daily volume that may be discharged in a 24-hour period.

One WWTF is located in the impaired lake or stream subwatersheds. The Wolf Lake WWTF (MN0069205) has primary and secondary stabilization ponds with a permitted discharge of 8,400 gal/day to an unnamed wetland (Class 2D, 3D, 4C) that discharges downstream to Mud Lake (Class 2B, 3B, 4A). No current NPDES permitted TP loading limit; the WLA will be set at 2 mg/L per communication with MPCA. The average annual TP load is estimated to be 23.0 kg/yr with an average wet weather design flow of 8,400 gal/day. The authorized discharge is for 6”/day from the 0.7 acre secondary pond which is equal to 114,048 gal/day.

4.1.4 Margin of Safety

An explicit 10% margin of safety (MOS) was accounted for in the TMDL for each impaired lake. This MOS is sufficient to account for uncertainties in predicting phosphorus loads to lakes and predicting how lakes respond to changes in phosphorus loading. This explicit MOS is considered to be appropriate based on the generally good agreement between the water quality models’ predicted and observed values. Since the models reasonably reflect the conditions in the lakes and their subwatersheds, the 10% MOS is considered to be adequate to address the uncertainty in the TMDL, based upon the data available.

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Most of the uncertainty in flow is the result of extrapolating flows (area-weighting and the use of regression equations) from the hydrologically-nearest stream gage. The explicit MOS, in part, accounts for this. See Section 15.2 for further LDC error analysis.
- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.

4.1.5 Seasonal Variation and Critical Conditions

In-lake and in-stream water quality varies seasonally. In Minnesota lakes and streams, the majority of the watershed phosphorus load often enters the lake during the spring. During the growing season months (June through September), phosphorus concentrations may not change drastically if major runoff events do not occur. However, chlorophyll-a concentration may still increase throughout the growing season due to warmer temperatures fostering higher algal growth rates. In shallow lakes, the phosphorus concentration more frequently increases throughout the growing season due to the additional phosphorus load from internal sources. This can lead to even greater increases in chlorophyll-a since not only is there more phosphorus but temperatures are also higher. This seasonal variation is taken into account in the TMDL by using the eutrophication standards (which are based on growing season averages) as the TMDL goals. The eutrophication standards were set with seasonal variability in mind. The load reductions are designed so that the lakes and streams will meet the water quality standards over the course of the growing season (June through September).

Critical conditions in these lakes occur during the growing season, which is when the lakes are used for aquatic recreation. Similar to the manner in which the standards take into account seasonal variation, since the TMDL is based on growing season averages, the critical condition is covered by the TMDL.

Critical conditions and seasonal variation in stream water quality are also addressed in this TMDL through the use of load duration curves and the evaluation of load variability in five flow regimes: from high flows, such as flood events, to low flows, such as baseflow. Through the use of load duration curves, phosphorus loading was evaluated at actual flow conditions at the time of sampling (and by month).

4.1.6 Future Growth Considerations

Potential changes in population and land use over time in the Crow Wing River Watershed could result in changing sources of pollutants. Possible changes and how they may or may not impact TMDL allocations are discussed below.

4.1.6.1 Load Transfer

Because MS4-permitted land areas can be subject to change the MPCA's Stormwater Program has outlined for TMDLs in general the potential circumstances in which transfer of watershed runoff allocations may need to occur and how load is transferred between and/or within the WLA and LA categories. These scenarios are described below, though not all are applicable to the specific TMDLs in the watershed boundaries of this project.

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

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL (see Section 4.1.3). One transfer rate was defined for each impaired lake or stream as the total wasteload allocation (kg/yr) divided by the watershed area downstream of any upstream impaired waterbody (acres). In the case of a load transfer, the amount transferred from LA to WLA will be based on the area (acres) of land coming under permit coverage multiplied by the transfer rate (kg/ac-yr). The MPCA will make these allocation shifts. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment. Individual transfer rates for each lake or stream TMDL are listed in Table 48.

Table 48. Transfer rates for any future MS4 discharger in the impaired lake watersheds

Lake name	Subwatershed	LA to WLA transfer rates (kg/ac-yr)	LA to WLA transfer rates (kg/ac-day)
Blueberry	Direct Drainage	0.044	0.000120
	Shell River	0.027	0.000075
	Blueberry River	0.038	0.000103
Eighth Crow Wing	Direct Drainage	0.036	0.000098
	Ninth Crow Wing Lake	0.008	0.000023
First Crow Wing	Direct Drainage	0.029	0.000080
	Second Crow Wing Lake	0.010	0.000027
Lower Twin	Direct Drainage	0.051	0.000141
	Upper Twin Lake	0.020	0.000056
Mayo	Direct Drainage	0.037	0.000100
	Sibley Lake	0.020	0.000055
Portage	Direct Drainage	0.024	0.000065
Sibley	Direct Drainage	0.043	0.000118
Swan Creek	High flow regime	N/A	0.000072
	Moist flow regime	N/A	0.000040
	Mid flow regime	N/A	0.000026
	Dry flow regime	N/A	0.000018
	Low flow regime	N/A	0.000011

4.1.6.2 Wasteload Allocation

Currently permitted discharges can be expanded and new NPDES discharges can be added while maintaining water quality standards provided the permitted NPDES effluent concentrations remain below the surface water targets. Given this circumstance, a streamlined process for updating TMDL wasteload allocations to incorporate new or expanding discharges will be employed. The following process will apply to the non-stormwater facilities and any new wastewater or cooling water discharge in the impaired lake or stream watersheds:

1. A new or expanding discharger will file with the MPCA permit program a permit modification request or an application for a permit reissuance. The permit application information will include documentation of the current and proposed future flow volumes and pollutant loads.

2. The MPCA permit program will notify the MPCA TMDL program upon receipt of the request/application, and provide the appropriate information, including the proposed discharge volumes and the pollutant loads.
3. TMDL Program staff will provide the permit writer with information on the TMDL wasteload allocation to be published with the permit's public notice.
4. The supporting documentation (fact sheet, statement of basis, effluent limits summary sheet) for the proposed permit will include information about the pollutant discharge requirements, noting that the effluent limit is below the in-stream target and the increased discharge will maintain water quality standards. The public will have the opportunity to provide comments on the new proposed permit, including the pollutant discharge and its relationship to the TMDL.
5. The MPCA TMDL program will notify the USEPA TMDL program of the proposed action at the start of the public comment period. The MPCA permit program will provide the permit language with attached fact sheet (or other appropriate supporting documentation) and new pollutant information to the MPCA TMDL program and the USEPA TMDL program.
6. USEPA will transmit any comments to the MPCA Permits and TMDL programs during the public comment period, typically via e-mail. MPCA will consider any comments provided by USEPA and by the public on the proposed permit action and wasteload allocation and respond accordingly, conferring with USEPA if necessary.
7. If following the review of comments, MPCA determines that the new or expanded effluent discharge, with a concentration below the in-stream target, is consistent with applicable water quality standards and the above analysis, MPCA will issue the permit with these conditions and send a copy of the final effluent information to the USEPA TMDL program. MPCA's final permit action, which has been through a public notice period, will constitute an update of the WLA only.
8. USEPA will document the update to the WLA in the administrative record for the TMDL.

Through this process USEPA will maintain an up-to-date record of the applicable wasteload allocation for permitted facilities in the watershed.

4.1.7 TMDL Summary

The individual impaired lake and stream TMDL and allocations are summarized in the following tables.

The load duration curve method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by USEPA.

4.1.7.1 Blueberry Lake (80-0034-00) TP TMDL

Table 49. Blueberry Lake TP TMDL and Allocations

Blueberry Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Wolf Lake WWTP (MN0069205)	23.0	23.0	0.86**	0.0	0%
	Construction stormwater (MNR100001)	0.45	0.45	0.001	0.0	0%
	Industrial stormwater (MNR50000)	0.45	0.45	0.001	0.0	0%
	Total WLA	**23.8**	**23.8**	**0.862**	**0.0**	
Load Allocations*	*Watershed runoff*	*89.6*	*78.8*	*0.216*	*10.8*	*12%*
	Failing septics	*3.5*	*0.0*	*0.000*	*3.5*	*100%*
	Shell River	*2,812.9*	*1,998.0*	*5.474*	*814.9*	*29%*
	Blueberry River	*3,075.8*	*2,309.8*	*6.328*	*766.0*	*25%*
	Internal load	*2,196.1*	*120.3*	*0.330*	*2,075.8*	*95%*
	Total Watershed/In-lake	8,177.9	4,506.9	12.348	3,671.0	45%
	Atmospheric	58.0	58.0	0.159	0.0	0%
	Total LA	**8,235.9**	**4,564.9**	**12.507**	**3,671.0**	
MOS			**510.0**	**1.397**		
TOTAL		**8,259.7**	**5,098.7**	**14.766**	**3,671.0**	**44%**

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

**Daily wasteload allocations for Minnesota facilities in the SM1 category are calculated from the 2 mg/L concentration assumption and the maximum permitted effluent flow rate of 6"/day over the area of the facility's discharging cell(s). These controlled discharge facilities are designed to store 180 days worth of influent and to discharge during spring and fall periods of relatively high stream flow and/or low receiving water temperature. Since these facilities discharge intermittently, their daily wasteload allocations do not represent their annual wasteload allocations divided by the days in a year. Rather they reflect the permitted daily effluent loads as described above. Based on these daily allocations, the median number of days per year these facilities may discharge (annual WLA divided by daily WLA) is 27.

Phosphorus Source Summary

- Approximately 27% of the watershed is cropland, developed, or pastured.
- There are 49 registered feedlots in the watershed with a total of 5,584 registered animal units.
- There are approximately 36 shoreline private on-site septic systems, which are estimated to have a 24.7% failure rate.
- In the past, the city of Menahga sewage treatment system discharged to Blueberry Lake.
- Curly-leaf pondweed is the dominant aquatic vegetation and common carp are present in the lake which can contribute to internal phosphorus load.

4.1.7.2 Eighth Crow Wing Lake (29-0072-00) TP TMDL

Table 50. Eighth Crow Wing Lake TP TMDL and Allocations

Eighth Crow Wing Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.05	0.05	0.00014	0.0	0%
	Industrial stormwater (MNR50000)	0.05	0.05	0.00014	0.0	0%
	Total WLA	**0.10**	**0.10**	**0.00027**	**0.0**	
Load Allocations*	*Watershed runoff*	*114.8*	*57.7*	*0.158*	*57.1*	*54%*
	Failing septics	*9.5*	*0.0*	*0.000*	*9.5*	*100%*
	Ninth Crow Wing Lake	*192.2*	*192.2*	*0.527*	*0.0*	*0%*
	Internal load	*295.2*	*295.2*	*0.809*	*0.0*	*0%*
	Total Watershed/In-lake	611.7	545.1	1.493	66.6	11%
	Atmospheric	53.7	53.7	0.147	0.0	0%
	Total LA	**665.4**	**598.8**	**1.640**	**66.6**	
MOS			**66.6**	**0.182**		
TOTAL		**665.5**	**665.5**	**1.822**	**66.6**	**10%**

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

Phosphorus Source Summary

- Approximately 17% of the watershed is cropland, developed, or pastured.
- There are 5 registered feedlots in the watershed with a total of 292 registered animal units.
- There are approximately 100 shoreline private on-site septic systems, which are estimated to have a 24.7% failure rate.

4.1.7.3 First Crow Wing Lake (29-0086-00) TP TMDL

Table 51. First Crow Wing Lake TP TMDL and Allocations

First Crow Wing Lake Load Component		Existing	Goal		Reduction	
		(kg/yr)	(kg/yr)	(kg/day)	(kg/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.4	0.4	0.0011	0.0	0%
	Industrial stormwater (MNR50000)	0.4	0.4	0.0011	0.0	0%
	Total WLA	**0.8**	**0.8**	**0.0022**	**0.0**	
Load Allocations*	*Watershed runoff*	*1,028.4*	*629.0*	*1.723*	*399.4*	*39%*
	Livestock	*3.8*	*2.3*	*0.006*	*1.5*	*39%*
	Failing septics	*3.4*	*0.0*	*0.000*	*3.4*	*100%*
	Second Crow Wing Lake	*1,424.1*	*1,424.1*	*3.902*	*0.0*	*0%*
	Internal load	*3,094.1*	*2,937.4*	*8.048*	*156.7*	*5%*
	Total Watershed/In-lake	5,553.8	4,992.8	13.679	561.0	10%
	Atmospheric	55.4	55.4	0.152	0.0	0%
	Total LA	**5,609.2**	**5,048.2**	**13.831**	**561.0**	
MOS			**561.0**	**1.537**		
TOTAL		**5,610.0**	**5,610.0**	**15.370**	**561.0**	**10%**

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

Phosphorus Source Summary

- Approximately 18% of the watershed is cropland, developed, or pastured.
- There are 15 registered feedlots in the watershed with a total of 1,118 registered animal units.
- There are approximately 37 shoreline private on-site septic systems, which are estimated to have a 24.7% failure rate.
- The watershed drains wetlands with high concentrations of phosphorus in the direct drainage area.
- Common carp are present in the lake which can contribute to internal phosphorus load.
- High primary production may be resulting in a high pH (8.94) measured during the 2009 MN DNR vegetation survey which can contribute to phosphorus release from the sediments.

4.1.7.4 Lower Twin Lake (80-0030-00) TP TMDL

Table 52. Lower Twin Lake TP TMDL and Allocations

Lower Twin Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.97	0.97	0.0027	0.0	0%
	Industrial stormwater (MNR50000)	0.97	0.97	0.0027	0.0	0%
	Total WLA	**1.9**	**1.9**	**0.0054**	**0.0**	
Load Allocations*	*Watershed runoff*	*110.3*	*82.8*	*0.227*	*27.5*	*28%*
	Failing septics	*6.1*	*0.0*	*0.000*	*6.1*	*100%*
	Upper Twin Lake	*8,720.1*	*7,819.4*	*21.423*	*900.7*	*10%*
	Internal load	*476.6*	*476.6*	*1.306*	*0.0*	*0%*
	Total Watershed/In-lake	9,313.1	8,378.9	22.956	934.2	10%
	Atmospheric	27.4	27.4	0.075	0.0	0%
	Total LA	**9,340.5**	**8,406.3**	**23.031**	**934.2**	
MOS			**934.2**	**2.559**		
TOTAL		**9,342.4**	**9,342.4**	**25.595**	**934.2**	**10%**

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

Phosphorus Source Summary

- Approximately 25% of the watershed is cropland, developed, or pastured
- There are 69 registered feedlots in the watershed with a total of 8,634 registered animal units.
- There are approximately 65 shoreline private on-site septic systems, which are estimated to have a 24.7% failure rate.
- Curly leaf pondweed and common carp are present in the lake which can contribute to internal phosphorus load.
- Phosphorus concentration in the deep sediments is high indicating high potential for internal loading from sediment phosphorus release.

4.1.7.5 Mayo Lake (18-0408-00) TP TMDL

Table 53. Mayo Lake TP TMDL and Allocations

Mayo Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	5.2	5.2	0.014	0.0	0%
	Industrial stormwater (MNR50000)	5.2	5.2	0.014	0.0	0%
	Total WLA	**10.4**	**10.4**	**0.028**	**0.0**	
Load Allocations*	*Watershed runoff*	*27.2*	*23.0*	*0.063*	*4.1*	*13%*
	Failing septics	*1.1*	*0.0*	*0.000*	*1.1*	*100%*
	Sibley Lake	*880.2*	*708.4*	*1.941*	*171.8*	*20%*
	Internal load	*198.3*	*88.0*	*0.241*	*110.3*	*56%*
	Total Watershed/In-lake	1,106.7	819.5	2.245	287.2	26%
	Atmospheric	16.4	16.4	0.045	0.0	0%
	Total LA	**1,123.1**	**835.9**	**2.290**	**287.2**	
MOS			**94.0**	**0.258**		
TOTAL		**1,133.5**	**940.3**	**2.576**	**287.2**	**25%**

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

Phosphorus Source Summary

- Approximately 30% of the watershed (located predominantly upstream of impaired Sibley Lake) is cropland, developed, or pastured.
- There are 7 registered feedlots in the watershed with a total of 1,576 registered animal units.
- There are approximately 80 shoreline private on-site septic systems, which are estimated to have a 4% failure rate.
- One impaired lake (Sibley Lake) discharges to Mayo Lake.
- Curly leaf pondweed is present in the lake which can contribute to internal phosphorus load.
- Phosphorus concentration in the sediments is high indicating high potential for internal loading from sediment phosphorus release.

4.1.7.6 Portage Lake (29-0250-00)TP TMDL

Table 54. Portage Lake TP TMDL and Allocations

Portage Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.004	0.004	0.000011	0.0	0%
	Industrial stormwater (MNR50000)	0.004	0.004	0.000011	0.0	0%
	Total WLA	**0.008**	**0.008**	**0.000022**	**0.0**	
Load Allocations*	*Watershed runoff*	*175.1*	*61.0*	*0.167*	*114.1*	*67%*
	Failing septics	*8.8*	*0.0*	*0.000*	*8.8*	*100%*
	Internal load	*73.3*	*17.3*	*0.047*	*56.0*	*76%*
	Total Watershed/In-lake	257.2	78.3	0.214	178.9	70%
	Atmospheric	45.4	45.4	0.124	0.0	0%
	Total LA	**302.6**	**123.7**	**0.338**	**178.9**	
MOS			**13.7**	**0.038**		
TOTAL		**302.6**	**137.4**	**0.376**	**178.9**	**59%**

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

Phosphorus Source Summary

- Approximately 20% of the watershed is cropland, developed, or pastured, and there are no registered feedlots in the watershed.
- There are approximately 94 shoreline private on-site septic systems, which are estimated to have a 24.7% failure rate.
- Curly leaf pondweed is abundant in the lake which can contribute to internal phosphorus load.

4.1.7.7 Sibley Lake (18-0404-00) TP TMDL

Table 55. Sibley Lake TP TMDL and Allocations

Sibley Lake Load Component		Existing	Goal		Reduction	
		(kg/yr)	(kg/yr)	(kg/day)	(kg/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	11.1	11.1	0.030	0.0	0%
	Industrial stormwater (MNR50000)	11.1	11.1	0.030	0.0	0%
	Total WLA	**22.2**	**22.2**	**0.060**	**0.0**	
Load Allocations*	*Watershed runoff*	*1,951.1*	*1,498.3*	*4.105*	*452.8*	*23%*
	Livestock	*47.5*	*36.5*	*0.100*	*11.0*	*23%*
	Failing septics	*3.2*	*0.0*	*0.000*	*3.2*	*100%*
	Internal load	*0.0*	*0.0*	*0.000*	*0.0*	*0%*
	Total Watershed/In-lake	2,001.8	1,534.9	4.205	466.9	23%
	Atmospheric	46.3	46.3	0.127	0.0	0%
	Total LA	**2,048.1**	**1,581.2**	**4.332**	**466.9**	
MOS			**178.0**	**0.488**		
TOTAL		**2,070.3**	**1,781.4**	**4.880**	**466.9**	**23%**

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

Phosphorus Source Summary

- Approximately 30% of the watershed is cropland, developed, or pastured
- There are 7 registered feedlots in the watershed with a total of 1576 registered animal units.
- There are approximately 230 shoreline private on-site septic systems, which are estimated to have a 4% failure rate.
- Curly leaf pondweed is present in the lake which can contribute to internal phosphorus load.
- Phosphorus concentration in the deep sediments is high and the lake strongly stratifies, indicating high potential for internal loading from sediment phosphorus release. However, BATHUB modeling calibration indicated that the amount of internal loading in Sibley Lake is similar to typical background levels for lakes. That is to say, the phosphorus released from the deep sediments during anoxic conditions is not transported to surface waters in a sufficient amount during the growing season to negatively affect water quality.

4.1.7.8 Swan Creek (07010106-527) TP TMDL

Due to the localized nature of anthropogenic impacts on Swan Creek, a TP TMDL was developed for this stream reach with the assumption that the BMPs put in place to meet the *E. coli* load reductions will also result in the necessary TP load reductions. Therefore, no specific actions are recommended for TP reductions at this time but the TP loading goals developed for this stream can be used if anthropogenic influences increase on this stream in the future.

Figure 21. Swan Creek TP Load Duration Curve

Note that the load duration curve is shown in lb TP/day. The TMDL and allocation table was converted to kg TP/day based on the conversion: 2.2046 lb = 1 kg.

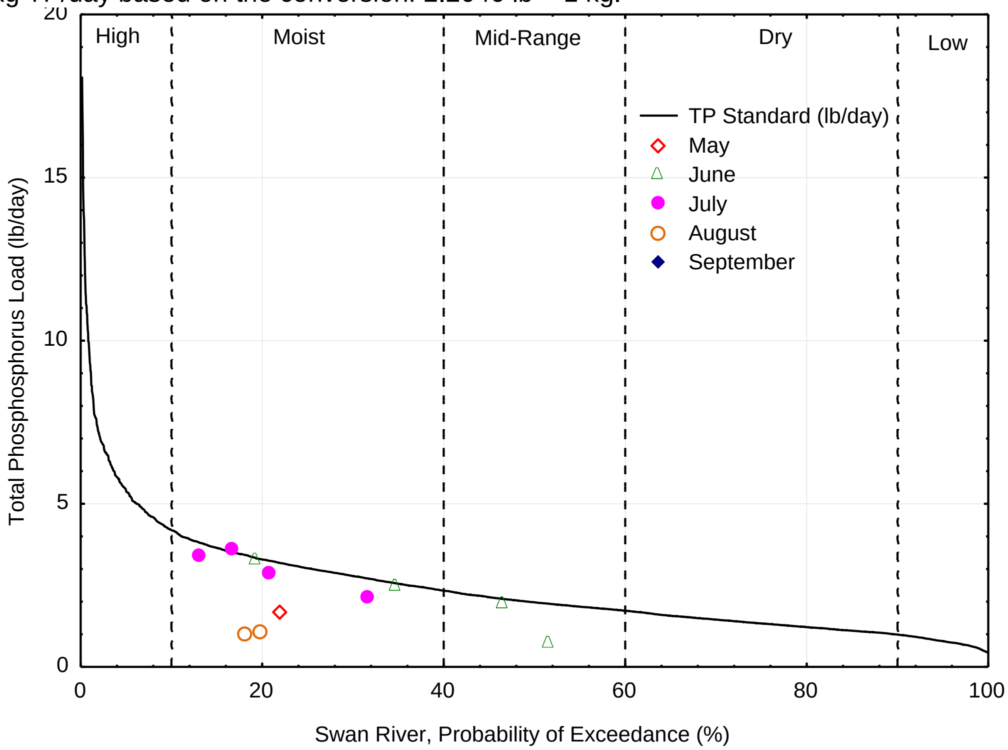


Table 56. Swan Creek TP TMDL and Allocations

Swan Creek (07010106-527) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		TP (kg/day)				
Existing Load		No Data	1.2	0.6	No Data	No Data
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocation	*Watershed runoff*	*1.08*	*0.61*	*0.40*	*0.26*	*0.15*
	Tributary: Iron Creek	*1.13*	*0.63*	*0.41*	*0.28*	*0.17*
	Total LA	**2.21**	**1.24**	**0.81**	**0.54**	**0.32**
MOS		**0.25**	**0.14**	**0.09**	**0.06**	**0.04**
Total Loading Capacity		**2.45**	**1.37**	**0.90**	**0.60**	**0.36**
Estimated Load Reduction		No Data	0%	0%	No Data	No Data

Phosphorus Source Summary

- Approximately 50% of the phosphorus load in Swan Creek originates from the Iron Creek watershed which covers just 20% of the total Swan Creek watershed area. The Iron Creek watershed is dominated by iron-rich wetland soils, naturally high in phosphorus.
- There are small, localized sources of phosphorus from pasturing animals wading in Swan Creek that were identified as stressors to low dissolved oxygen levels in Swan Creek. While no overall phosphorus reductions from watershed runoff are needed to meet the stream loading capacity for phosphorus, implementation activities aimed at limiting livestock access to the stream will help to improve dissolved oxygen levels in Swan Creek.

4.1.8 TMDL Baseline Years

The TMDLs are based on water quality data through 2011. Any activities implemented during or after 2011 that lead to a reduction in phosphorus loads to the lake or stream, or an improvement in lake water quality, may be considered as progress towards meeting a WLA or LA. Types of activities that can be credited toward achieving a WLA are defined in the applicable NPDES/SDS permits.

4.2 Temperature

4.2.1 Loading Capacity

Because temperature cannot directly be described as a load, the TMDL was calculated by using the amount of energy in the water at specific temperatures and flows. The total energy of flow is composed of three parts: kinetic, potential, and internal energy. In the Straight and Shell rivers and other systems similar to it, the kinetic and potential energy are negligible compared to the internal energy. To calculate the internal energy load, the following equation was used:

$$E = m\,h$$

where E is the energy flow rate in kilowatts (kW), m is the mass flow rate of water in kilograms per second (kg/s), and h is the internal energy of water in kilojoules per kilogram (kJ/kg). The internal energy of water was estimated as the specific heat capacity of water (4.186 kJ/kg-°C) multiplied by the water temperature (in °C). The internal energy load equation was used to calculate the energy flow rate at all flow rates and temperatures monitored during the period of record. This equation was also used to define the load duration curve and monitored loads by using the monitored stream flows and temperatures, the specific heat capacity of water, and the temperature-dependent density of water. The TMDL and allocations were calculated in terms of the million kJ per day that the stream can assimilate and maintain water temperatures below the in-stream temperature targets identified in Section 2.3.1.2.

For the stream TMDL derivations, daily stream flows records for the period 2000-2009 were used to develop flow and heating capacity load duration curves for each impaired reach. Flow records from gaged sources were used where possible and flow records from the HSPF model (AquaTerra 2013) where used in all other cases. Where an impaired stream reach was located upstream of a gaging station or the outlet of an HSPF modeled subbasin, the flows from the contributing drainage area were area-weighted to account for differences in flow volume at the two locations.

In the development of load duration curves, gaged flows or HSPF modeled stream flows were used with overlapping temperature monitoring data wherever possible. In most cases, however, overlapping temperature and stream flow data were not available for one or both years of the monitoring record. To estimate missing flow records, regression equations were developed using 2000-2009 mean daily flow records for USGS gage #05347500 (Sylvan Dam outlet), and the corresponding flow records (gaged or HSPF modeled) for each impaired reach. Regression equations where then used to predict missing flow records using the 2010-2011 record at USGS gage #05347500. The sources of all temperature and stream flow data used in the development of load duration curves are described in Section 15 at the end of this report.

The loading capacities were determined by applying the heating capacity to flow duration curves to produce a pollutant standard curve for each impaired reach. Loading capacities were calculated as the median value of the heating load (in million KJ/day) along the pollutant standard curve within each flow regime. Heating capacity load duration curves and monitored data are included with TMDL summaries for each reach in Section 4.2.7.

The loading capacities for impaired stream reaches receiving a TMDL as a part of this study were determined using load duration curves. Flow and load duration curves (LDCs) are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. LDCs take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (loading capacity) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

The load duration curve method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by USEPA.

4.2.2 Load Allocations

Load allocations (LAs) represent the portion of the heating load that is designated for non-regulated sources described in Section 3.6.2. The LA includes all sources of heating capacity that do not require NPDES permit coverage described in Section 3.6.2. The remainder of the loading capacity (TMDL) after subtraction of the MOS and calculation of the WLA was used to determine the LA for each impaired stream, on an areal basis.

4.2.3 Wasteload Allocations

There is no regulated stormwater or wastewater for heating capacity loads located in the TMDL project area.

4.2.4 Margin of Safety

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Most of the uncertainty in flow is the result of extrapolating flows (area-weighting and the use of regression equations) from the hydrologically-nearest stream gage. The explicit MOS, in part, accounts for this. See Section 15.2 for further LDC error analysis.
- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.

4.2.5 Seasonal Variation and Critical Conditions

In-stream temperatures vary seasonally due to climatic cycles in air temperatures. Peak stream temperatures generally occur in the summer months. In addition, the contribution of stream flow from groundwater versus surface water varies with the flow regime and season. Spring is associated with large flows from snowmelt, the summer is associated with greater stress to baseflows from increased groundwater appropriation uses for crop irrigation and periodic storm events, and the fall brings increasing precipitation.

Critical conditions and seasonal variation are addressed in this TMDL through the use of load duration curves and the evaluation of load variability in five flow regimes: from high flows, such as flood events, to low flows, such as baseflow. Through the use of load duration curves, heating capacity loading was evaluated at actual flow conditions at the time of sampling (and by month).

4.2.6 Reserve Capacity and Future Growth

Potential changes in population and land use over time in the Crow Wing River Watershed could result in changing sources of pollutants. Possible changes and how they may or may not impact TMDL allocations are discussed below.

4.2.6.1 Load Transfer

Because MS4-permitted land areas can be subject to change the MPCA's Stormwater Program has outlined for TMDLs in general the potential circumstances in which transfer of watershed runoff allocations may need to occur and how load is transferred between and/or within the WLA and LA categories. These scenarios are described below, though not all are applicable to the specific TMDLs in the watershed boundaries of this project.

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

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL (see Section 4.2.3). One transfer rate was defined for each impaired stream as the total wasteload allocation (million kJ/ac/day) divided by the watershed area downstream of any upstream impaired waterbody (acres). In the case of a load transfer, the amount transferred from LA to WLA will be based on the area (acres) of land coming under permit coverage multiplied by the transfer rate (million kJ/ac/day). The MPCA will make these allocation shifts. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment. Individual transfer rates for each stream TMDL are listed in Table 57.

Table 57. Transfer rates for any future MS4 discharger in the impaired lake watersheds

Stream name	AUID	LA to WLA transfer rates (million kJ/acre/day)				
		High	Moist	Mid	Dry	Low
Straight River	07010106-558	0.29	0.21	0.18	0.16	0.13
Shell River	07010106-681	0.28	0.18	0.14	0.11	0.06

4.2.6.2 Wasteload Allocation

Currently permitted discharges can be expanded and new NPDES discharges can be added while maintaining water quality standards provided the permitted NPDES effluent concentrations remain below the surface water targets. Given this circumstance, a streamlined process for updating TMDL wasteload allocations to incorporate new or expanding discharges will be employed. The following process will apply to the non-stormwater facilities and any new wastewater or cooling water discharge in the impaired lake watersheds:

1. A new or expanding discharger will file with the MPCA permit program a permit modification request or an application for a permit reissuance. The permit application information will include documentation of the current and proposed future flow volumes and pollutant loads.
2. The MPCA permit program will notify the MPCA TMDL program upon receipt of the request/application, and provide the appropriate information, including the proposed discharge volumes and the pollutant loads.
3. TMDL Program staff will provide the permit writer with information on the TMDL wasteload allocation to be published with the permit's public notice.
4. The supporting documentation (fact sheet, statement of basis, effluent limits summary sheet) for the proposed permit will include information about the pollutant discharge requirements, noting that the effluent limit is below the in-stream target and the increased discharge will maintain water quality standards. The public will have the opportunity to provide comments on the new proposed permit, including the pollutant discharge and its relationship to the TMDL.
5. The MPCA TMDL program will notify the USEPA TMDL program of the proposed action at the start of the public comment period. The MPCA permit program will provide the permit language with attached fact sheet (or other appropriate supporting documentation) and new pollutant information to the MPCA TMDL program and the USEPA TMDL program.
6. USEPA will transmit any comments to the MPCA Permits and TMDL programs during the public comment period, typically via e-mail. MPCA will consider any comments provided by USEPA and by the public on the proposed permit action and wasteload allocation and respond accordingly, conferring with USEPA if necessary.

7. If following the review of comments, MPCA determines that the new or expanded effluent discharge, with a concentration below the in-stream target, is consistent with applicable water quality standards and the above analysis, MPCA will issue the permit with these conditions and send a copy of the final effluent information to the USEPA TMDL program. MPCA's final permit action, which has been through a public notice period, will constitute an update of the WLA only.
8. USEPA will document the update to the WLA in the administrative record for the TMDL.

Through this process USEPA will maintain an up-to-date record of the applicable wasteload allocation for permitted facilities in the watershed.

4.2.7 TMDL Summary

The individual impaired stream TMDL and allocations are summarized in table format in the following sections. Load duration curves used in the determination of loading capacity are included in these sections. A brief overview of allocations is discussed below. For detailed information on potential sources of heating load in watershed runoff see the heating capacity source assessment, section 3.6.2.

The load duration curve method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by USEPA.

4.2.7.1 Straight River (07010106-558) Heating Capacity TMDL

Figure 22. Straight River Heating Capacity Load Duration Curve at S002-960

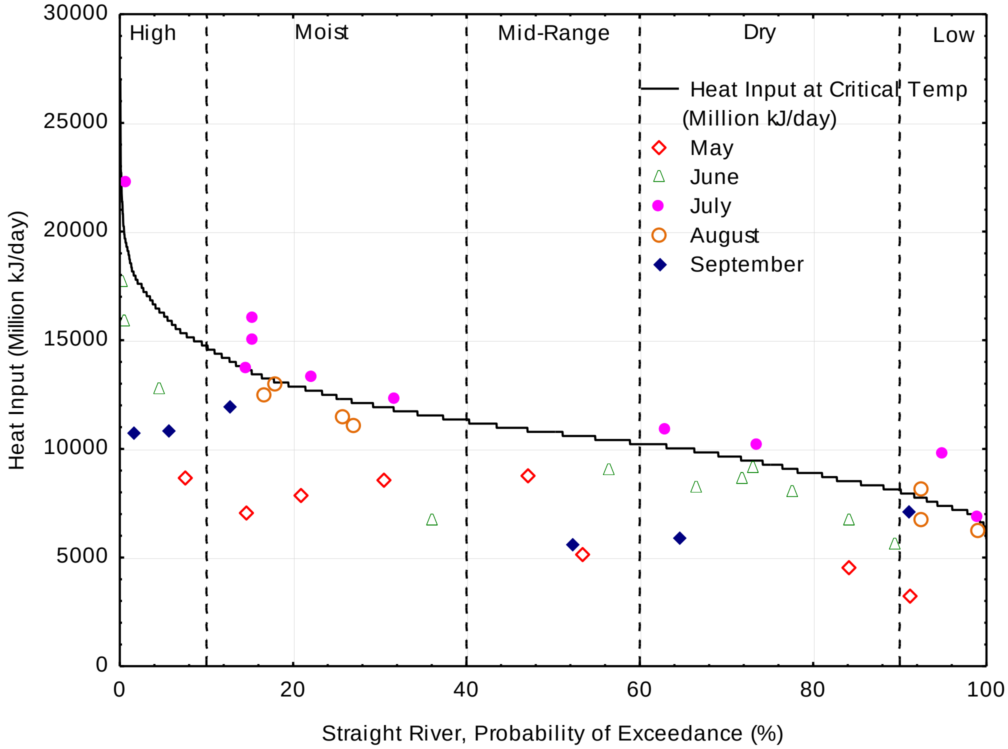


Table 58. Straight River Heating Capacity TMDL and Allocations

Straight River (07010106-558) Load Component	Flow Regime				
	High	Moist	Mid	Dry	Low
	Heat Input (Million kJ/day)				
Existing Load	10,877	11,708	5,098	5,772	6,821
Wasteload Allocation	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocation	**15,048**	**11,237**	**9,705**	**8,343**	**6,640**
MOS	**1,672**	**1,249**	**1,078**	**927**	**738**
Total Loading Capacity	**16,720**	**12,486**	**10,783**	**9,270**	**7,378**

4.2.7.2 Shell River (07010106-681) Heating Capacity TMDL and Allocations

Figure 23. Shell River Heating Capacity Load Duration Curve at S003-833

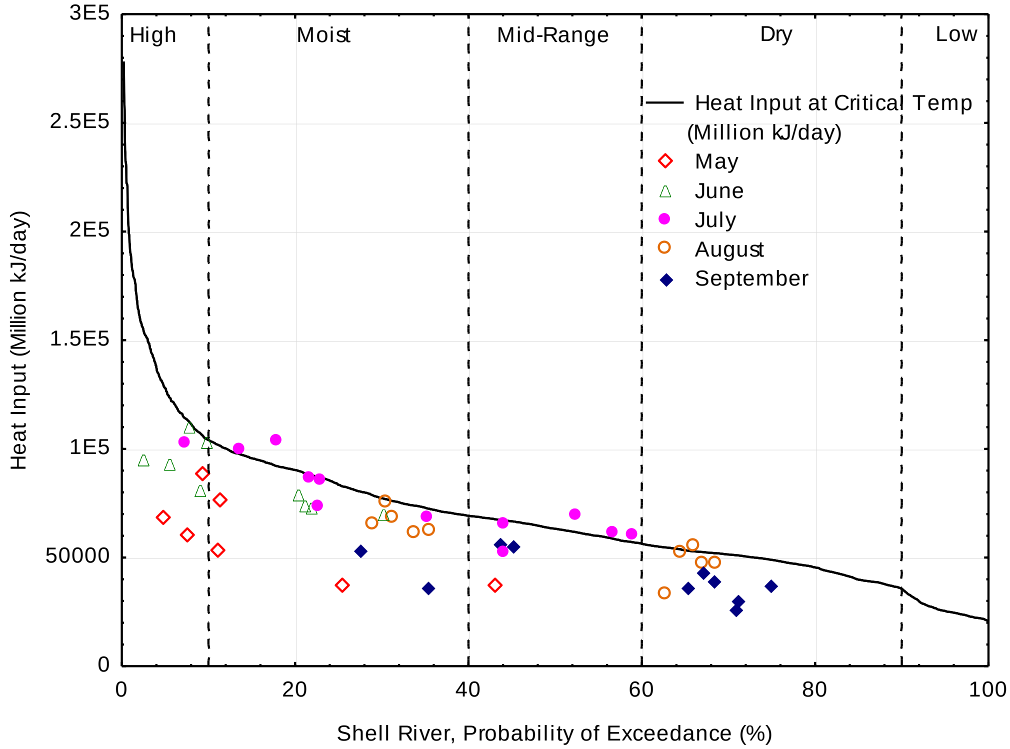


Table 59. Shell River Heating Capacity TMDL and Allocations

Shell River (07010106-681) Load Component	Flow Regime				
	High	Moist	Mid	Dry	Low
	Heat Input (Million kJ/day)				
Existing Load	88,944	65,919	56,382	36,081	No Data
Wasteload Allocation	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocation	**115,123**	**75,103**	**56,945**	**44,018**	**22,854**
MOS	**12,791**	**8,345**	**6,327**	**4,891**	**2,539**
Total Loading Capacity	**127,915**	**83,448**	**63,272**	**48,909**	**25,393**

4.2.8 TMDL Baseline Years

The TMDLs are based on water quality data through 2011. Any activities implemented during or after 2011 that lead to a reduction in heating capacity loads to the streams or an improvement in stream water quality may be considered as progress towards meeting a WLA or LA. Types of activities that can be credited toward achieving a WLA are defined in the applicable NPDES/SDS permits.

4.3 *Escherichia coli*

4.3.1 Loading Capacity

The loading capacities for impaired stream reaches receiving an *E. coli* TMDL as a part of this study were determined using load duration curves. Flow and load duration curves (LDCs) are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. LDCs take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (loading capacity) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

For the stream TMDL derivations, daily stream flows records for the period 2000-2009 were used to develop flow and pollutant (*E. coli)* load duration curves for each impaired reach. Flow records from gaged sources were used where possible and flow records from the HSPF model (AquaTerra, 2013) where used in all other cases. Where an impaired stream reach was located upstream of a gaging station or the outlet of an HSPF modeled subbasin, the flows from the contributing drainage area were area-weighted to account for differences in flow volume at the two locations.

For each impaired stream reach, two years of consecutive water quality monitoring (*E. coli*) were conducted over the period 2009-2011 (either 2009-2010 or 2010-2011). In the development of load duration curves, gaged flows or HSPF modeled stream flows were used with overlapping *E. coli* monitoring data wherever possible. In most cases, however, overlapping water quality and stream flow data were not available for one or both years of the monitoring record. To estimate missing flow records, regression equations were developed using 2000-2009 mean daily flow records for USGS gage #05347500 (Sylvan Dam outlet), and the corresponding flow records (gaged or HSPF modeled) for each impaired reach. Regression equations where then used to predict missing flow records using the 2010-2011 record at USGS gage #05347500. The sources of all water quality and stream flow data used in the development of load duration curves are described in Section 15 at the end of this report.

The loading capacities were determined by applying the *E. coli* standard of 126 org/100 ml [billion org/day], to flow duration curves to produce a pollutant standard curve for each impaired reach. Loading capacities were calculated as the median value of the *E. coli* load (in billion org/day) along the pollutant standard curve within each flow regime. *E. coli* load duration curves and monitored data are included with TMDL summaries for each reach in Section 4.3.7.

The load duration curve method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by USEPA.

4.3.2 Load Allocations

Load allocations (LAs) represent the portion of the loading capacity that is designated for non-regulated sources of *E. coli*, described in Section 3.6.3, that are located downstream of any other impaired waters with TMDLs located in the watershed. The only impaired reach for which upstream *E. coli* TMDLs had to be considered was Home Brook. For Home Brook, water quality monitoring data was available from two stations, an upper reach, located in the vicinity of the outlet to HSPF subbasin 587 (MPCA #S006-384) and a lower reach, located downstream of the confluence with Corey Brook (MPCA#S004-728). TMDLs were written for both the upper and lower reach. For the lower reach, load allocations were made for the *E. coli* loads contributed by the upper portion of Home Brook and by Corey Brook. These load allocation are equivalent to the loading capacity for each tributary within the specified flow regime. The watershed load allocation for the lower reach of Home Brook was than calculated as the remaining allowable load after the tributary load allocations and an explicit 10% margin of safety were subtracted from the Loading Capacity. In all other cases, only a watershed Load Allocation was written in the *E. coli* TMDL. The watershed load includes all non-regulated sources of *E. coli* within the contributing watershed area.

4.3.3 Wasteload Allocations

4.3.3.1 Regulated Construction Stormwater

E. coli WLAs for regulated construction stormwater (permit #MNR100001) were not developed since *E. coli* is not a typical pollutant from construction sites.

4.3.3.2 Regulated Industrial Stormwater

There are no *E. coli* benchmarks associated with the industrial stormwater permit because no industrial sectors regulated under the permit are known to be *E. coli* sources. Therefore, *E. coli* TMDLs will not include an industrial stormwater WLA. Since sites with MNG permits are not known to be sources of *E. coli*, sites with MNG permits that are within the *E. coli* TMDL Subwatersheds will not receive an *E. coli* WLA.

4.3.3.3 Feedlots Requiring NPDES/SDS Permit Coverage

An animal feeding operation (AFO) is a general term for an area intended for the confined holding of animals, where manure may accumulate, and where vegetative cover cannot be maintained within the enclosure due to the density of animals. Animal feeding operations that either (a) have a capacity of 1,000 animal units or more, or (b) meet or exceed the USEPA's Concentrated Animal Feeding Operation (CAFO) threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. If item (a) is triggered, the permit can be an SDS or NPDES/SDS permit; if item (b) is triggered, the permit must be an NPDES permit. These permits require that the feedlots have zero discharge to surface water. Based on a desktop review of MPCA data there are no permitted feedlots within this watershed. There are feedlots within this watershed, but none are large enough to trigger the MPCA permit requirements. The non-permitted feedlots are referenced in the non-point source inventory section (3.6.3 Non-permitted Sources of *E. coli*).

4.3.3.1 Municipal and Industrial Wastewater Treatment Systems

WLAs were provided for all NPDES-permitted WWTFs that have fecal coliform discharge limits (200 org/100mL, April 1 through October 31) and whose surface discharge stations fall within the TMDL Subwatersheds. Based on a desktop review of MPCA data there is one NPDES permitted wastewater facilities within the Partridge River TMDL subwatershed impaired for aquatic recreation due to *E. coli* (AUID 07010106-518) (Table 60). The daily wasteload allocation for the Bertha WWTP was calculated from the facility's Fecal Coliform bacteria effluent limit of 200 organisms/100 mL (equivalent to the 126 organism 100/mL E. coli water quality standard) and the maximum permitted effluent flow rate of 6"/day from the facility's 6.2 acre discharging cell. Unlike the stream TMDL the WLAs for the WWTFs do not vary based on in stream flow.

The WLAs are based on *E. coli* loads even though the facilities' discharge limits are based on fecal coliform. If a discharger is meeting the fecal coliform limits of their permit, it is assumed that they are also meeting the *E. coli* WLA in these TMDLs. Expanding and new dischargers permitted at the fecal coliform limit will be added to the *E. coli* WLA via the NPDES permit public notice process (see Section 4.3.6 for a discussion regarding new or expanded WWTFs).

Table 60. NPDES-permitted WWTFs in the TMDL Subwatersheds.

Permit Name (Number)	Maximum Daily Permitted Discharge (million gal/day)	Bacteria Permit Effluent Limits	Type	TMDL Subwatershed
Bertha WWTP (MN0022799)	1.01*	*Fecal coliform*: 200 org /100 mL	Controlled discharge stabilization pond	Partridge River (AUID 07010106-518)

*Based on 6 inches/day from the facility's 6.2 acre discharging cell

4.3.4 Margin of Safety

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Most of the uncertainty in flow is a result of extrapolating flows (area-weighting and the use of regression equations) from the hydrologically-nearest stream gage. The explicit MOS, in part, accounts for this. See Section 15.2 for further LDC error analysis.
- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.
- With respect to the *E. coli* TMDLs, the load duration analysis does not address bacteria re-growth in sediments, die-off, and natural background levels. The MOS helps to account for the variability associated with these conditions.

4.3.5 Seasonal Variation and Critical Conditions

Use of these water bodies for aquatic recreation occurs from April through October, which includes all or portions of the spring, summer and fall seasons. *E. coli* loading varies with the flow regime and season. Spring is associated with large flows from snowmelt, the summer is associated with the growing season as well as periodic storm events and receding streamflows, and the fall brings increasing precipitation and rapidly changing agricultural landscapes.

Critical conditions and seasonal variation are addressed in this TMDL through several mechanisms. The *E. coli* standard applies during the recreational period, and data was collected throughout this period. The water quality analysis conducted on these data evaluated variability in flow through the use of five flow regimes: from high flows, such as flood events, to low flows, such as baseflow. Through the use of load duration curves and monthly summary figures, *E. coli* loading was evaluated at actual flow conditions at the time of sampling (and by month), and monthly *E. coli* concentrations were evaluated against precipitation and streamflow.

4.3.6 Reserve Capacity and Future Growth

Potential changes in population and land use over time in the Crow Wing River Watershed could result in changing sources of pollutants. Possible changes and how they may or may not impact TMDL allocations are discussed below.

4.3.6.1 Load Transfer

Because MS4-permitted land areas can be subject to change the MPCA's Stormwater Program has outlined for TMDLs in general the potential circumstances in which transfer of watershed runoff allocations may need to occur and how load is transferred between and/or within the WLA and LA categories. These scenarios are described below, though not all are applicable to the specific TMDLs in the watershed boundaries of this project.

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

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL (see Section 4.3.3). One transfer rate was defined for each impaired stream as the total wasteload allocation (millions of organisms /day) divided by the watershed area downstream of any upstream impaired waterbody (acres). In the case of a load transfer, the amount transferred from LA to WLA will be based on the area (acres) of land coming under permit coverage multiplied by the transfer rate (millions of organisms/ac/day). The MPCA will make these allocation shifts. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment. Individual transfer rates for each stream TMDL are listed in Table 61.

Table 61. Transfer rates for any future MS4 discharger in the impaired lake watersheds

Stream name	AUID	LA to WLA transfer rates (million org/acre/day)				
		High	Moist	Mid	Dry	Low
Cat River	07010106-544	4.4	2.3	1.4	0.9	0.5
Corey Brook	07010106-700	32.9	9.6	4.1	1.9	0.3
Farnham Creek	07010106-702	3.9	2.3	1.6	1.1	0.7
Home Brook	07010106-524	4.9	1.5	0.6	0.3	0.05
Mayo Creek	07010106-604	2.4	1.1	0.8	0.6	0.3
Partridge River	07010106-518	5.6	2.5	1.3	0.5	0.4
Pillager Creek	07010106-577	3.3	1.9	1.3	0.9	0.5
Stoney Brook	07010106-698	5.4	2.6	1.9	1.4	0.7
Swan Creek	07010106-527	4.4	2.5	1.6	1.1	0.6
Unnamed Creek	07010106-684	5.5	2.5	0.9	1.1	0.6

4.3.6.2 Wasteload Allocation

Currently permitted discharges can be expanded and new NPDES discharges can be added while maintaining water quality standards provided the permitted NPDES effluent concentrations remain below the surface water targets. Given this circumstance, a streamlined process for updating TMDL wasteload allocations to incorporate new or expanding discharges will be employed. The following process will apply to the non-stormwater facilities and any new wastewater or cooling water discharge in the impaired lake watersheds:

1. A new or expanding discharger will file with the MPCA permit program a permit modification request or an application for a permit reissuance. The permit application information will include documentation of the current and proposed future flow volumes and pollutant loads.
2. The MPCA permit program will notify the MPCA TMDL program upon receipt of the request/application, and provide the appropriate information, including the proposed discharge volumes and the pollutant loads.
3. TMDL Program staff will provide the permit writer with information on the TMDL wasteload allocation to be published with the permit's public notice.
4. The supporting documentation (fact sheet, statement of basis, effluent limits summary sheet) for the proposed permit will include information about the pollutant discharge requirements, noting that the effluent limit is below the in-stream target and the increased

discharge will maintain water quality standards. The public will have the opportunity to provide comments on the new proposed permit, including the pollutant discharge and its relationship to the TMDL.

5. The MPCA TMDL program will notify the USEPA TMDL program of the proposed action at the start of the public comment period. The MPCA permit program will provide the permit language with attached fact sheet (or other appropriate supporting documentation) and new pollutant information to the MPCA TMDL program and the USEPA TMDL program.
6. USEPA will transmit any comments to the MPCA Permits and TMDL programs during the public comment period, typically via e-mail. MPCA will consider any comments provided by USEPA and by the public on the proposed permit action and wasteload allocation and respond accordingly, conferring with USEPA if necessary.
7. If following the review of comments, MPCA determines that the new or expanded effluent discharge, with a concentration below the in-stream target, is consistent with applicable water quality standards and the above analysis, MPCA will issue the permit with these conditions and send a copy of the final effluent information to the USEPA TMDL program. MPCA's final permit action, which has been through a public notice period, will constitute an update of the WLA only.
8. USEPA will document the update to the WLA in the administrative record for the TMDL.

Through this process USEPA will maintain an up-to-date record of the applicable wasteload allocation for permitted facilities in the watershed.

4.3.7 TMDL Summary

The individual impaired stream TMDL and allocations are summarized in table format in the following sections. Load duration curves used in the determination of loading capacity are included in these sections. For detailed information on potential sources of *E. coli* in watershed runoff see the Bacterial Source Assessment, section 3.6.3.

The load duration curve method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by USEPA.

4.3.7.1 Cat River (07010106-544) *E. coli* TMDL

Figure 21. Cat River *E. coli* Load Duration Curve

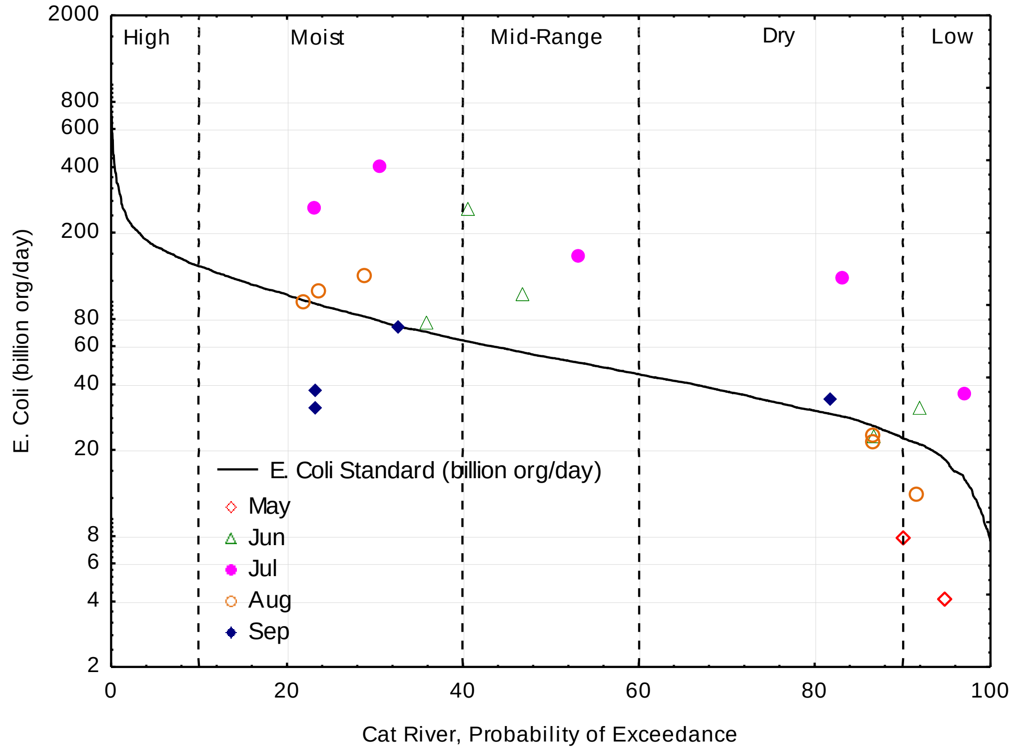


Table 35. Cat River *E. coli* TMDL and Allocations

Cat River (07010106-544) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**No Data**	**99.5**	**162.4**	**34.9**	**13.6**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed runoff*	*155.7*	*80.9*	*47.7*	*30.1*	*16.0*
	Total LA	**155.7**	**80.9**	**47.7**	**30.1**	**16.0**
MOS		**17.3**	**9.0**	**5.3**	**3.3**	**1.8**
Total Loading Capacity		**173.0**	**89.9**	**53.0**	**33.4**	**17.8**
Estimated Load Reduction		**N/A**	**10%**	**67%**	**4%**	**0%**

Bacteria Source Summary

- High potential from livestock (cattle)

4.3.7.1 Corey Brook (07010106-700) *E. coli* TMDL

Figure 26. Corey Brook *E. coli* Load Duration Curve

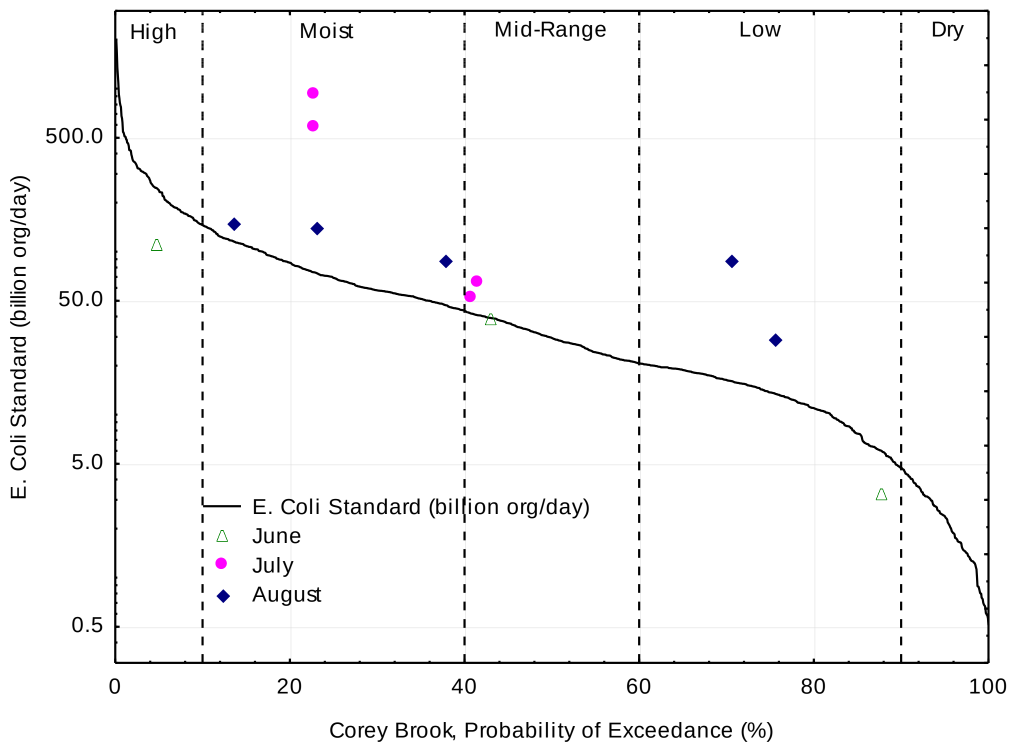


Table 62. Corey Brook *E. coli* TMDL and Allocations

Corey Brook (07010106-700) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**110.9**	**251.2**	**50.5**	**20.3**	**No Data**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed runoff*	*211.9*	*62.2*	*26.7*	*12.3*	*2.2*
	Total LA	**211.9**	**62.2**	**26.7**	**12.3**	**2.2**
MOS		**23.5**	**6.9**	**3.0**	**1.4**	**0.2**
Total Loading Capacity		**235.4**	**69.1**	**29.7**	**13.7**	**2.4**
Estimated Load Reduction		**N/A**	**73%**	**41%**	**33%**	**N/A**

Bacteria Source Summary

- High potential from wildlife
  - High potential from feral cats
  - Medium-high potential from ducks
- Medium-high potential from livestock (cattle)

4.3.7.1 Farnham Creek (07010106-702) *E. coli* TMDL

Figure 27. Farnham Creek *E. coli* Load Duration Curve

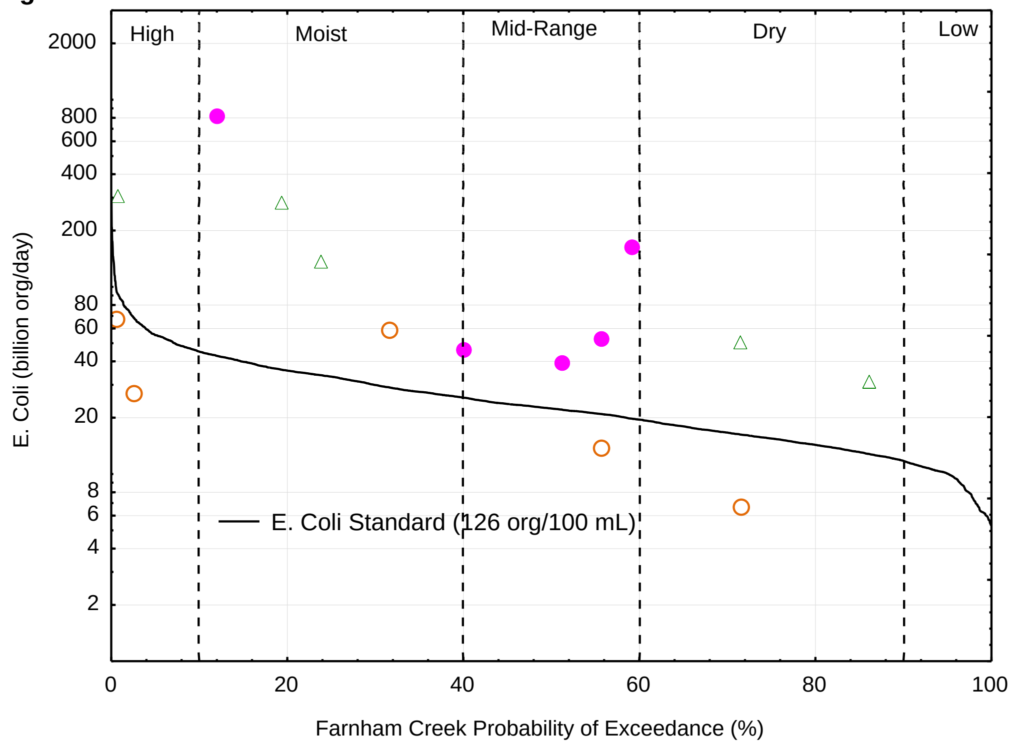


Table 63. Farnham Creek *E. coli* TMDL and Allocations

Farnham Creek (07010106-702) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**82.6**	**209.2**	**47.3**	**21.9**	**No Data**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed runoff*	*49.8*	*29.9*	*20.2*	*13.9*	*9.1*
	Total LA	**49.8**	**29.9**	**20.2**	**13.9**	**9.1**
MOS		**5.5**	**3.3**	**2.2**	**1.6**	**1.0**
Total Loading Capacity		**55.3**	**33.2**	**22.4**	**15.5**	**10.1**
Estimated Load Reduction		**33%**	**84%**	**53%**	**29%**	**N/A**

Bacteria Source Summary

- High potential from wildlife (ducks)
- High potential from livestock (cattle)
- Beaver populations have also been observed on this stream reach which may be directly contributing bacteria within the stream

4.3.7.2 Home Brook (07010106-524) *E. coli* TMDL

Figure 19. Home Brook *E. coli* Load Duration Curve

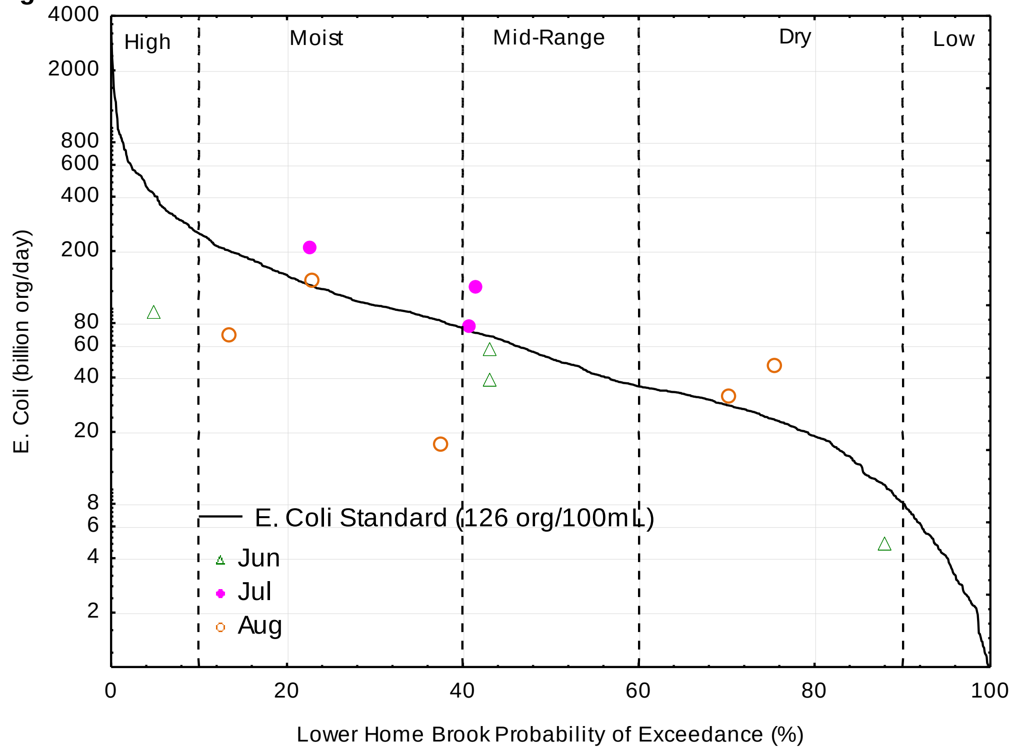


Table 64. Home Brook *E. coli* TMDL and Allocations

Home Brook (07010106-524) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**94.2**	**76.4**	**69.2**	**19.4**	**No Data**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed Runoff*	*126.9*	*38.4*	*16.2*	*7.6*	*1.3*
	Upstream Impaired Tributary: Corey Brook	*235.4*	*69.1*	*29.7*	*13.7*	*2.4*
	Total LA	**362.3**	**107.5**	**45.9**	**21.3**	**3.7**
MOS		**40.3**	**11.9**	**5.1**	**2.4**	**0.4**
Total Loading Capacity		**402.6**	**119.4**	**51.0**	**23.7**	**4.1**
Estimated Load Reduction		**0%**	**0%**	**26%**	**0%**	**N/A**

Bacteria Source Summary

- High potential from wildlife
  - High potential from feral cats
  - Medium-high potential from ducks
- Medium-high potential from livestock (cattle)

4.3.7.1 Mayo Creek (07010106-604) *E. coli* TMDL

Figure 23. Mayo Creek *E. coli* Load Duration Curve

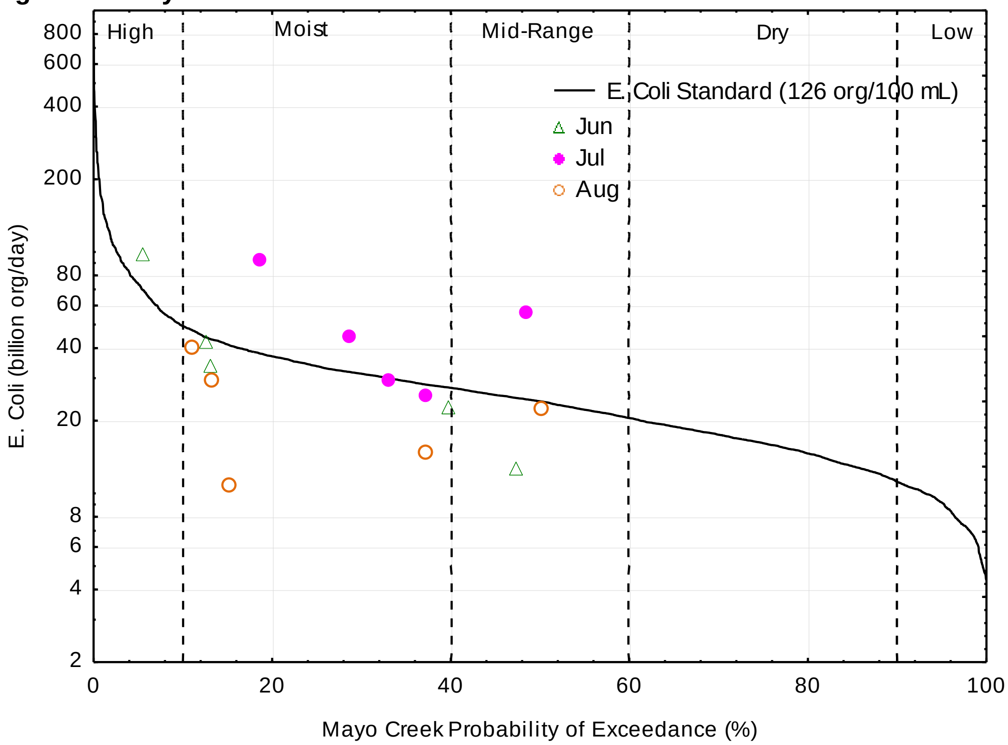


Table 37. Mayo Creek *E. coli* TMDL and Allocations

Mayo Creek (07010106-604) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**99.4**	**30.4**	**25.4**	**No Data**	**No Data**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed runoff*	*66.5*	*30.2*	*21.6*	*15.5*	*8.3*
	Total LA	**66.5**	**30.2**	**21.6**	**15.5**	**8.3**
MOS		**7.4**	**3.4**	**2.4**	**1.6**	**0.9**
Total Loading Capacity		**73.9**	**33.6**	**24.0**	**16.1**	**9.2**
Estimated Load Reduction		**26%**	**0%**	**6%**	**N/A**	**N/A**

Bacteria Source Summary

- High potential from wildlife (ducks)
- High potential from livestock (cattle)

4.3.7.1 Partridge River (07010106-518) *E. coli* TMDL

Figure 17. Partridge River *E. coli* Load Duration Curve

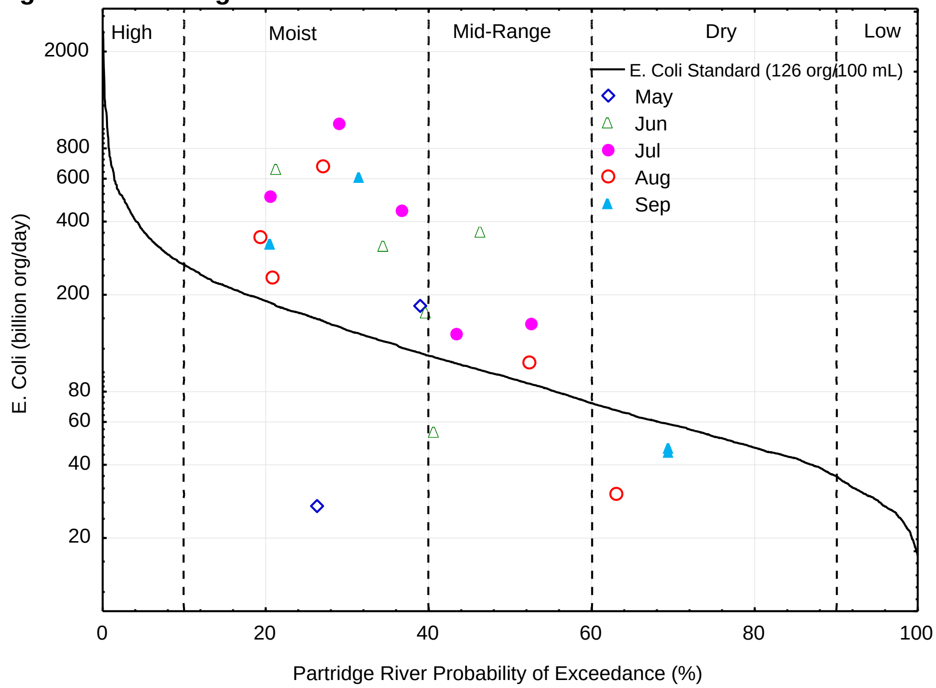


Table 65. Partridge River *E. coli* TMDL and Allocations

Partridge River (07010106-518) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**No data**	**322.5**	**133.9**	**39.9**	**No Data**
Wasteload Allocations	Bertha WWTP (MN 0022799)	4.82*	4.82*	4.82*	4.82*	4.82*
	Total WLA	**4.82**	**4.82**	**4.82**	**4.82**	**4.82**
Load Allocations	*Watershed Runoff*	*324.13*	*143.59*	*76.9*	*27.58*	*21.01*
	Total LA	**324.13**	**143.59**	**76.9**	**27.58**	**21.01**
MOS		**36.55**	**16.49**	**9.08**	**3.6**	**2.87**
Total Loading Capacity		**365.5**	**164.9**	**90.8**	**36**	**28.7**
Estimated Load Reduction		**N/A**	**48%**	**31%**	**2%**	**N/A**

*The daily wasteload allocation for the Bertha WWTP is calculated from the facility's Fecal Coliform bacteria effluent limit of 200 organisms/100 mL (equivalent to the 126 organism 100/mL E. coli water quality standard) and the maximum permitted effluent flow rate of 6"/day from the facility's 6.2 acre discharging cell.

Bacteria Source Summary

- High potential from livestock
    - High potential from poultry, Medium high potential from cattle

4.3.7.1 Pillager Creek (07010106-577) *E. coli* TMDL

Figure 22. Pillager Creek *E. coli* Load Duration Curve

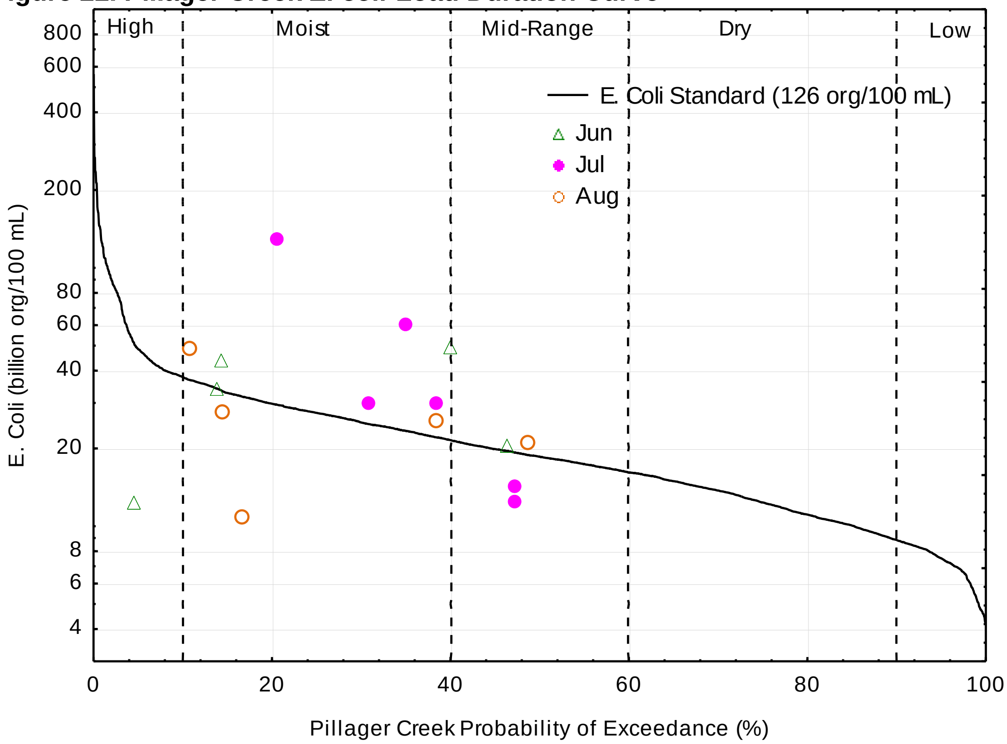


Table 36. Pillager Creek *E. coli* TMDL and Allocations

Pillager Creek (07010106-577) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**12.5**	**37.5**	**16.7**	**No Data**	**No Data**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed runoff*	*43.6*	*24.7*	*16.7*	*11.2*	*6.7*
	Total LA	**43.6**	**24.7**	**16.7**	**11.2**	**6.7**
MOS		**4.8**	**2.8**	**1.9**	**1.2**	**0.8**
Total Loading Capacity		**48.4**	**27.5**	**18.6**	**12.4**	**7.5**
Estimated Load Reduction		**0%**	**27%**	**0%**	**N/A**	**N/A**

Bacteria Source Summary

- High potential from wildlife
  - Medium-high potential from feral cats
  - Medium-high potential from ducks
- High potential from livestock (cattle)

4.3.7.1 Stoney Brook (07010106-698) *E. coli* TMDL

Figure 25. Stoney Brook *E. coli* Load Duration Curve

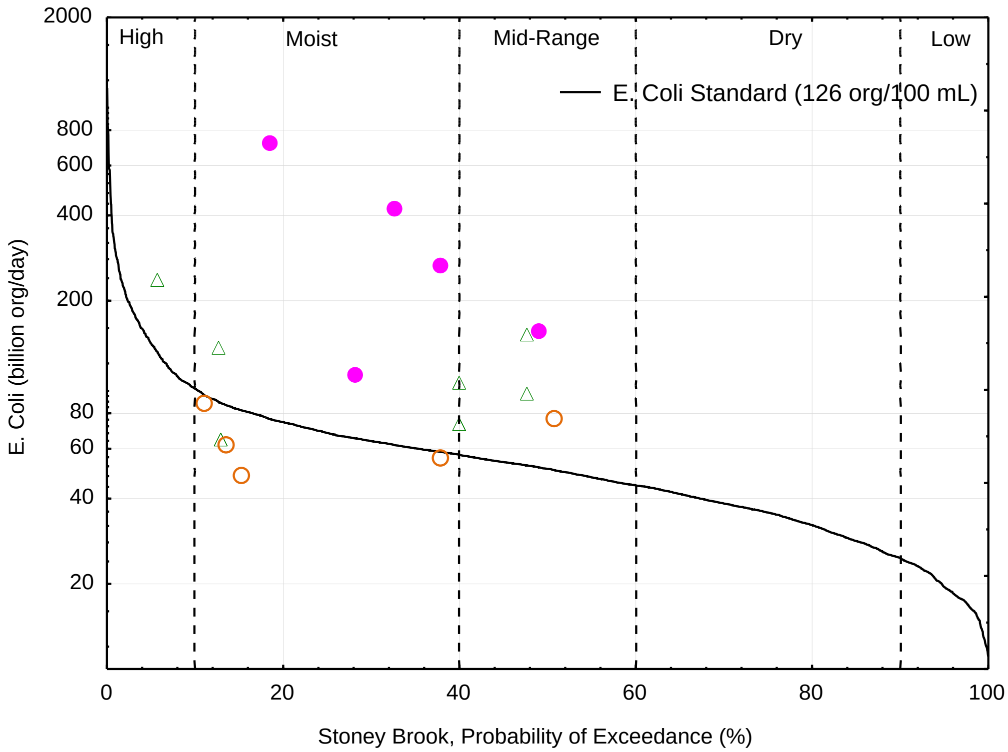


Table 66. Stoney Brook *E. coli* TMDL and Allocations

Stoney Brook (07010106-698) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**237.3**	**120.2**	**115.4**	**No data**	**No Data**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed runoff*	*127.3*	*61.4*	*45.8*	*32.1*	*17.5*
	Total LA	**127.3**	**61.4**	**45.8**	**32.1**	**17.5**
MOS		**14.1**	**6.8**	**5.1**	**3.6**	**2.0**
Total Loading Capacity		**141.4**	**68.2**	**50.9**	**35.7**	**19.5**
Estimated Load Reduction		**40%**	**43%**	**56%**	**N/A**	**N/A**

Bacteria Source Summary

- High potential from wildlife
    - Medium-high potential from ducks
- High potential from livestock (cattle)

4.3.7.2 Swan Creek (07010106-527) *E. coli* TMDL

Figure 20. Swan Creek *E. coli* Load Duration Curve

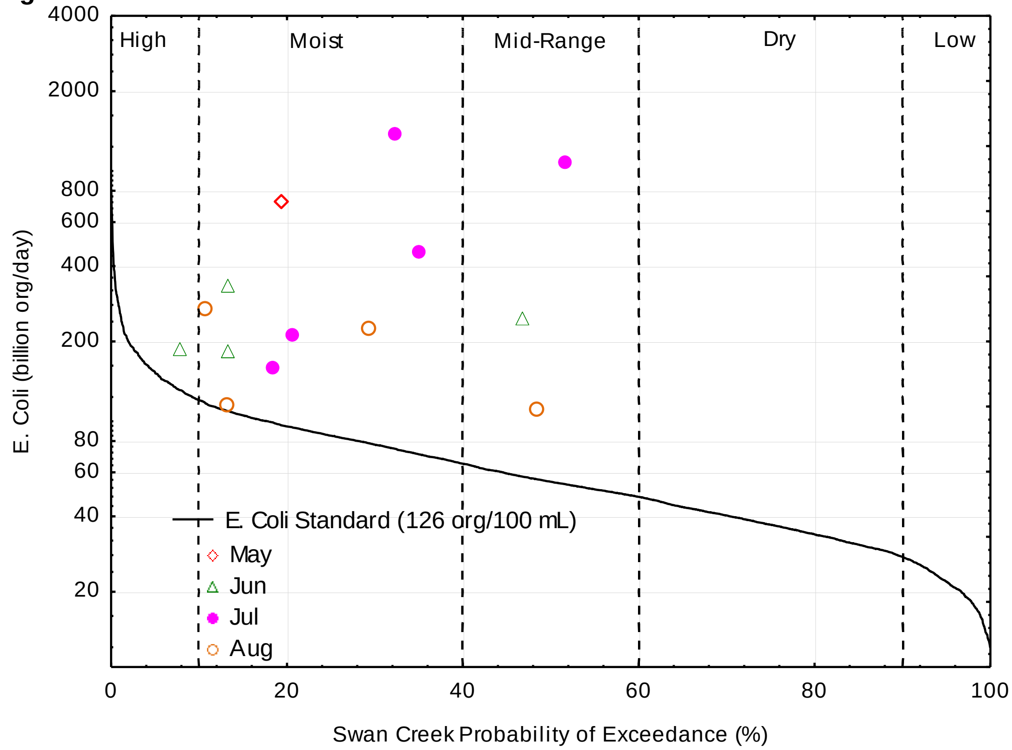


Table 34. Swan Creek *E. coli* TMDL and Allocations

Swan Creek (070106-527) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**188.9**	**302.9**	**304.4**	**No Data**	**No Data**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed runoff*	*135.3*	*75.7*	*49.5*	*33.4*	*19.8*
	Total LA	**135.3**	**75.7**	**49.5**	**33.4**	**19.8**
MOS		**15.0**	**8.4**	**5.5**	**3.7**	**2.2**
Total Loading Capacity		**150.3**	**84.1**	**55.0**	**37.1**	**22.0**
Estimated Load Reduction		**20%**	**72%**	**82%**	**N/A**	**N/A**

Bacteria Source Summary

- High potential from wildlife (feral cats and ducks)
- Medium-high potential from livestock (cattle)
- Pasturing cattle were observed in the stream channel during the stressor identification study for the macroinvertebrate bioassessment impairment in Swan Creek

4.3.7.3 Unnamed Creek (07010106-684) *E. coli* TMDL

Figure 24. Unnamed Creek *E. coli* Load Duration Curve

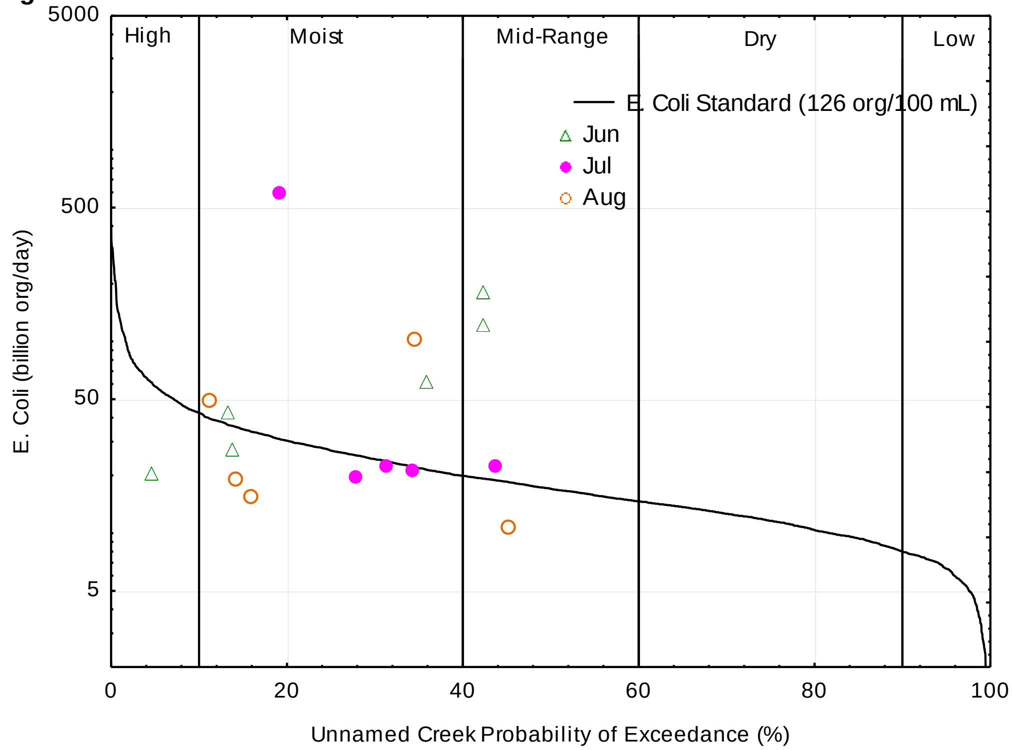


Table 38. Unnamed Creek *E. coli* TMDL and Allocations

Unnamed Creek (07010106-684) Load Component		Flow Regime				
		High	Moist	Mid	Dry	Low
		Billion organisms per day				
Existing Load		**20.6**	**41.6**	**48.7**	**No data**	**No Data**
Wasteload Allocation		*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Load Allocations	*Watershed runoff*	*52.5*	*24.2*	*9.0*	*10.4*	*5.8*
	Total LA	**52.5**	**24.2**	**9.0**	**10.4**	**5.8**
MOS		**5.8**	**2.7**	**1.7**	**1.2**	**0.7**
Total Loading Capacity		**58.3**	**26.9**	**10.7**	**11.6**	**6.5**
Estimated Load Reduction		**0%**	**35%**	**78%**	**N/A**	**N/A**

Bacteria Source Summary

- High potential from livestock
  - High potential from poultry
  - Medium-high potential from cattle

4.3.8 TMDL Baseline Years

The TMDLs are based on water quality data through 2011. Any activities implemented during or after 2011 that lead to a reduction in *E. coli* loads to impaired stream, or an improvement in stream water quality, may be considered as progress towards meeting a WLA or LA. Types of activities that can be credited toward achieving a WLA are defined in the applicable NPDES/SDS permits.

5 REASONABLE ASSURANCES

5.1 Non-regulatory

At the local level, the Becker Soil & Water Conservation District (SWCD), Cass SWCD, Crow Wing County and SWCD, Hubbard SWCD, Morrison SWCD, Otter Tail SWCD, Todd SWCD and Wadena SWCD and other local entities currently implement programs that target improving water quality and have been actively involved in projects to improve water quality in the past. Willing landowners within this watershed have implemented many practices in the past including: conservation tillage, buffer strips, urban BMPs, gully stabilizations, prescribed grazing, manure management, etc. It is assumed that these activities will continue. Potential state funding of Restoration and Protection projects include Clean Water Fund grants. At the federal level, funding can be provided through Section 319 grants that provide cost-share dollars to implement activities in the watershed. Various other funding and cost-share sources exist, which will be listed in the Crow Wing Watershed Restoration and Protection Strategy report. The implementation strategies described in this plan have demonstrated to be effective in reducing nutrient loading to lakes and streams. There are programs in place within the watershed to continue implementing the recommended activities. Monitoring will continue and adaptive management will be in place to evaluate the progress made towards achieving water quality goals.

5.2 Regulatory

5.2.1 Regulated Construction Stormwater

State implementation of the TMDL will be through action on NPDES permits for regulated construction stormwater. To meet the WLA for construction stormwater, construction stormwater activities are required to meet the conditions of the 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.

5.2.2 Regulated Industrial Stormwater

To meet the WLA for industrial stormwater, industrial stormwater activities are required to meet the conditions of the industrial stormwater general permit or Nonmetallic Mining & Associated Activities general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

5.2.3 Municipal Separate Storm Sewer System (MS4) Permits

Stormwater discharges associated with MS4s are regulated through National Pollutant Discharge Elimination System/State Disposal System (NPDES/SDS) permits. The Stormwater Program for MS4s is designed to reduce the amount of sediment and pollution that enters surface and ground water from storm sewer systems to the maximum extent practicable. MS4 Permits require the implementation of BMPs to address WLAs. In addition, the owner or operator is required to develop a stormwater pollution prevention program (SWPPP) that incorporates best management practices (BMPs) applicable to their MS4. The SWPPP must cover six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge, detection and elimination;
- Construction site runoff control;
- Post-construction site runoff control; and
- Pollution prevention/good housekeeping.

5.2.4 Wastewater & State Disposal System (SDS) Permits

The MPCA issues permits for wastewater treatment facilities that discharges into waters of the state. The permits have site specific limits on bacteria that are based on water quality standards. Permits regulate discharges with the goals of 1) protecting public health and aquatic life, and 2) assuring that every facility treats wastewater. In addition, SDS permits set limits and establish controls for land application of sewage.

5.2.5 Subsurface Sewage Treatment Systems Program (SSTS)

Subsurface Sewage Treatment Systems (SSTS), commonly known as septic systems, are regulated by Minnesota Statutes 115.55 and 115.56.

These regulations detail:

- Minimum technical standards for individual and mid-size SSTS;
- A framework for local administration of SSTS programs and;
- Statewide licensing and certification of SSTS professionals, SSTS product review and registration, and establishment of the SSTS Advisory Committee.

5.2.6 Feedlot Rules

The Minnesota Pollution Control Agency (MPCA) regulates the collection, transportation, storage, processing and disposal of animal manure and other livestock operation wastes. The MPCA Feedlot Program implements rules governing these activities, and provides assistance to counties and the livestock industry. The feedlot rules apply to most aspects of livestock waste management including the location, design, construction, operation and management of feedlots and manure handling facilities.

There are two primary concerns about feedlots in protecting water:

- Ensuring that manure on a feedlot or manure storage area does not run into water;
- Ensuring that manure is applied to cropland at a rate, time and method that prevents bacteria and other possible contaminants from entering streams, lakes and ground water.

6 MONITORING PLAN

6.1 Lake and Stream Monitoring

Lake associations and other groups participate in monitoring activities to meet their specific needs. Volunteers throughout the watershed conduct stream and lake condition monitoring through the MPCA Volunteer Monitoring Program. The MPCA currently monitors the Crow Wing River near the Sylvan Dam for Flow, Total Phosphorus, Ortho Phosphorus, Nitrite + Nitrate Nitrogen, Total Kjeldahl Nitrogen, Total Suspended Solids, Turbidity, and Total Volatile Solids. The Shell River and the Crow Wing River at Nimrod will also be sampled for the same parameters starting in 2015.

If funding is available, the SWCDs will set up a monitoring program to monitor for nutrients, *E. coli*, and flow. Ideally it would be a twice per month plus storm event program. If funding is not available for new monitoring programs, the monitoring that is completed will be done following MPCA's 10-year monitoring cycle.

The MN DNR conducts lake and stream surveys to collect information about game fish populations which are then used to evaluate abundance, relative abundance size (length and weight), condition, age and growth, natural reproduction/recruitment, and effects of management actions (stocking and regulations). Other information collected for lake population assessments include basic water quality information (temperature, dissolved oxygen profile, secchi, pH, and alkalinity), water level and for fish disease and parasites. Additional information collected for lake surveys include lab water chemistry (TP, alkalinity, TDS, Chl-a, Conductivity, pH), watershed characteristics, shoreline characteristics, development, substrates and aquatic vegetation. In the last few years, the MN DNR has begun near-shore sampling to develop fish IBIs at lakes in watersheds that have ongoing assessments.

The frequency of sampling depends on importance/use. The most important/heavily used lakes are sampled about every five years. Less important/heavily used lakes are sampled every 7, 10, 12, or 15 years. If there is a management action (regulation or stocking) that needs to be evaluated more quickly, sampling could occur every other year. Full surveys are often only done about every 20 years.

6.2 BMP Monitoring

On-site monitoring of implementation practices should also take place in order to better assess BMP effectiveness. A variety of criteria such as land use, soil type, and other watershed characteristics, as well as monitoring feasibility, will be used to determine which BMPs to monitor. Under these criteria, monitoring of a specific type of implementation practice can be accomplished at one site but can be applied to similar practices under similar criteria and scenarios. Effectiveness of other BMPs can be extrapolated based on monitoring results.

7 IMPLEMENTATION STRATEGY

7.1 Adaptive Management

The response of the lakes and streams will be evaluated as management practices are implemented. This evaluation will occur every five years after the commencement of implementation actions; for the next 25 years. Data will be evaluated and decisions will be made as to how to proceed for the next five years. The management approach to achieving the goals should be adapted as new information is collected and evaluated.

7.2 Best Management Practices

A variety of best management practices to restore and protect the lakes and streams within the Crow Wing Watershed have been outlined and prioritized in the Watershed Restoration and Protection Strategy report.

7.3 Education and Outreach

A crucial part in the success of the Restoration and Protection plan that will be designed to clean up the impaired lakes and streams and protect the non-impaired water bodies will be participation from local citizens. In order to gain support from these citizens, education and civic engagement opportunities will be necessary. A variety of educational avenues can and will be used throughout the watershed. These include (but are not limited to): press releases, meetings, workshops, focus groups, trainings, websites, etc. Local staff (conservation district, watershed, county, etc.) and board members work to educate the residents of the watersheds about ways to clean up their lakes and streams on a regular basis. Education will continue throughout the watershed.

7.4 Technical Assistance

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

Programs such as state cost share, Clean Water Legacy funding, Environmental Quality Incentives Program (EQIP), and Conservation Reserve Program (CRP) are available to help implement the best conservation practices that each parcel of land is eligible for to target the best conservation practices per site. Conservation practices may include, but are not limited to: stormwater bioretention, septic system upgrades, feedlot improvements, invasive species control, wastewater treatment practices, agricultural and rural best management practices and internal loading reduction. More information about types of practices and implementation of BMPs will be discussed in the Crow Wing River Watershed Restoration and Protection Strategy report.

7.5 Partnerships

Partnerships with counties, cities, townships, citizens, businesses, watersheds, and lake associations are one mechanism through which the Becker Soil & Water Conservation District (SWCD), Cass SWCD, Crow Wing County and SWCD, Hubbard SWCD, Morrison SWCD, Otter Tail SWCD, Todd SWCD and Wadena SWCD will protect and improve water quality. Strong partnerships with state and local government to protect and improve water resources and to bring waters within the Crow Wing River Watershed into compliance with State standards will continue. A partnership with local government units and regulatory agencies such as cities, townships and counties may be formed to develop and update ordinances to protect the areas water resources.

7.6 Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation of the cost to implement a TMDL [MN Statutes 2007, section 114D.25]. The initial estimate for implementing the Crow Wing River Watershed Restoration and Protection Strategies is approximately $3,000,000 to $5,500,000. This estimate will be refined when the more detailed implementation plan is developed.

8 PUBLIC PARTICIPATION

8.1 Steering Committee Meetings

The Crow Wing Watershed is made up of numerous local partners who have been involved at various levels throughout the project. The steering committee is made up of members representing the Department of Natural Resources, Department of Agriculture, Counties and Soil and Water Conservation Districts within the watershed, The Nature Conservancy, The White Earth Nation, Region 5 Development Commission, Envision MN, and the Board of Water and Soil Resources. The following table outlines the meetings that occurred regarding the Crow Wing Watershed monitoring, TMDL development, and Watershed Restoration and Protection Strategy report planning.

Date	Location	Meeting Focus
5/27/10	MPCA office Brainerd, MN	Workplan Discussions
2/10/11	Tri-County Hospital in Wadena, MN	Quarterly Meeting
5/25/11	Northwoods Bank in Park Rapids, MN	Quarterly Meeting
9/27/11	Lakewood Health in Staples, MN	Quarterly Meeting
12/14/11	Lakewood Health in Staples, MN	Quarterly Meeting
4/4/12	MPCA in Brainerd, MN	Quarterly Meeting
1/23/13	The Shante in Pillager, MN	Quarterly Meeting
2/21/13	The Shante in Pillager, MN	Civic Engagement Planning Meeting
6/19/13	MPCA office Brainerd, MN	Quarterly Meeting – HSPF Focus
10/24/13	MPCA office Brainerd, MN	Quarterly Meeting – TMDL Focus
3/6/14	Lakewood Health in Staples, MN	Quarterly Meeting
5/12/14	Wadena County Courthouse	Quarterly Meeting – WRAPS Focus

8.2 Public Meetings

The MPCA along with the local partners and agencies in the Crow Wing Watershed recognize the importance of public involvement in the watershed process. The following table outlines the opportunities used to engage the public and targeted stakeholders in the Crow Wing Watershed.

Date	Location	Meeting Focus
1/13/10	Lakewood Health in Staples, MN	Watershed Project Kick-Off
1/10/12	Staples, MN	Discussion with Crow Wing Forage Basin Council
6/13/12	Central Lakes College in Staples, MN	Watershed Gathering
7/21/12	Gull River near Baxter, MN	Gull River Association Meeting
9/12/12	City Hall Pequot Lakes, MN	Sibley & Mayo Lakes Public Meeting
9/13/12	St. Peter's Catholic Church in Park Rapids, MN	Watershed Gathering and TMDL Open House
10/4/12	Menahga, MN	Twin Lakes Association Meeting
5/10/13	Park Rapids, MN	Booth at Governor's Fishing Opener
5/18/13	Menahga, MN	Twin Lake Association Meeting
7/25/13	Leader, MN	Leader Lions Farm Tour
8/31/13	Menahga, MN	Stocking Lake Annual Meeting Presentation
9/16/13	Menahga, MN	Twin Lakes Association Meeting
1/23/14	Parkers Prairie, MN	Booth at Central Minnesota Irrigators Annual Meeting
2/11/14	Staples, MN	Booth at Crow Wing Forage Basin Council Meeting
8/4/14	Pequot Lakes Library, MN	Sibley & Mayo Lakes Public Meeting to present TMDL results and gather input on WRAPS
8/12/14	St. John's Lutheran Church in Park Rapids, MN	Public Meeting to present TMDL results and gather input on WRAPS

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10 WATERSHED SUMMARY

The watershed has approximately 1,137 total river miles of which 889 miles are considered perennial. The Crow Wing River is the major river in the watershed. Other major rivers within the watershed include the Blueberry, Cat, Fishhook, Gull, Kettle, Partridge, Shell and Straight Rivers. The watershed contains 1,133 lakes with a total surface area of 78,658 acres. Major lakes in the watershed include Sylvan Reservoir, Gull, Margaret, Placid, Sylvan, the Crow Wing Chain, Belle Taine, Straight, Fish Hook, Potato, Roy, Nisswa, Shell, Big Sand, and Little Sand Lakes (MPCA 2003).

10.1 Soils

The soils in the Crow Wing River Watershed are dominated by 'A', 'A/D', and 'B' hydrologic soil groups (Figure 24). The soils were classified into groups based on the hydrologic characteristics of the soils according to runoff generation potential. 'A' soils are characterized by deep, well drained to excessively drained sands or gravelly sands. 'B' soils are characterized by moderately deep or deep, moderately well drained or well drained with moderate to moderately coarse texture. Certain soils were assigned a dual soil group (e.g., A/D) based on the presence of a water table within two feet of the surface but may have properties that would otherwise make them capable of infiltration (USDA NRCS, 2007).

10.2 Topography

The Crow Wing River Watershed topography is characterized by flat and rolling glacial till plains, basin, and outwash plains consisting of calcareous and siliceous deposits. In some areas of the watershed these glacial deposits of sand and gravel are up to 600 feet deep (MPCA 2000). The overall topography is characterized by greater relief in the southeastern and northern/northwestern lake regions and flatter in the central river plain (Figure 1).

10.3 Population and Growth

The impaired lakes are located in all or part of six counties in central Minnesota. Most of the impaired lake subwatersheds are located in Hubbard (49%) and Becker (39%) Counties with the remaining 12% distributed across Cass, Clearwater, Crow Wing, and Wadena Counties. This region experienced small population growth between the 2000 census and the 2010 census, but this growth was smaller than that projected by the Minnesota State Demographic Center (MSDC) for 2010, except for Hubbard County (Table 4).

Table 47. Crow Wing River Watershed 2000 and 2010 Population Summary

County	Impaired Lake Watershed Area [% Total]	2000 Population	2010 Population	% Change in Population (2000-2010)	2010 Estimate (MSDC)
Becker	36%	30,000	32,504	+8%	34,300
Cass	12%	27,150	28,567	+5%	31,040
Clearwater	3%	8,423	8,695	+3%	8,790
Crow Wing	1%	55,099	62,500	+13%	65,200
Hubbard	45%	18,376	20,428	+11%	19,560
Wadena	2%	13,713	13,843	+1%	14,110

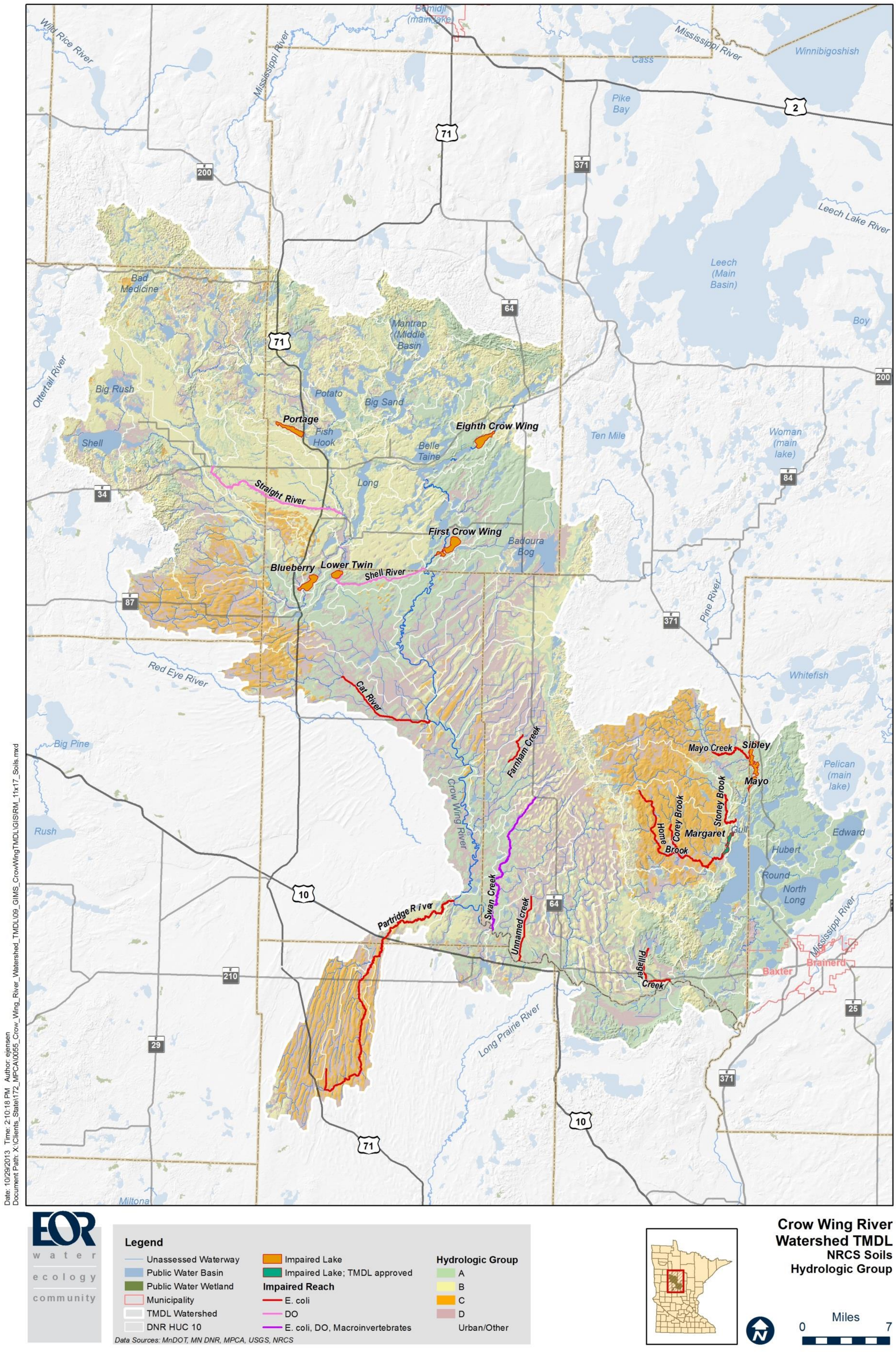


Figure 24. Crow Wing River Watershed Soils

11 LAKE SUMMARIES

11.1 Blueberry Lake

Blueberry Lake is located two miles north of Menahga, Minnesota. The lake is managed and stocked for walleye, and also provides fishing opportunities for northern pike, yellow perch, and carp. Blueberry Lake and its fishery are particularly important because there are so few lakes in Wadena County. Lake water quality has been monitored since the mid-1990s by Lefty (Leofwin) Lindblom of Menagha, the Blueberry Lake Association, and Wadena SWCD. Blueberry Lake has two large river inlets and a large watershed, resulting in a large contribution of nutrients. In the past, the city of Menahga sewage treatment system discharged to Blueberry Lake. The lake is not always suitable for swimming and wading due to high phosphorus levels, frequent algae blooms and dense growth of aquatic vegetation. Dense growth of submerged vegetation, particularly curly leaf pondweed is a concern on Blueberry Lake. Fisheries staff, along with Ecological Resources personnel will also help those interested in managing the exotic curly leaf pondweed by providing information or advice, and by assisting with permits. Aerial fish house counts were conducted in 1984-85, and annually since 1987 to monitor trends in ice fishing pressure. Counts have ranged from 4 to 37 and averaged 23. There were 36 homes/cabins observed during the 2007 assessment (an average of 7.3 per shoreline mile) which is in the 46th percentile of 100 lakes in the Park Rapids area where development density has been calculated.

Contributor(s): Anne Oldakowski, Wadena SWCD, MN DNR 2009 Lake Management Plan

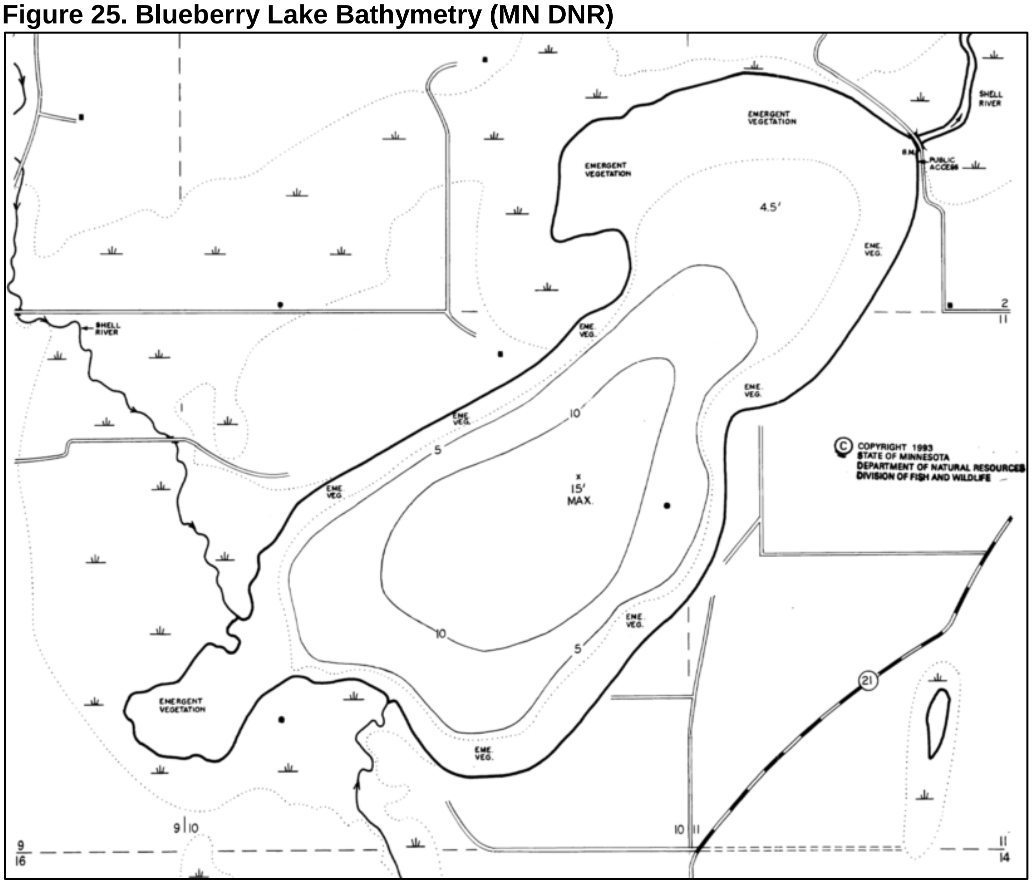
11.1.1 Physical Characteristics

Blueberry Lake (MN DNR Lake ID 80-0034-00) is located in Wadena County with portions of its watershed located in Becker County (87%), Wadena County (7%), and Hubbard County (6%). The Blueberry Lake watershed comprises the western portion of the Lower Twin Lake watershed. Three major rivers discharge to Blueberry Lake: the Shell, Blueberry, and Kettle Rivers. Blueberry Lake discharge flows through the Shell River to Upper and Lower Twin Lakes. Table 67 summarizes the lake's physical characteristics, Figure 26 shows the 2011 aerial photography, and Figure 25 illustrates the available bathymetry.

Table 67. Blueberry Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	533	0 m depth contour digitized from 2010 aerial photo
Percent lake littoral surface area	100%	Calculated from MN DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	3,634	
Mean depth (feet)	6.8	Lake volume ÷ surface area
Maximum depth (feet)	15	MN DNR Lake Finder
Drainage area (acre)	136,332	MN DNR Catchments
Watershed area: Lake area	256: 1	Calculated

Figure 25. Blueberry Lake Bathymetry (MN DNR)



11.1.2 Water Quality

Water quality monitoring data were available for Blueberry Lake from 1996-2011. Only data from the most recent 10 years (2002-2011) were used to determine whether Blueberry Lake meets water quality standards. The lake does not meet the North Central Hardwood Forest (NCHF) shallow lake water quality standard for TP, Chl-a, or Secchi (Table 37). Growing season mean TP and Chl-a have not met lake water quality standards in nearly all years during the period of record, except in 1997 for TP and 2002 for Chl-a (Figures 9 and 10). Secchi depth has been more variable, with recent years below the standard, except for 2011. Historical secchi disc readings (not shown) were very low, ranging from 1.0 feet in 1963 to 2.5 feet in 1987 and 1992 fisheries samples. The secchi disc reading improved substantially, to 6.3 feet in 1997 and 4.5 feet in 2002 samples. This improvement may be due, at least partially, to improvements in the Menahga sewage treatment system. From 1996 to the present, the worst water quality occurred in 2003 and has been improving since then (Figure 27, Figure 28, and Figure 29). Growing season water quality trends in 2011 indicated that peak TP and Chl-a and minimum Secchi transparency occurred at the beginning of September (Figure 30).

Table 68. 10 year Growing Season Mean TP, Chl-*a*, and Secchi for Blueberry Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Shallow Lake Standard
Total phosphorus (µg/L)	93	8%	< 60
Chlorophyll-*a* (µg/L)	52	10%	< 20
Secchi transparency (m)	0.9	5%	> 1.0

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 26. Aerial photograph of Blueberry Lake (Google Earth, September 2011)

Figure 27. Growing Season Means ± SE of Total Phosphorus for Blueberry Lake by Year.
The dashed line represents the water quality standard for TP (60 µg/L).

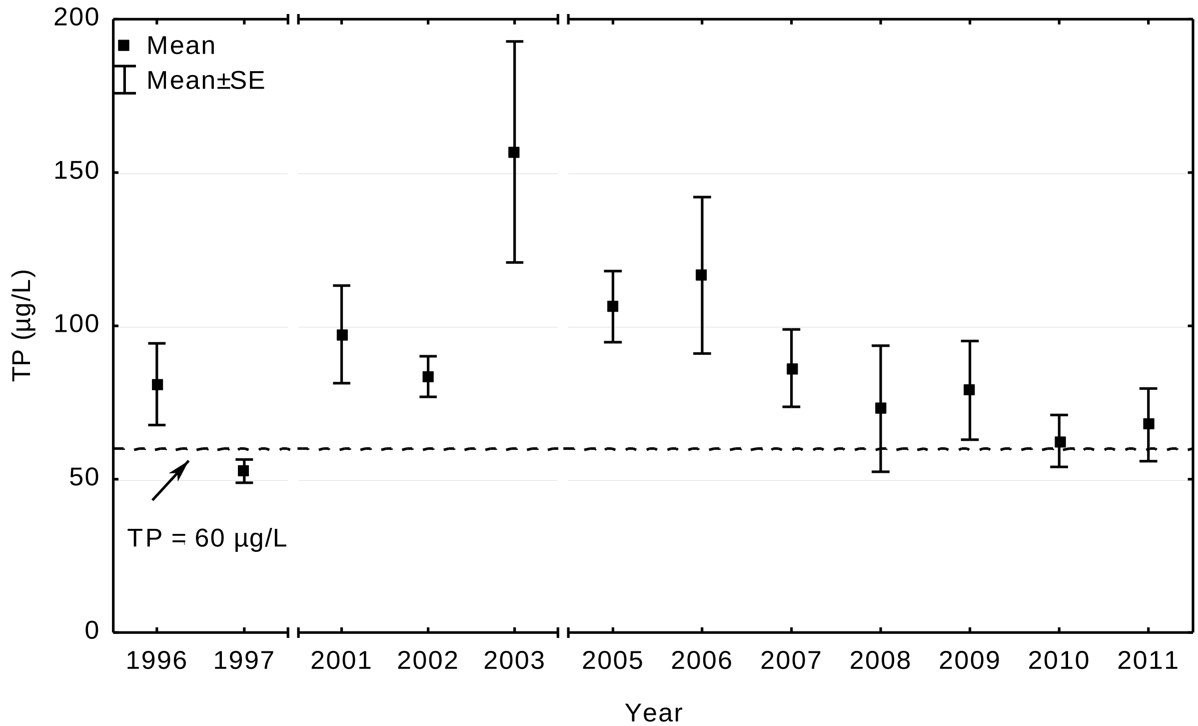


Figure 28. Growing Season Means ± SE of Chlorophyll-*a* for Blueberry Lake by Year. The dashed line represents the water quality standard for Chl-*a* (20 µg/L).

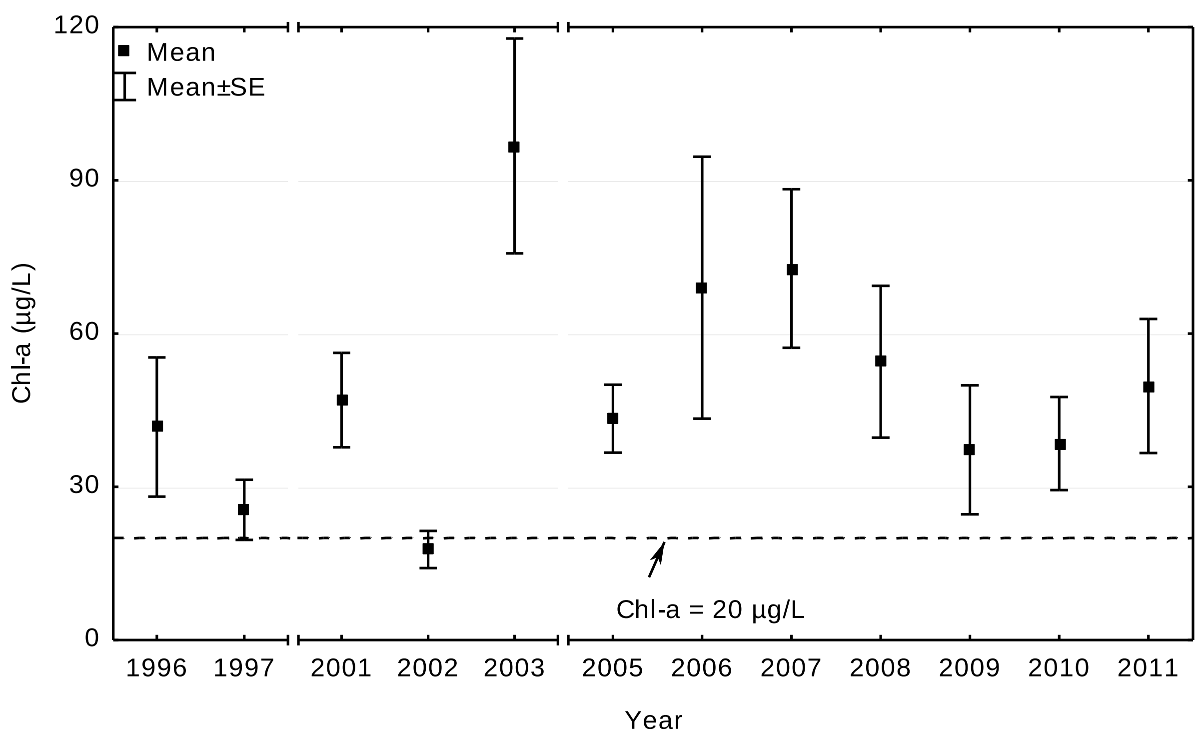


Figure 29. Growing Season Means ± SE of Secchi Transparency for Blueberry Lake by Year. The dashed line represents the lake water quality standard for transparency (1.0 m).

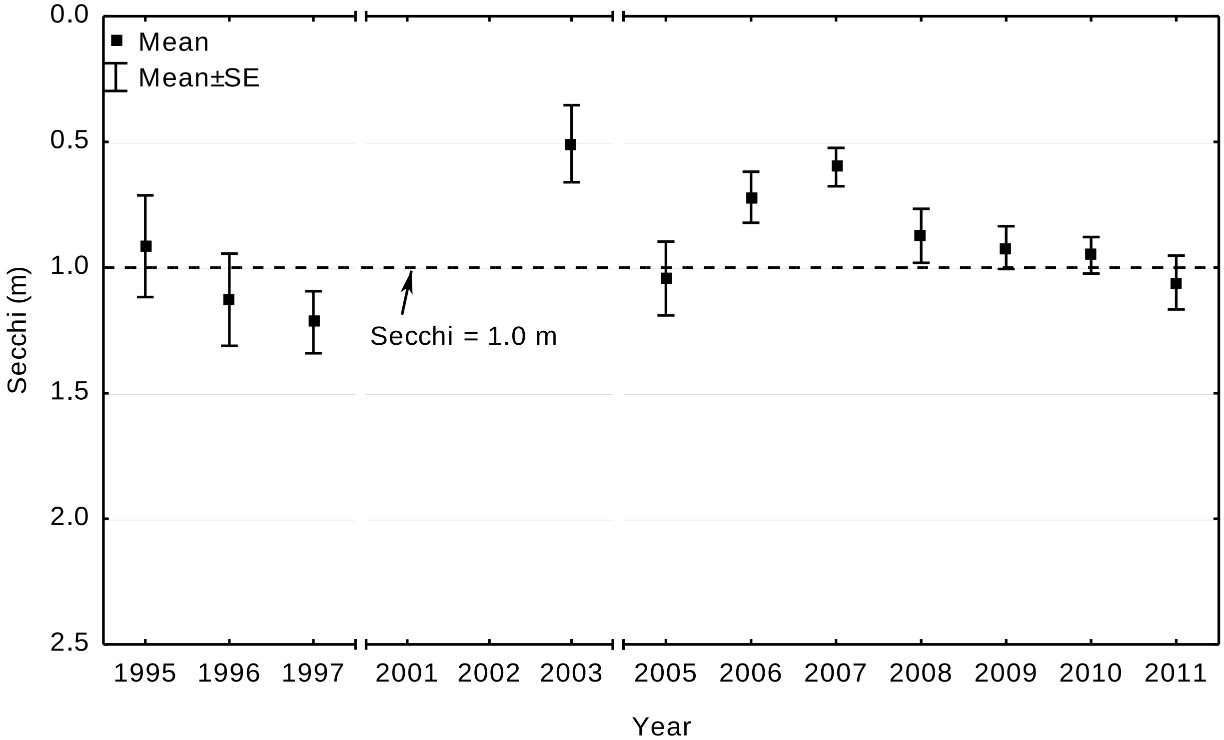


Figure 30. Growing Season Trends of Chl-*a*, TP, and Secchi depth for Blueberry Lake, 2011

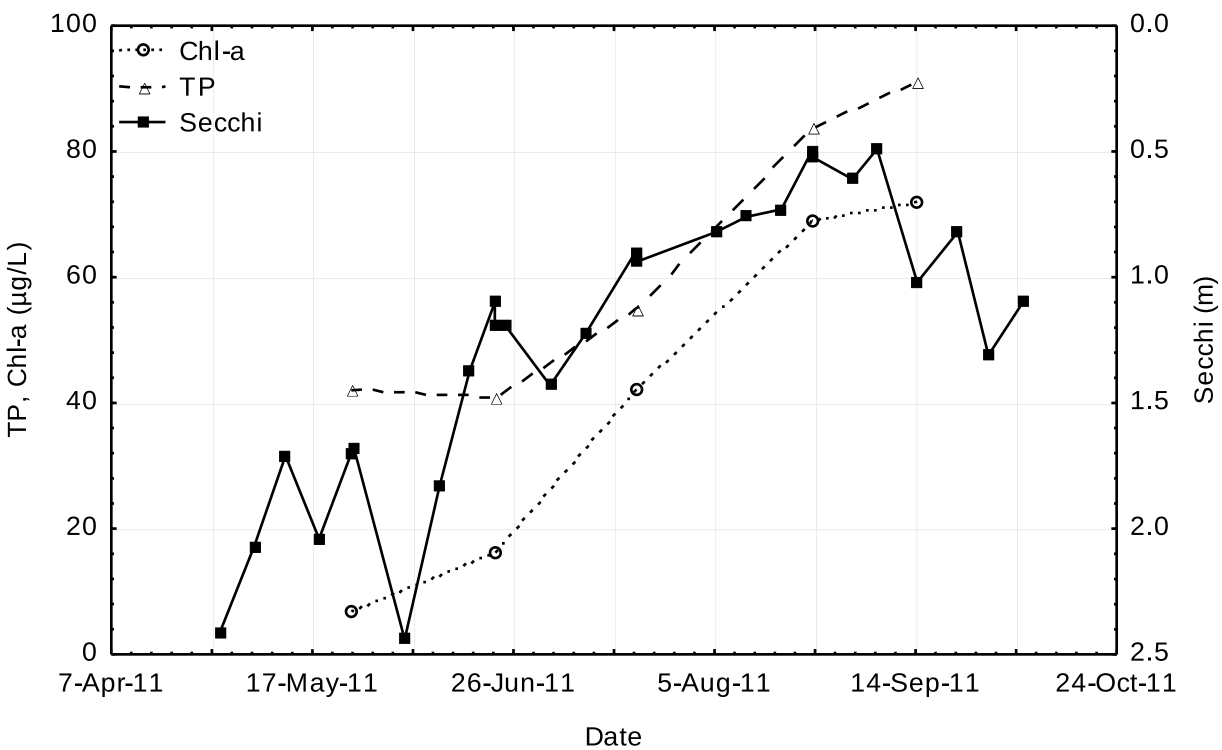


Figure 31. Bottom and surface TP concentrations, Blueberry Lake, 2005

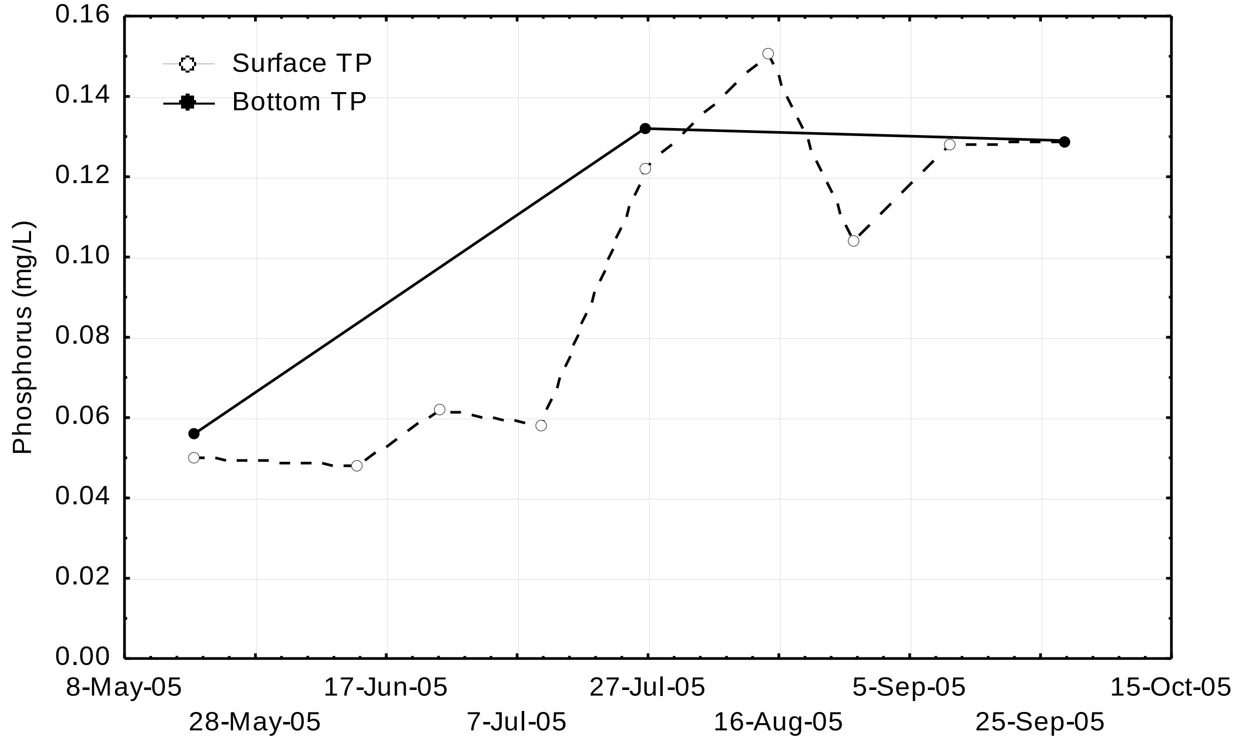


Figure 32. Temperature depth profiles, Blueberry Lake, 2005

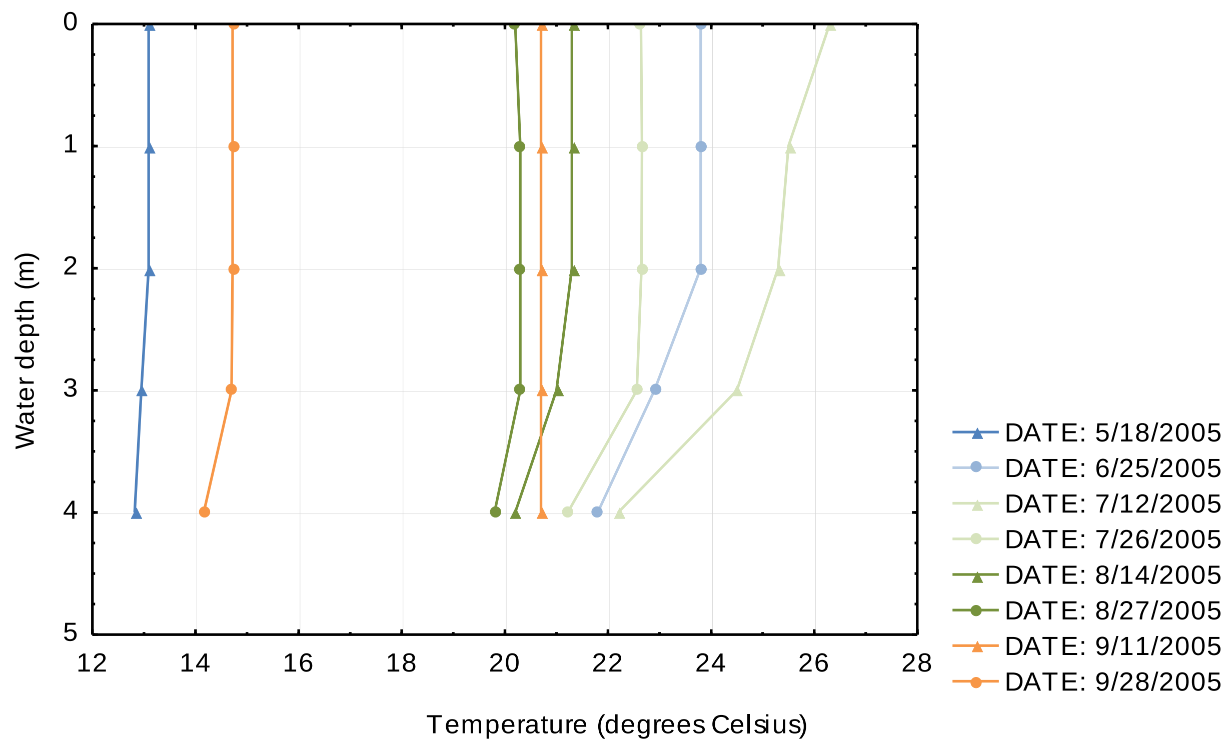


Figure 33. Dissolved oxygen depth profiles, Blueberry Lake, 2005

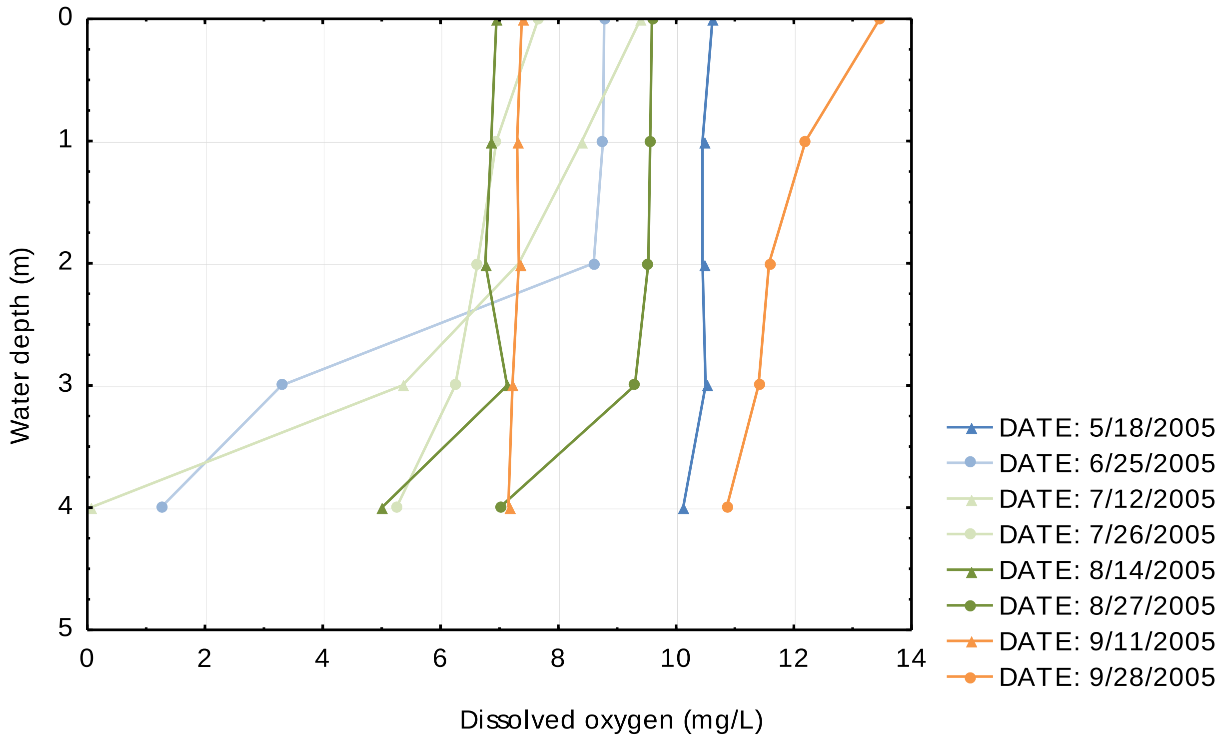


Figure 34. pH depth profiles, Blueberry Lake, 2005

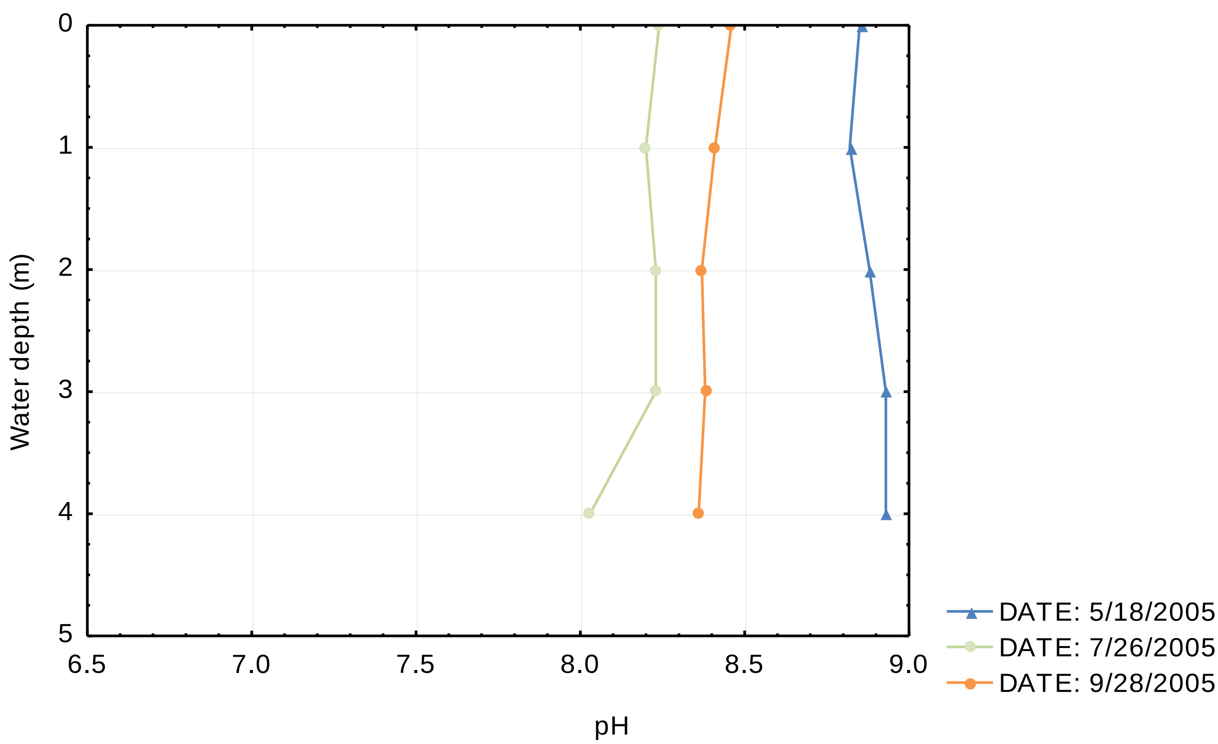
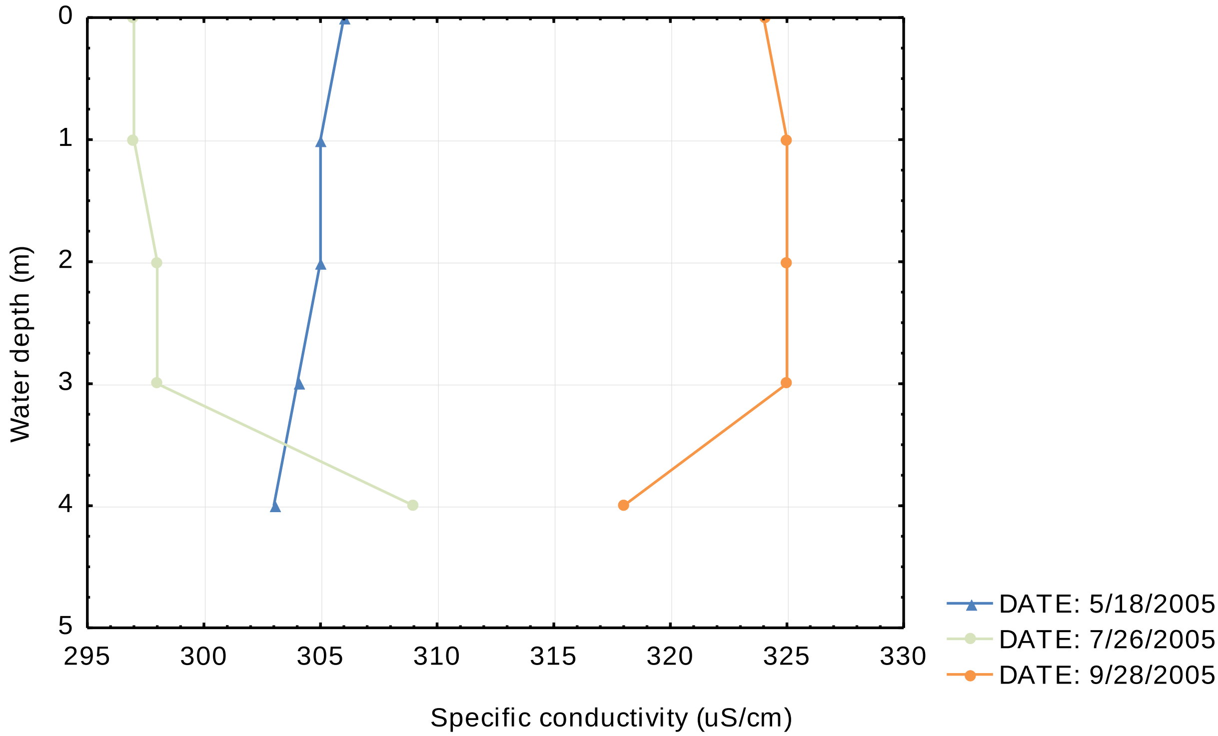


Figure 35. Specific conductivity depth profiles, Blueberry Lake, 2005



11.1.3 Fish

Blueberry Lake is stocked annually with 525,000 walleye fry in the spring which supports angling opportunities for walleye, in addition to native populations of northern pike. Yellow perch and minnows support the walleye and northern pike populations, but there are low numbers of black crappie and bluegill panfish. Common carp is present in Blueberry Lake. During the most recent fish survey in 2007, there were 2.00 carp caught per trap net which is within the normal range for lake class 41. However, the common carp population is large enough to provide angling opportunities and stir up the bottom sediments.

Northern pike reproduction and recruitment are regulated by the amount of seasonally flooded vegetation and marsh areas that provide suitable spawning habitat. The amount of habitat in Blueberry Lake for pike production appears to be more than adequate. Good recruitment of pike has at times resulted in an overabundance of small fish, poor growth, and poor size structure. A lack of older, larger size northerns appears to be due to high mortality, probably a result of overharvest. Large northern pike can act as a predatory control of smaller pike. Removing too many large pike can lead to even higher abundance of small northerns. [Excerpt from the 2009 MN DNR Lake Management Plan]

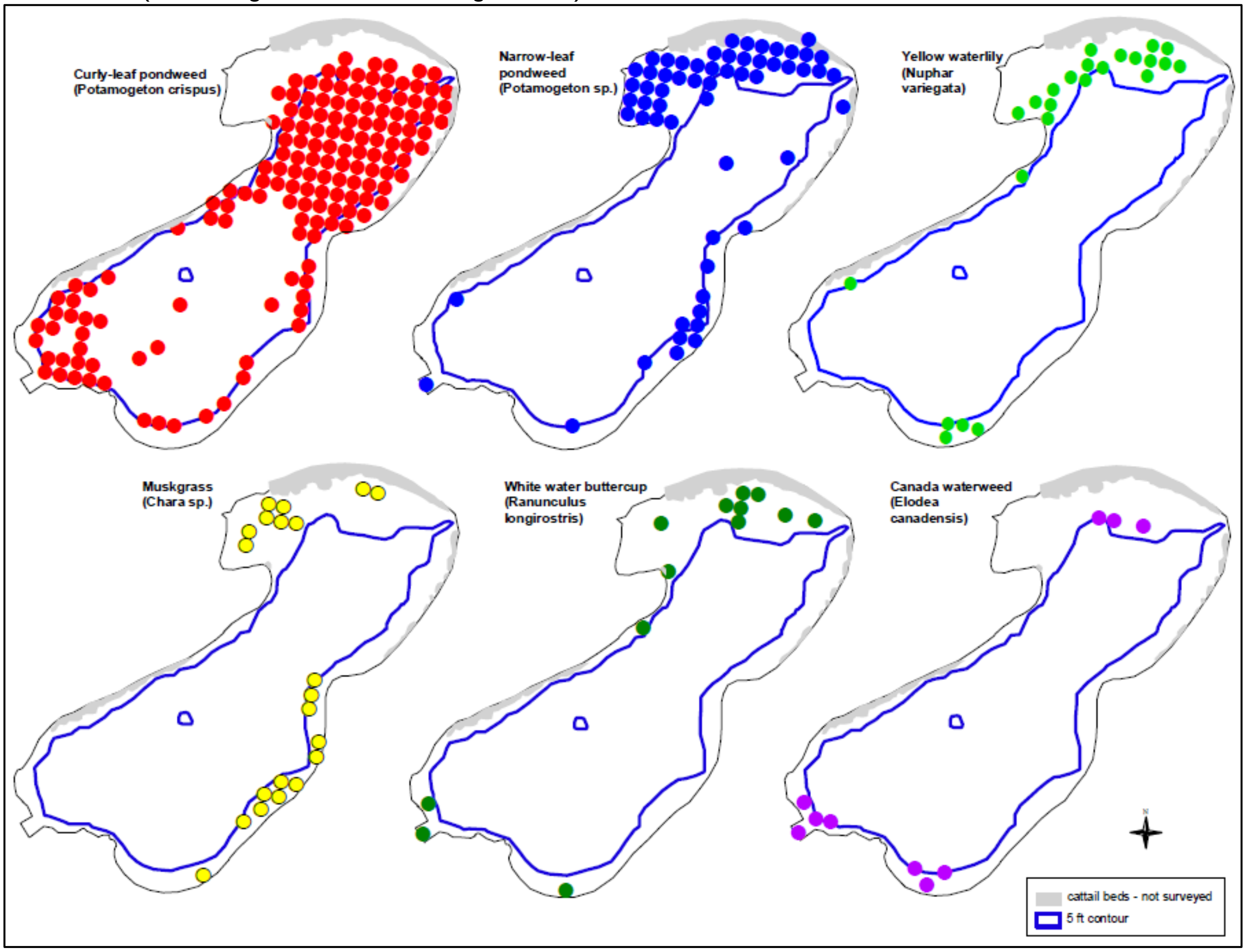
11.1.4 Macrophytes

Increased use, development or other land use changes on Blueberry Lake and within its watershed have resulted in removal of riparian vegetation and further increased contribution of nutrients to the lake. High nutrients and shallow depths make the lake conducive to growth of algae or aquatic vegetation. Poor water quality or dense growth of algae or submerged plants could negatively affect fish populations, reduce recreational opportunities, and reduce the aesthetic quality of the lake. The exotic plant curly leaf pondweed was first observed in Blueberry Lake in the late 1990s. By 2002 it had spread to cover a large portion of the lake. Emergent vegetation like bulrush provides spawning habitat for fish like black crappie, bluegill and largemouth bass. Emergent vegetation also helps stabilize substrates, helps remove nutrients and protects shoreline from erosion. It is important to protect this type of vegetation. [Excerpt from the 2009 MN DNR Lake Management Plan]

A vegetation survey was conducted in June 2005 to assess the aquatic plant community of Blueberry Lake (Perleberg 2005a; Figure 36). According to the report, the dominant submerged plant species was curly-leaf pondweed (*Potamogeton crispus).* Curly-leaf occurred in 43 percent of all sample sites, 72 percent of sample sites at four to nine feet deep, and was the only plant species found at depths greater than nine feet. Other common submerged plant species were Narrowleaf pondweed, Muskgrass, White water buttercup, and Canada waterweed. Cattails were common along the north and northwest shores, and waterlilies were concentrated in the northern end of the lake.

A chemical treatment of all curly-leaf pondweed in Blueberry Lake was conducted in spring of 2011, totaling 117 acre application of a low rate of endothall herbicide funded by the MN DNR.

Figure 36. Distribution of common aquatic plant species in Blueberry Lake, June 15-16, 2005
(From: Figure 13 in Perleberg, 2005a)



11.2 Eighth Crow Wing Lake

Eighth Crow Wing Lake is located one mile southeast of Nevis, Minnesota. The Crow Wing River is both the inlet and outlet of 8th Crow Wing Lake. Both 9th and 10th Crow Wing Lakes are accessible from 8th, but a dam at the outlet of 8th Crow Wing prevents boat access downstream. The lake fishery is managed primarily for Walleye and Northern pike; secondary species management includes Yellow perch, Largemouth bass, Bluegill, Black crappie, and Tullibee. Low dissolved oxygen levels (<2 ppm) were recorded below the thermocline (about 30 feet) from 1977 to 1988. Aerial fish house counts were conducted in 1985, and annually since 1988 to monitor trends in ice fishing pressure. Counts have averaged 6 with a range of 3 to 9 houses. There were 100 home/cabins recorded during the 2008 assessment (an average of 20.4 cabins/homes per shoreline mile) which is in the 83rd percentile of 100 lakes in the Park Rapids area where shoreline development has been recorded.

Contributor(s): Doug Kingsley and Mike Kelly, Park Rapids MN DNR-Fisheries
MN DNR 2010 Lake Management Plan

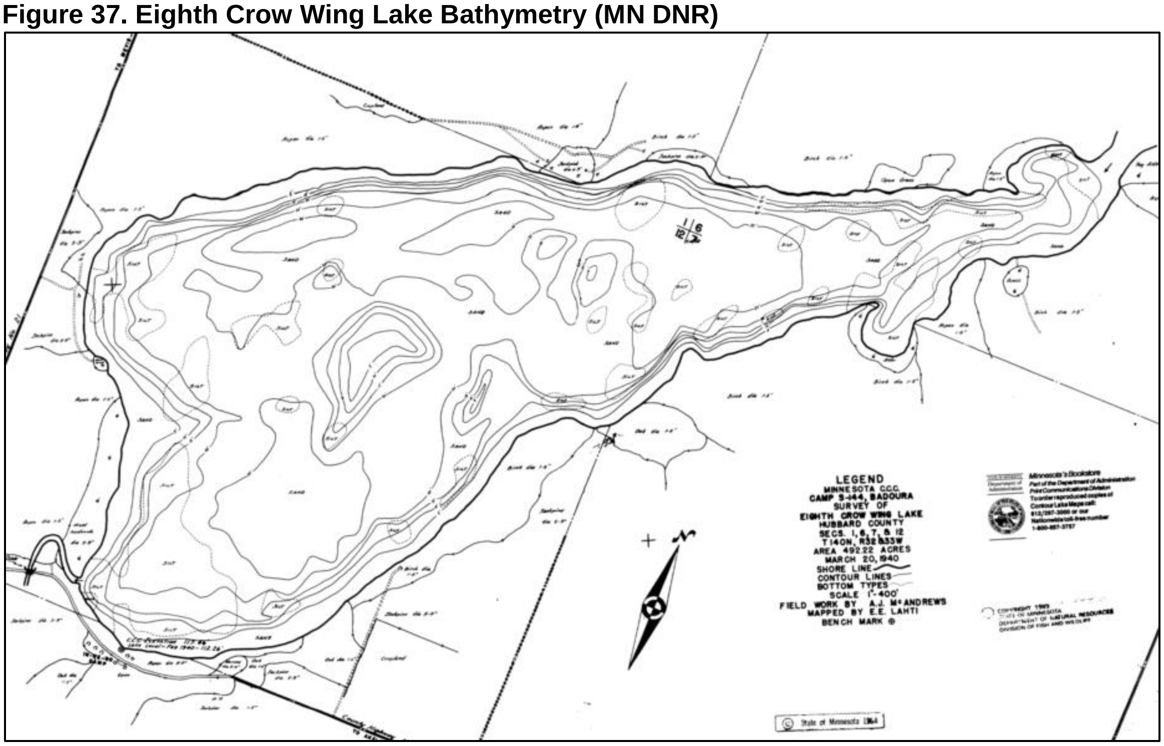
11.2.1 Physical Characteristics

Eighth Crow Wing Lake (MN DNR Lake ID 29-0072-00) is located in Hubbard County. The Eighth Crow Wing Lake watershed is located in the northern portion of the Crow Wing River watershed and drains to the Crow Wing Chain of Lakes. Table 69 summarizes the lake's physical characteristics, Figure 38 shows the 2011 aerial photography, and Figure 37 illustrates the available bathymetry.

Table 69. Eighth Crow Wing Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	493	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area	30%	Calculated from MN DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	9,050	
Mean depth (feet)	18.4	Lake volume ÷ surface area
Maximum depth (feet)	30	MN DNR Lake Finder
Drainage area (acre)	25,083	MN DNR Catchments
Watershed area: Lake area	51: 1	Calculated

Figure 37. Eighth Crow Wing Lake Bathymetry (MN DNR)



11.2.2 Water Quality

Water quality monitoring data were available for Eighth Crow Wing Lake from 1997-2011. Only data from the most recent 10 years (2002-2011) were used to determine whether Eighth Crow Wing Lake meets water quality standards. The lake does not meet the State Northern Lakes and Forest (NLF) lake water quality standards for TP or Chl-*a* (Table 70). Growing season mean TP has met the lake water quality standard in all recent years except 2010 (Figure 39), while growing season mean Chl-a has not met the lake water quality standard for all years on record except 2009 (Figure 40). In contrast, growing season mean Secchi has met the lake water quality standard for all years on record (Figure 41). There are no apparent long-term trends in Chl-a or Secchi, but growing season mean TP since 2007 is lower than TP prior to 2004 (Figure 39, Figure 40, and Figure 41). Growing season water quality trends in 2010 indicated that peak TP and Chl-a and minimum Secchi transparency occurred in August and September (Figure 42).

Table 70. 10 year Growing Season Mean TP, Chl-*a*, and Secchi, Eighth Crow Wing L., 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NLF Lake Standard
Total phosphorus (µg/L)	29	8%	< 30
Chlorophyll-*a* (µg/L)	14	16%	< 9
Secchi transparency (m)	2.7	6%	> 2.0

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 38. Aerial photograph of Eighth Crow Wing Lake (Google Earth, September 2011)

Figure 39. Growing Season Means ± SE of Total Phosphorus for Eighth Crow Wing Lake by Year. The dashed line represents the water quality standard for TP (30 µg/L).

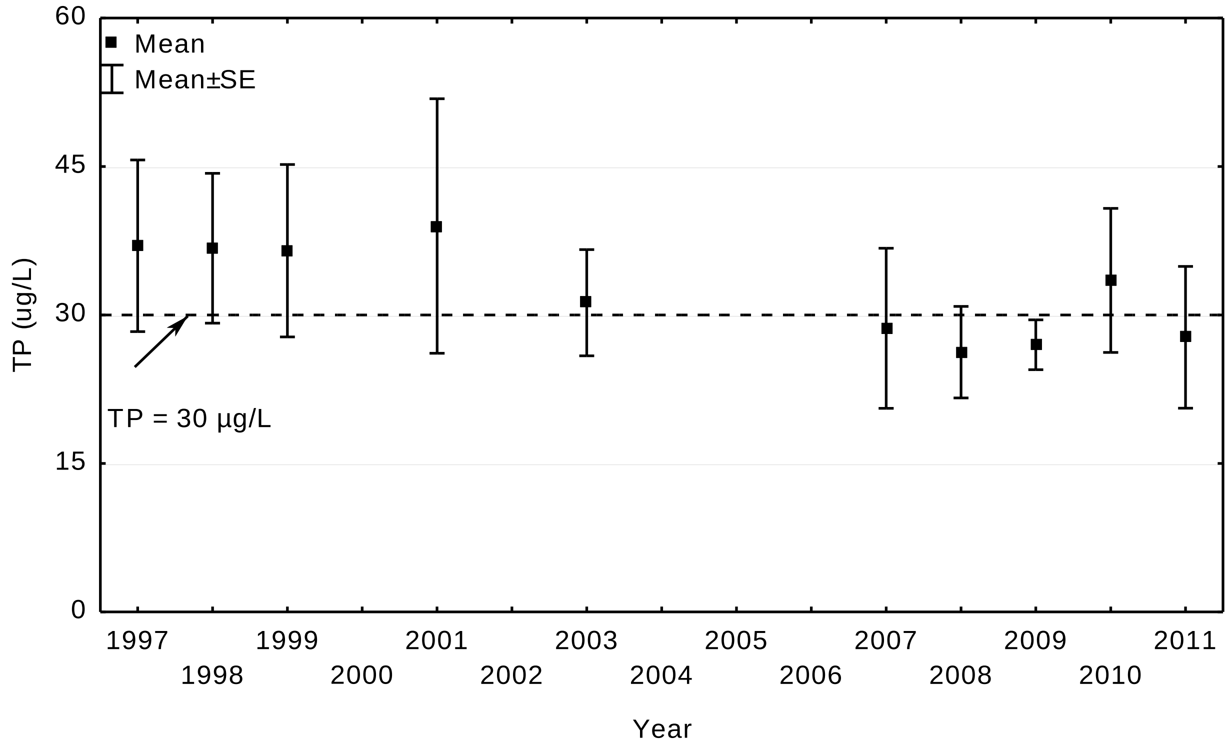


Figure 40. Growing Season Means ± SE of Chlorophyll-*a* for Eighth Crow Wing Lake by Year. The dashed line represents the water quality standard for Chl-*a* (9 µg/L).

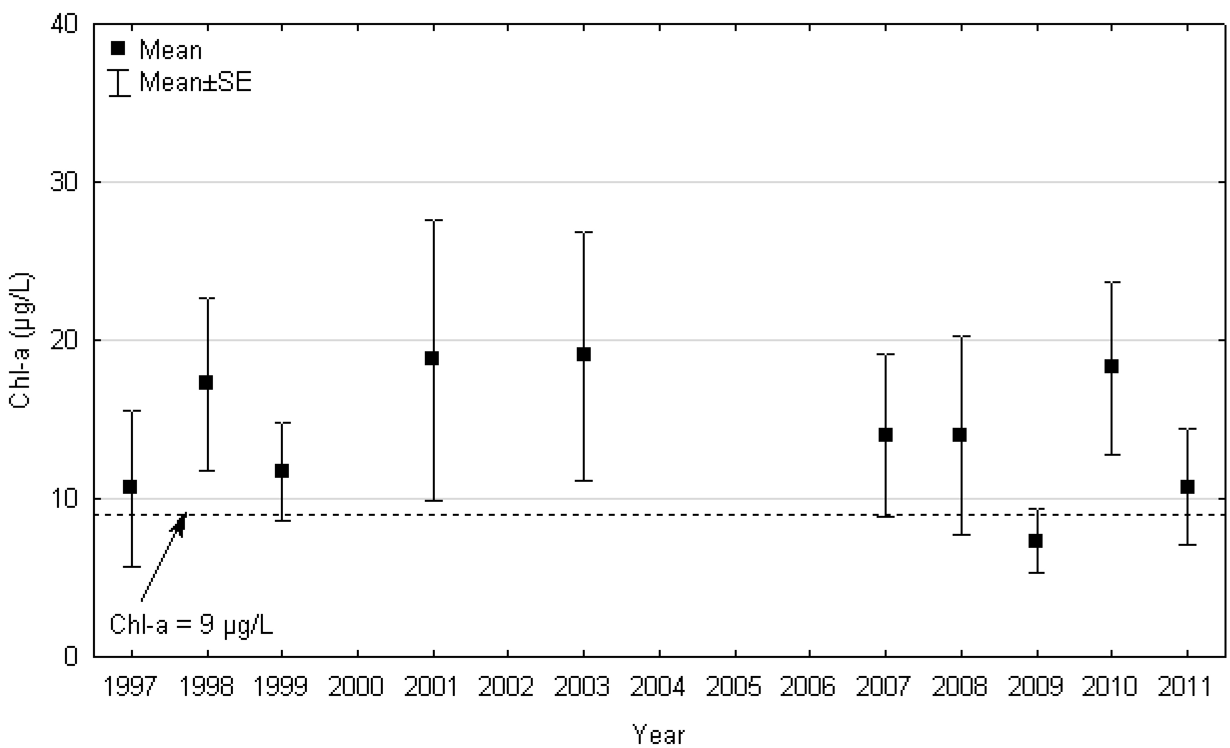


Figure 41. Growing Season Means ± SE of Secchi Transparency for Eighth Crow Wing L. by Year. The dashed line represents the lake water quality standard for transparency (2.0 m).

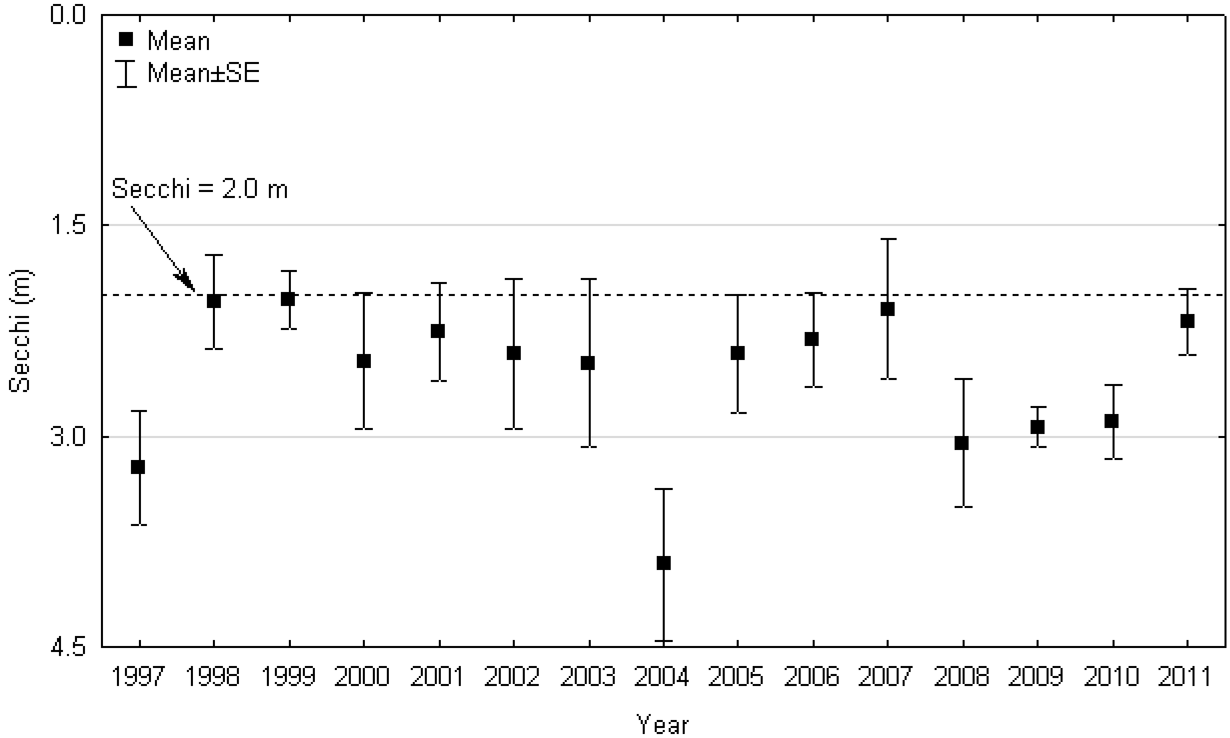


Figure 42. Growing Season Trends of Chl-*a*, TP, and Secchi depth for Eighth Crow Wing L., 2010

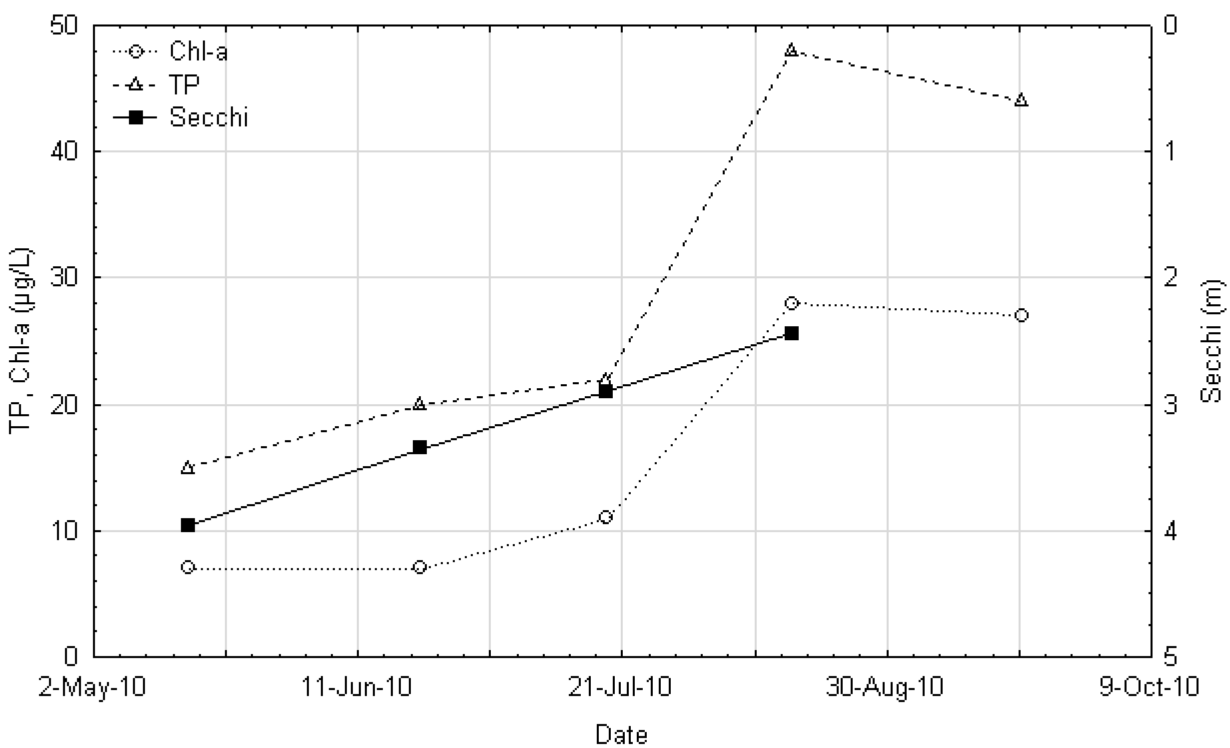


Figure 43. Bottom and surface TP concentrations, Eighth Crow Wing Lake, 2005

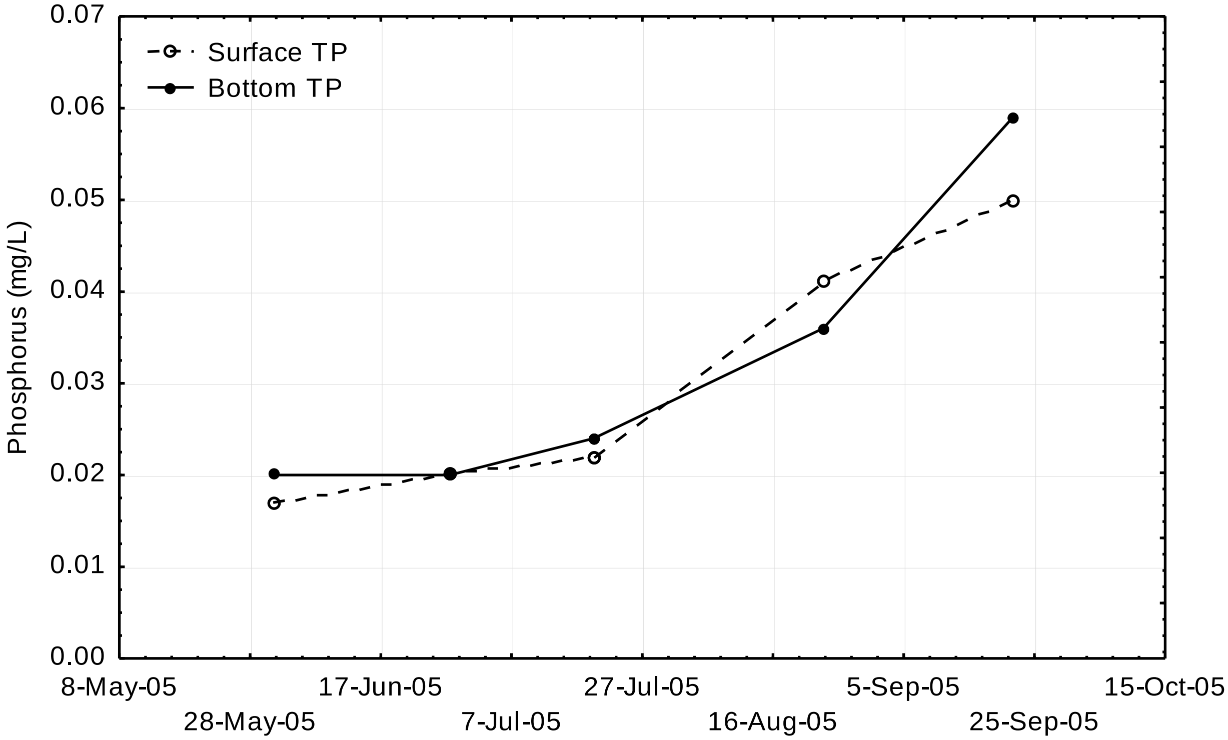


Figure 44. Temperature depth profiles, Eighth Crow Wing Lake, 2005

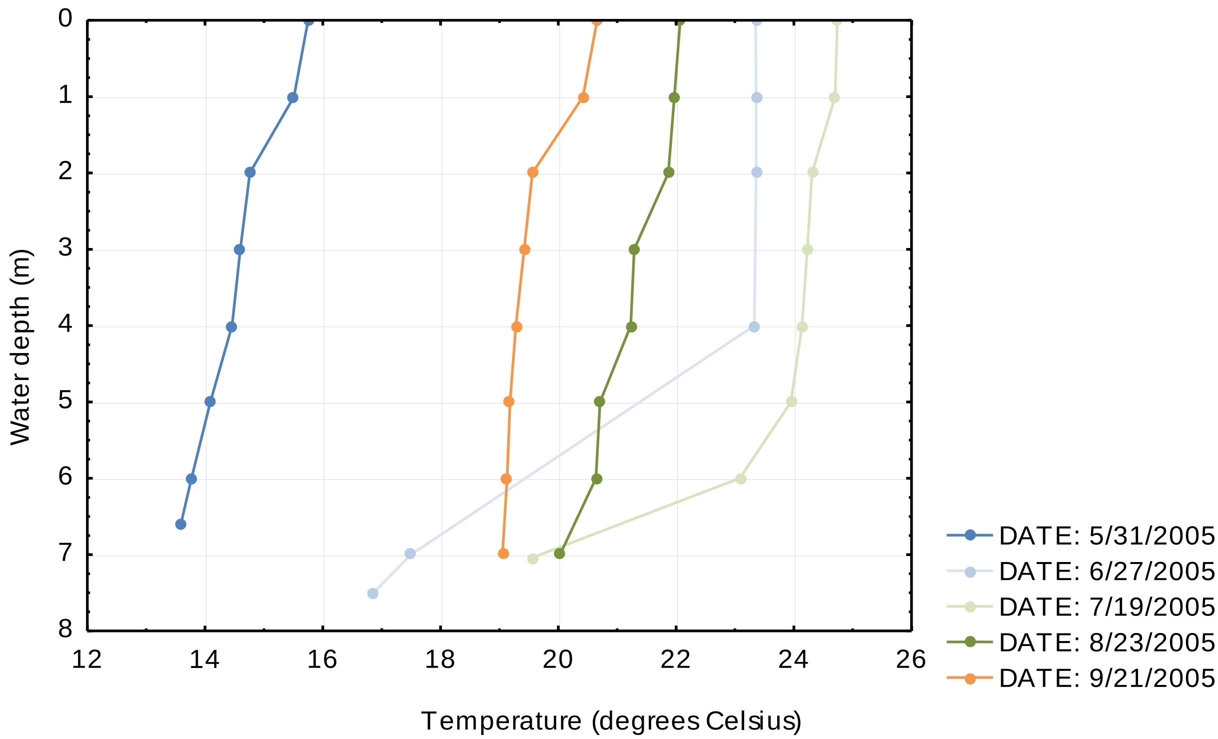


Figure 45. Dissolved oxygen depth profiles, Eighth Crow Wing Lake, 2005

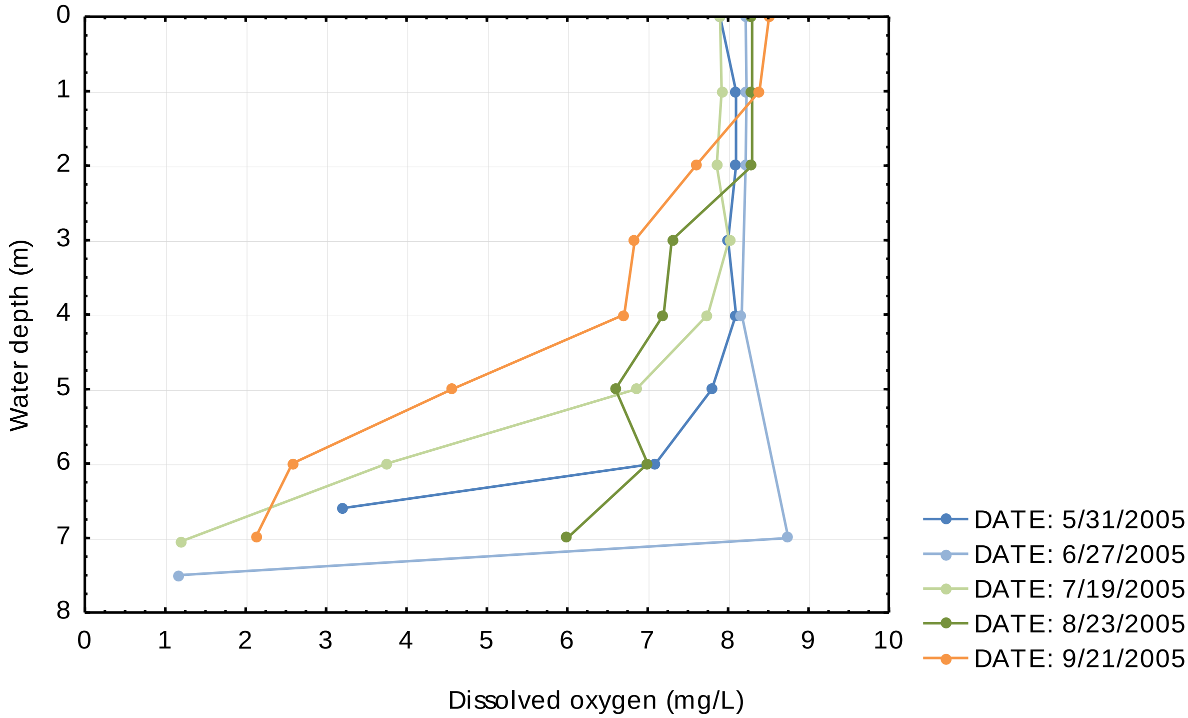


Figure 46. pH depth profiles, Eighth Crow Wing Lake, 2005

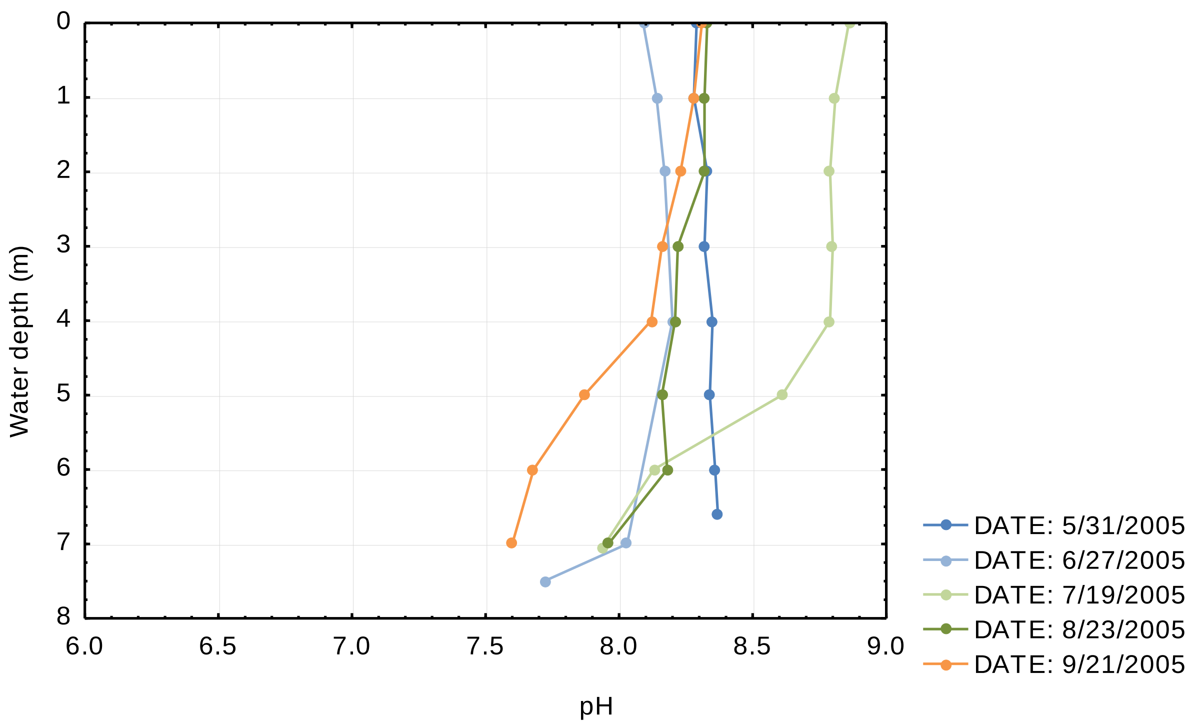
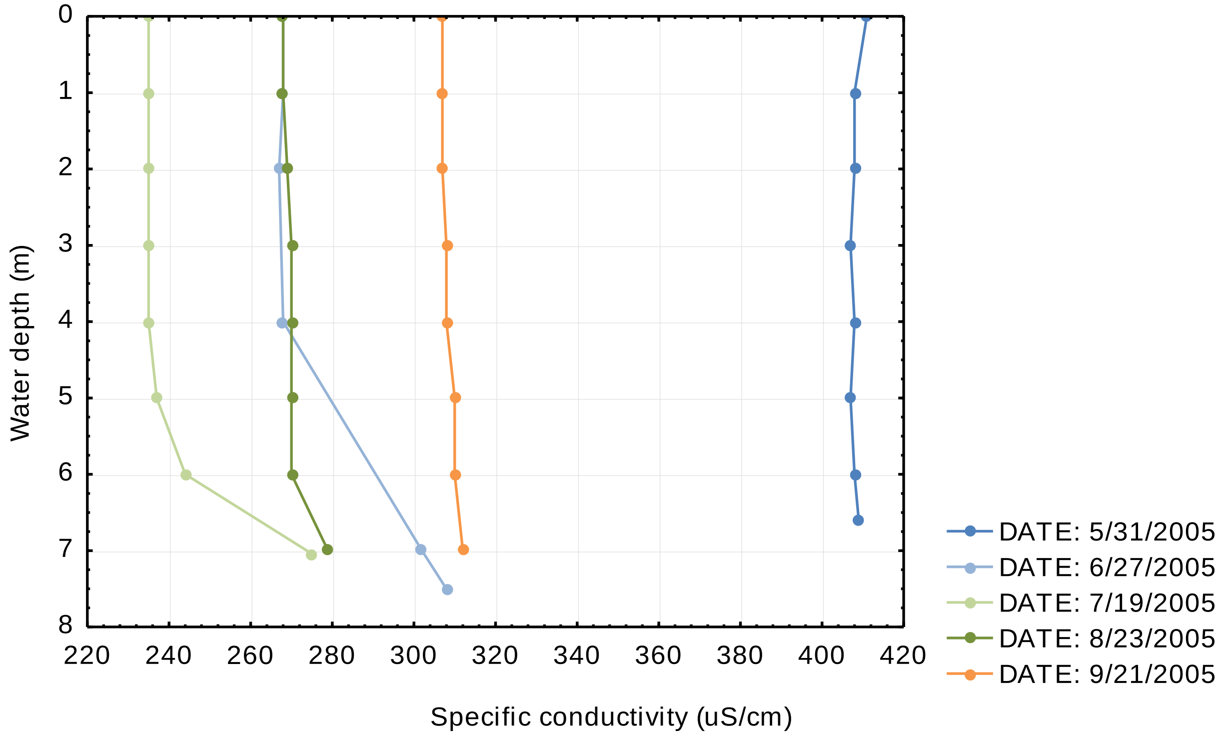


Figure 47. Specific conductivity depth profiles, Eighth Crow Wing Lake, 2005



11.2.3 Macrophytes

Eighth Crow Wing Lake has a good habitat of aquatic vegetation cover that supports a healthy panfish and bass population (MN DNR Lake Files). The most recent vegetation survey was conducted in 1998; the MN DNR does not plan to conduct another vegetation survey in the near future. Curly-leaf pondweed is not present in the lake.

11.2.4 Fish

The most recent MN DNR fish survey was conducted in 2008 (MN DNR Lake Finder). According to this report:

- Abundant walleye, largemouth bass, and panfish (bluegill, pumpkinseed, and black crappie) populations for anglers
- Low to moderate northern pike population that is typical for this lake class, with a large forage base of tullibee (cisco), white sucker, and yellow perch
- Walleye abundance (7.3 walleye/gillnet) is above the management goal of 7.0 walleye/gillnet; walleye fingerlings are stocked during odd years
- Other fish species present include high numbers of rock bass, and moderate numbers of yellow bullhead, bowfin, hybrid sunfish, and golden shiner

Heavy development on 8th Crow Wing Lake and within its immediate watershed has resulted in removal of aquatic and riparian vegetation and probably increased contribution of nutrients to the lake. Loss of vegetation, and the resulting loss of habitat and degraded water quality could negatively affect fish populations, reduce recreational opportunities, and reduce the aesthetic quality of the lake. In particular, emergent vegetation like bulrush provides spawning habitat for black crappie, bluegill and largemouth bass. Removal of aquatic vegetation will have the greatest negative impacts on these species. [Excerpt from Lake Management Plan]

Although 8th Crow Wing supports a population of tullibee, the lake is relatively shallow. Water temperatures in the upper layers of water are sometimes higher than preferred or tolerated by coldwater species like tullibee. At the same time, dissolved oxygen levels in the lower layer of water sometimes declines lower than tullibee can tolerate. The combination of high water temperatures and low dissolved oxygen has resulted in occasional summer fish kills, with the most recent in 2007. If climate change results in increasing air temperatures or land use changes result in greater oxygen consumption and lower dissolved oxygen levels, summer kills of coldwater species like tullibee may become more frequent. [Excerpt from Lake Management Plan]

11.3 First Crow Wing Lake

First Crow Wing Lake is located 7 miles east of Park Rapids and is mainly used for fishing, wild rice harvesting, and duck hunting. Some boating and possibly some swimming take place by lakeshore residents. First Crow Wing is managed primarily for Walleye, and secondarily for Yellow Perch, Northern Pike, Black Crappie, Bluegill, and Largemouth Bass. The lake is stocked for walleye in odd years. First Crow Wing is at the lower end of a chain of lakes connected by the Crow Wing River. From 1st Crow Wing Lake, boats are able to travel upstream through about three miles of the Crow Wing River to 2nd, 3rd, and 4th Crow Wing Lakes. Dams at the outlets of 5th Crow Wing Lake, and at County Road 109 below 1st Crow Wing Lake, prevent boat access further up or downstream the lake chain. High water levels are an issue of concern to lakeshore property owners on the lower Crow Wing Lakes. However, water levels or water level fluctuations in 1st Crow Wing Lake have not been abnormal in recent years. There were 37 homes recorded during the 2009 assessment (an average of 8.0 cabins/homes per shoreline mile) which is in the 48th percentile of 103 lakes in the Park Rapids area where shoreline development has been recorded. Much of the shoreline of 1st Crow Wing Lake is an undeveloped, state (DNR) owned, Wildlife Management Area (WMA). Many residents of 1st Crow Wing Lake are members of the Lower Crow Wing Lakes Association, which sponsored a cooperative walleye rearing pond program by sharing lease costs, to provide access to three walleye rearing ponds. Those leases were taken over by MN DNR Fisheries in 2011. Residents have periodically conducted some water quality sampling, but not on a regular schedule.

Contributor(s): Doug Kingsley and Mike Kelly, Park Rapids MN DNR-Fisheries
MN DNR 2011 Lake Management Plan

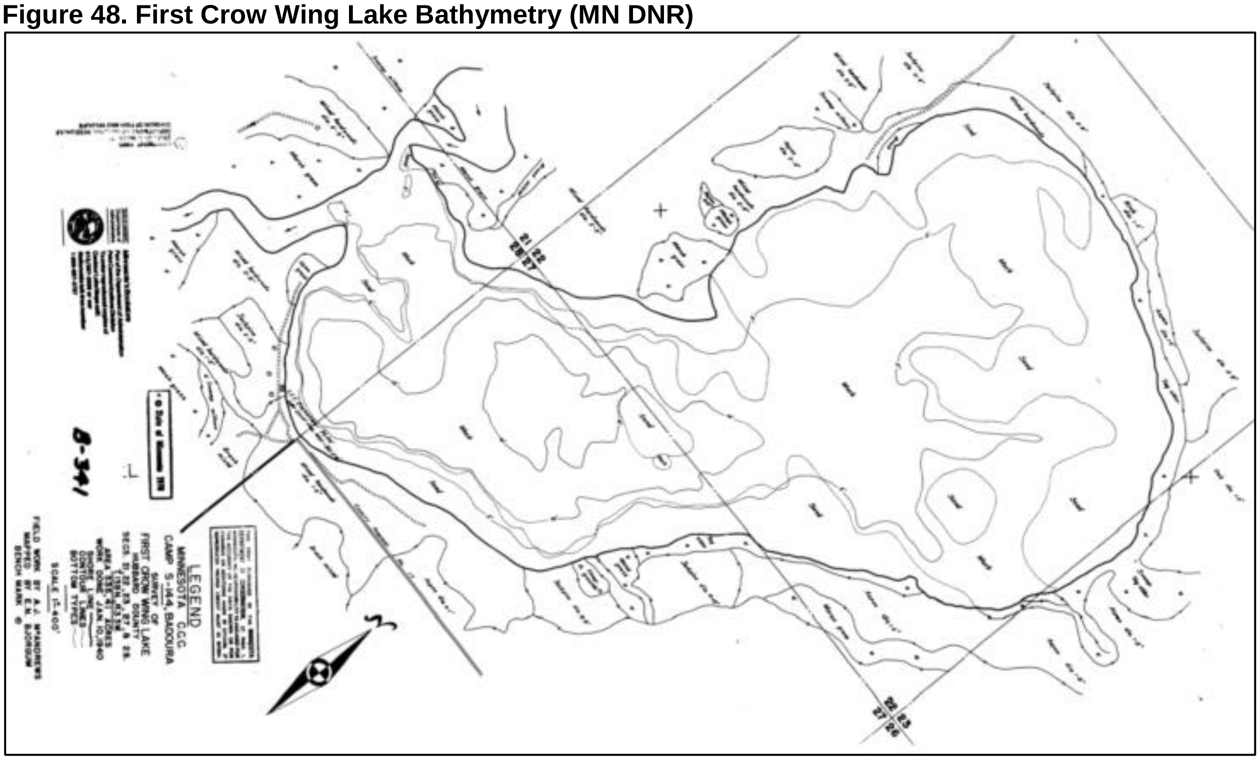
11.3.1 Physical Characteristics

First Crow Wing Lake (MN DNR Lake ID 29-0086-00) is located in Hubbard County. The First Crow Wing Lake watershed is located in the northern portion of the Crow Wing River watershed and includes the drainage area to Big and Little Sand Lakes, Lake Belle Taine, and the Crow Wing Chain of Lakes. First Crow Wing Lake is the last lake the Crow Wing River flows through except for two man-made reservoirs (Lake Placid and Sylvan Reservoir) near the Crow Wing River outlet to the Mississippi River. Table summarizes the lake's physical characteristics, Figure 49 shows the 2011 aerial photography, and Figure 48 illustrates the available bathymetry.

Table 52. First Crow Wing Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	509	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	100%	Calculated from MN DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	2,926	
Mean depth (feet)	5.8	Lake volume ÷ surface area
Maximum depth (feet)	15	MN DNR Lake Finder
Drainage area (acre)	166,458	MN DNR Catchments
Watershed area: Lake area	327: 1	Calculated

Figure 48. First Crow Wing Lake Bathymetry (MN DNR)



11.3.2 Water Quality

Water quality monitoring data were available for First Crow Wing Lake from 1997-2011. Only data from the most recent 10 years (2002-2011) were used to determine whether First Crow Wing Lake meets water quality standards. The lake does not meet the North Central Hardwood Forest (NCHF) shallow lake water quality standard for Chl-*a*, and is basically at the standard for TP and Secchi (Table). Growing season means for TP and Secchi have varied around water quality standards in recent years (Figure 50, Figure 52), while the last time Chl-a met the standard was in 2004 (Figure 51). Neither TP, Chl-a, nor Secchi display any apparent long-term trends. Growing season trends in 2010 indicated that peak TP and Chl-a and minimum Secchi transparency occurred in mid-August (Figure 30). The Crow Wing River enters First Crow Wing Lake on the northwest side, and flows out at the southwest end. Much of the water flowing through the lake from the Crow Wing River does not circulate through the lake's eastern end, and the lake's northeast part is fairly shallow with soft substrates. As a result, water quality in the eastern end has often been poorer than the west (MN DNR 2011 Lake Management Plan).

Table 53. 10-year Growing Season Mean TP, Chl-*a*, and Secchi, First Crow Wing Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Shallow Lake Standard
Total phosphorus (µg/L)	59	8%	< 60
Chlorophyll-*a* (µg/L)	32	12%	< 20
Secchi transparency (m)	1.1	5%	> 1.0

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 49. Aerial photograph of First Crow Wing Lake (Google Earth, September 2011)

Figure 50. Growing Season Means ± SE of Total Phosphorus for First Crow Wing Lake by Year. The dashed line represents the water quality standard for TP (60 µg/L).

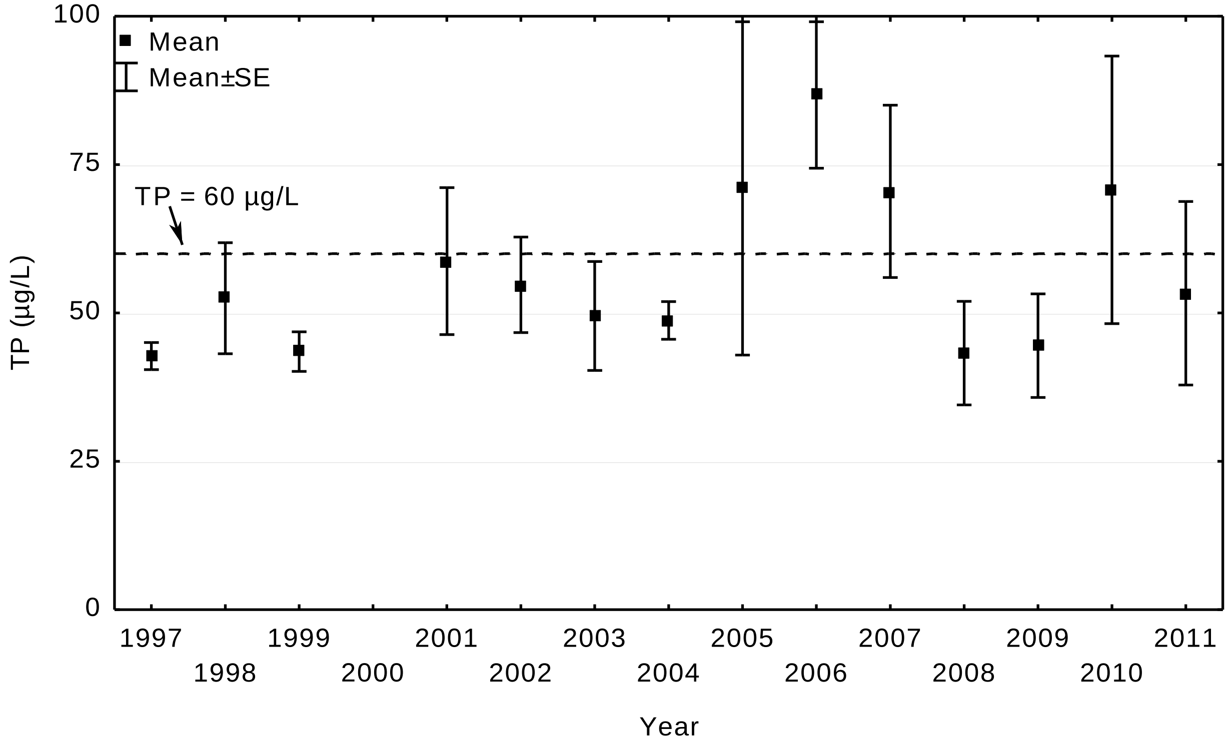


Figure 51. Growing Season Means ± SE of Chlorophyll-*a* for First Crow Wing Lake by Year. The dashed line represents the water quality standard for Chl-*a* (20 µg/L).

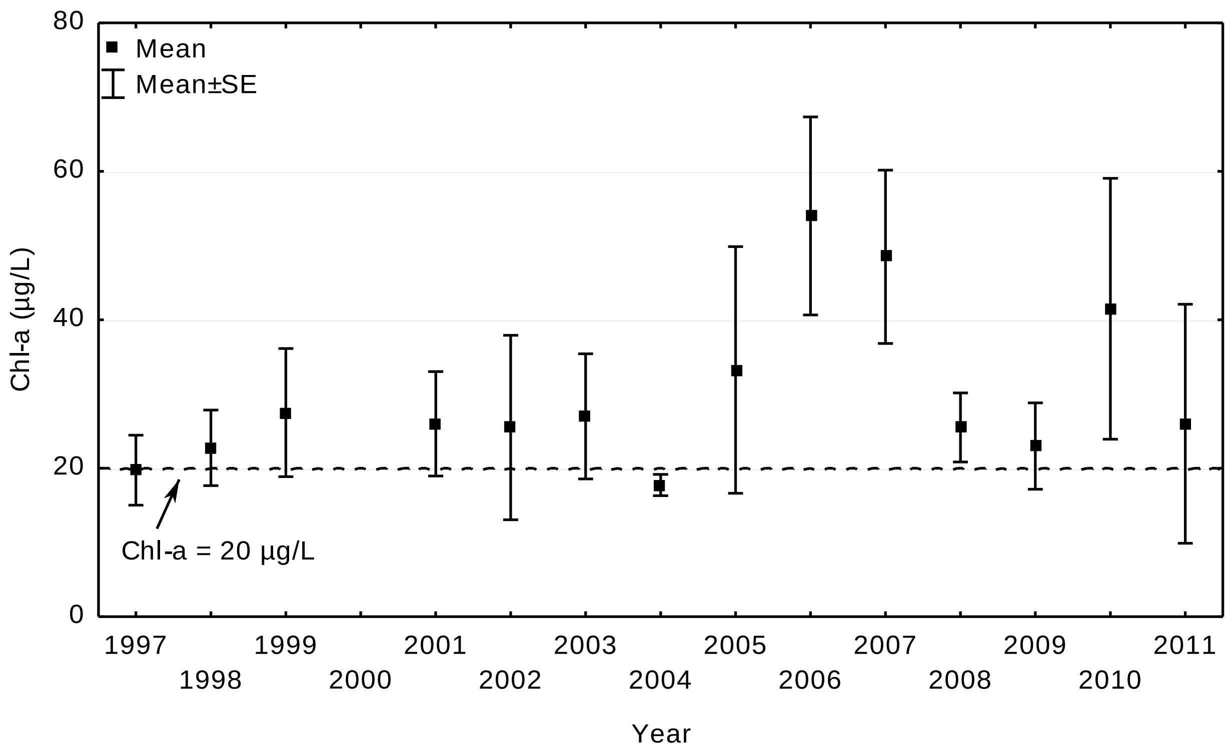


Figure 52. Growing Season Means ± SE of Secchi transparency for First Crow Wing Lake by Year The dashed line represents the lake water quality standard for transparency (1.0 m).

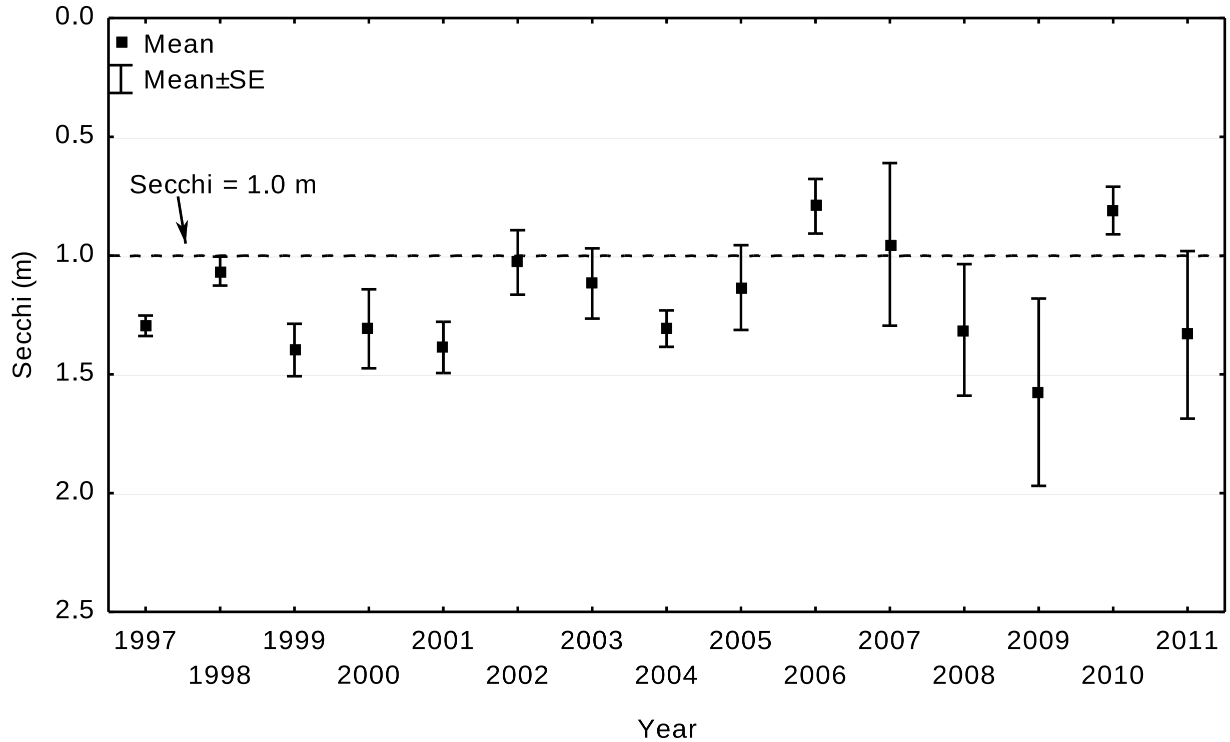
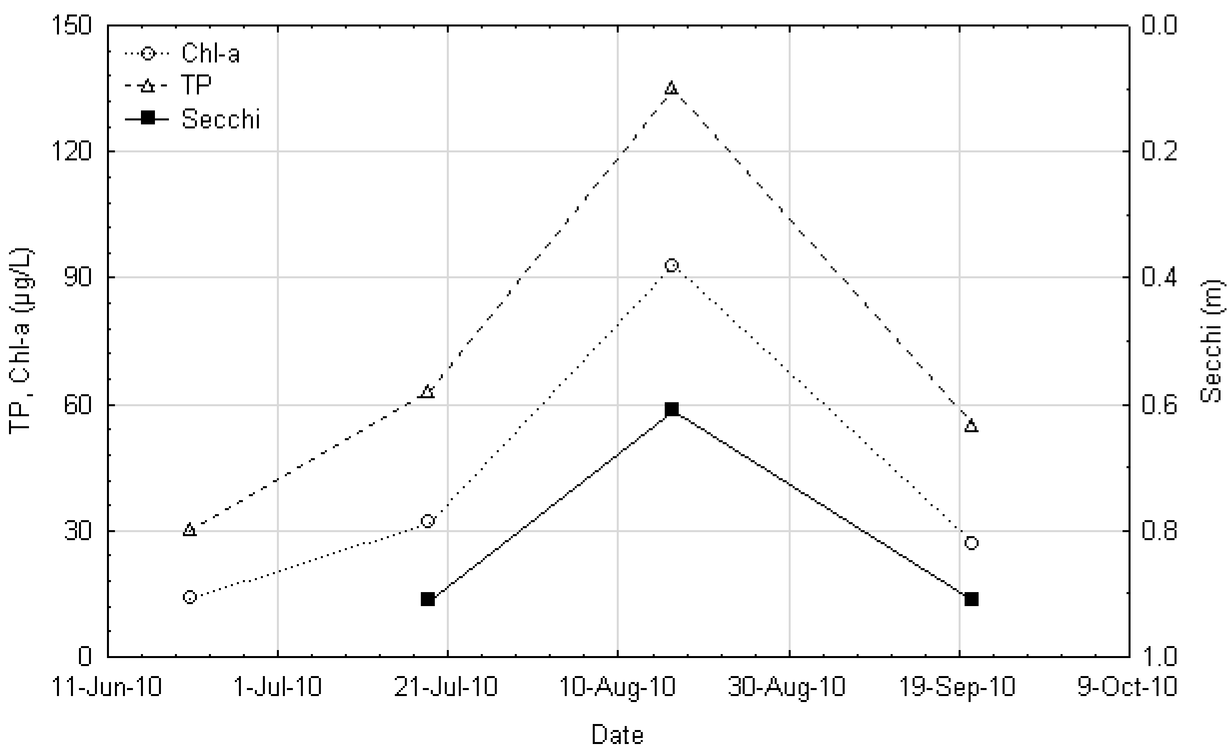


Figure 53. Growing Season Trends of Chl-*a*, TP, and Secchi depth for First Crow Wing, 2010



11.3.3 Macrophytes

First Crow Wing has abundant stands of both emergent and submergent aquatic vegetation. The most commonly found species with high abundance are submergent Coontail and Flat-stem, emergent Northern wild rice, Duckweed, and Filamentous algae. Large beds of wild rice are located on the north shoreline and are an important food source for waterfowl. [MN DNR 2009 Vegetation Resurvey]

Some residents have expressed concern about the extent of aquatic vegetation in 1st Crow Wing Lake. This lake does have more aquatic vegetation and wetland fringe than some lakes. However, the vegetation is important to the lake and its aquatic organisms because it provides cover, provides habitat for food organisms, helps filter nutrients, adds oxygen to the water, and stabilizes the shoreline and substrates. The physical and chemical characteristics that make 1st Crow Wing more conducive to aquatic plant growth, and the aquatic plants themselves, are probably also responsible for better fish production than many lakes. [Excerpt from the Lake Management Plan]

11.3.4 Fish

The most recent MN DNR fish survey was conducted in 2009 (MN DNR Lake Finder). According to this report:

- Abundant northern pike spawning habitat of shallow submerged and flooded aquatic vegetation results in excellent reproduction and recruitment of pike in First Crow Wing.
- Bluegill abundance (42.4 bluegill/trapnet) was up from past surveys, with good numbers of bluegill and pumpkinseed in the 6-8 inch size range.
- Black crappie were sampled in moderate numbers, similar to past surveys.
- Walleye abundance (1.3 walleye/gillnet) was within the range "typical" for this lake class, but below the current management goal of 4.0 walleye/gillnet. First Crow Wing is stocked with walleye fingerlings during odd numbered years.
- Other species sampled included high numbers of yellow bullhead and bowfin (dogfish) and moderate numbers of shorthead redhorse, tullibee (cisco), and white sucker. Brown bullhead, yellow perch, carp, hybrid sunfish were sampled in low numbers.

The following are excerpts from the Lake Management Plan:
"Increased fishing pressure and harvest in recent decades may be affecting abundance, size, or age structure of some game fish populations. In particular, it appears that there may be an opportunity to increase the size structure of black crappie and/or bluegill in 1st Crow Wing with more restrictive size and/or bag limit regulations.

Development on 1st Crow Wing Lake and within its immediate watershed has resulted in removal of aquatic and riparian vegetation and probably increased contribution of nutrients to the lake. Loss of vegetation and the resulting loss of habitat and degraded water quality could negatively affect fish populations, reduce recreational opportunities, and reduce the aesthetic quality of the lake. In particular, emergent vegetation like bulrush provides spawning habitat for black crappie, bluegill and largemouth bass. Removal of aquatic vegetation will have the greatest impacts on these species."

11.4 Lower Twin Lake

Lower Twin Lake is located 3 miles northeast of Menahga, Minnesota. The Shell River flows through Upper Twin Lake, then Lower Twin before it outlets from the southeast side of Lower Twin. The two lakes are separated by Wadena County Road 21 with a narrow channel between the two that is navigable by boats. Lower Twin is a very popular fishing lake. The lake is managed and stocked for walleye, and provides fishing opportunities for northern pike, panfish, white sucker, redhorse, bass, rock bass, pumpkinseed, and bullhead. Muskellunge and brown trout have also been found in gill net surveys. The lake receives moderate to heavy fishing pressure for northern pike, walleye, and panfish, and receives some of the heaviest winter ice fishing pressure for the area. Lower Twin is not always suitable for swimming and wading due to low clarity or excessive algae caused by the presence of phosphorus in the water. Curly-leaf pondweed and the faucet snail are present in the lake. Lake water quality has been monitored since the mid-1990s by Don Broughton and Chuck Tritz of Menahga, the Twin Lakes Association, and the Wadena SWCD. Aerial fish house counts have been conducted annually since 1983 to monitor trends in ice fishing pressure. Counts have averaged 53 with a range of 22 to 88 houses. House counts have been lower than “normal” since 2001. There were 65 homes/cabins counted during the 2003 resurvey (an average of 28.3 homes/cabins per shoreline mile) which is in the 97th percentile of 100 lakes in the Park Rapids area where shoreline development has been recorded. Lower Twin Lake was developed much earlier than other lakes, as evidenced by the high density of homes/cabins, but few new structures in recent years. There is also 1 resort located on Lower Twin Lake.

Contributor(s): Anne Oldakowski, Wadena SWCD
MN DNR 2010 Lake Management Plan

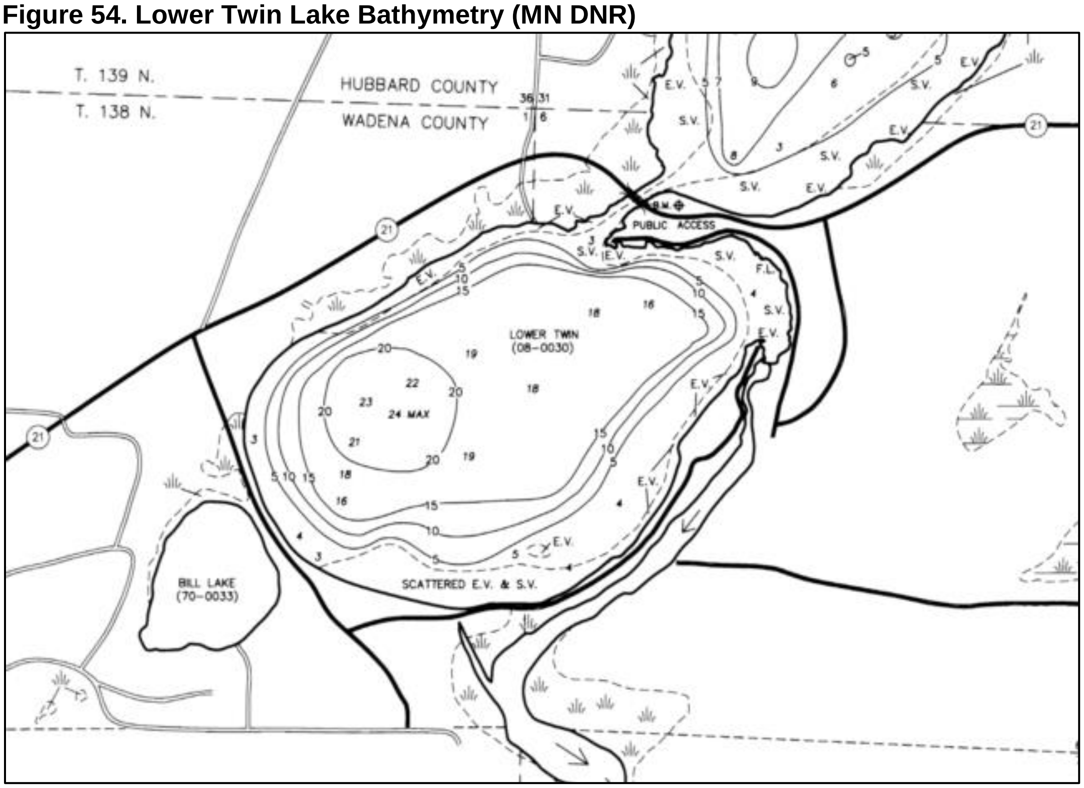
11.4.1 Physical Characteristics

Lower Twin Lake (MN DNR Lake ID 80-0030-00) is located in Wadena County with portions of its watershed located in Becker County (60%), Hubbard County (31%), Clearwater County (6%), and Wadena County (3%). The Lower Twin Lake watershed includes the drainage area to the impaired Blueberry and Portage Lakes and is located in the north-west portion of the Crow Wing River watershed. The Lower Twin Lake watershed also includes the drainage to the major lakes Shell, Straight, Fish Hook, and Potato, and the Kettle, Blueberry, Shell, and Straight Rivers. Blueberry Lake is located upstream of Lower Twin Lake on the Shell River. Table 71 summarizes the lake's physical characteristics, Figure 55 shows the 2011 aerial photography, and Figure 54 illustrates the available bathymetry.

Table 71. Lower Twin Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	252	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	53%	Calculated from MN DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	2,859	
Mean depth (feet)	11.4	Lake volume ÷ surface area
Maximum depth (feet)	26	MN DNR Lake Finder
Drainage area (acre)	383,638	MN DNR Catchments
Watershed area: Lake area	1,522: 1	Calculated

Figure 54. Lower Twin Lake Bathymetry (MN DNR)



11.4.2 Water Quality

Water quality monitoring data were available for Lower Twin Lake from 1980-2011. Only data from the most recent 10 years (2002-2011) were used to determine whether Lower Twin Lake meets water quality standards. The lake does not meet the North Central Hardwood Forest (NCHF) general lake water quality standards for TP and Chl-*a* (Table). Growing season mean TP and Chl-a have varied above and below water quality standards during the period of record (Figure 56 and Figure 57). Growing season mean Secchi transparency has varied, though has not exceeded water quality standards during the period of record (Figure 58). There are no apparent long-term trends in TP, Chl-a, or Secchi transparency. Growing season water quality trends in 2011 indicated that peak Chl-a and minimum Secchi transparency occurred twice, once in June and once in August (Figure 59). Peak TP, peak Chl-*a* and minimum Secchi transparency typically occurs in the middle of the growing season due to rapid algal growth from warm water temperatures and high levels of sunlight.

Table 55. 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Lower Twin Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Lake Standard
Total phosphorus (µg/L)	40	5%	< 40
Chlorophyll-*a* (µg/L)	15	9%	< 14
Secchi transparency (m)	1.9	3%	> 1.4

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 55. Aerial photograph of Lower Twin Lake (Google Earth, September 2011)

Figure 56. Growing Season Means ± SE of Total Phosphorus for Lower Twin Lake by Year. The dashed line represents the water quality standard for TP (40 µg/L).

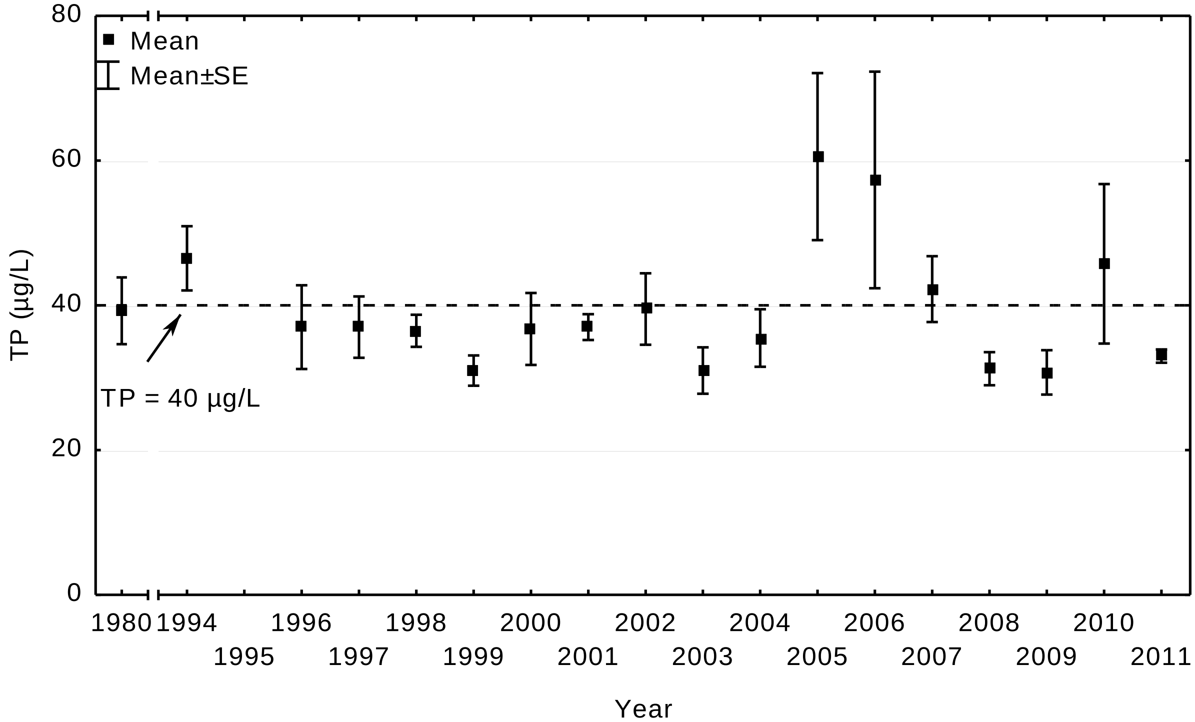


Figure 57. Growing Season Means ± SE of Chlorophyll-*a* for Lower Twin Lake by Year. The dashed line represents the water quality standard for Chl-*a* (14 µg/L).

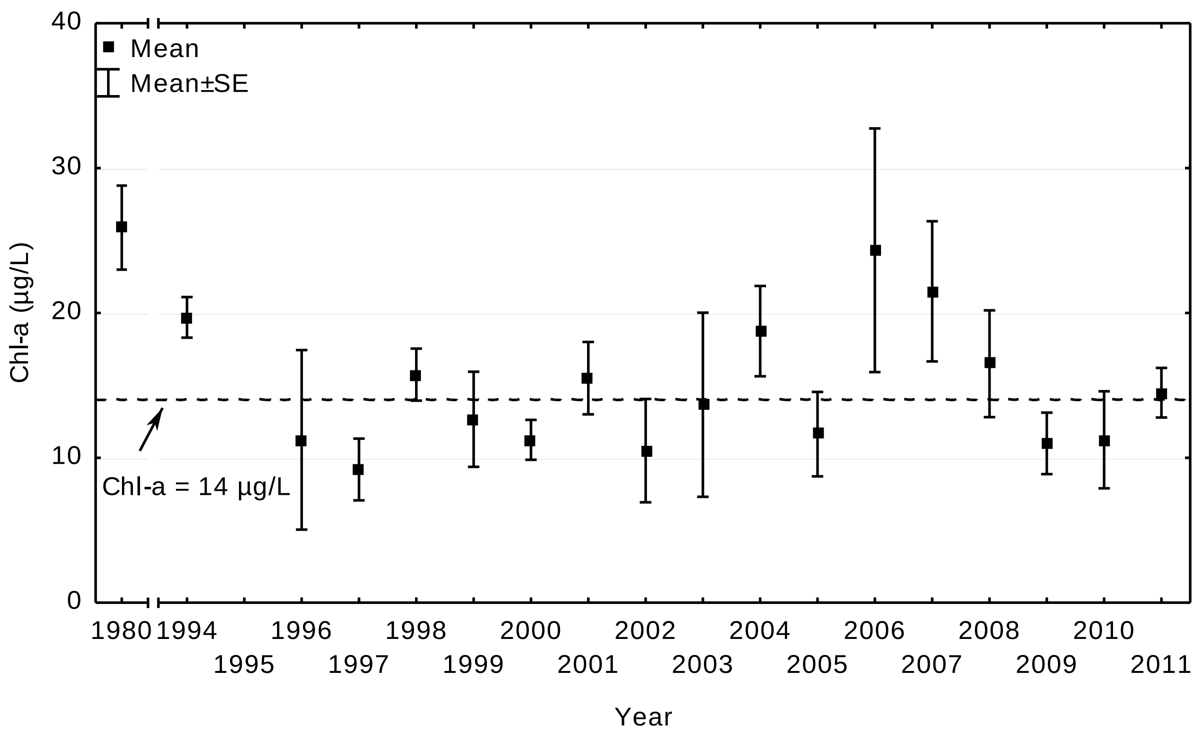


Figure 58. Growing Season Means ± SE of Secchi transparency for Lower Twin Lake by Year The dashed line represents the lake water quality standard for transparency (1.4 m).

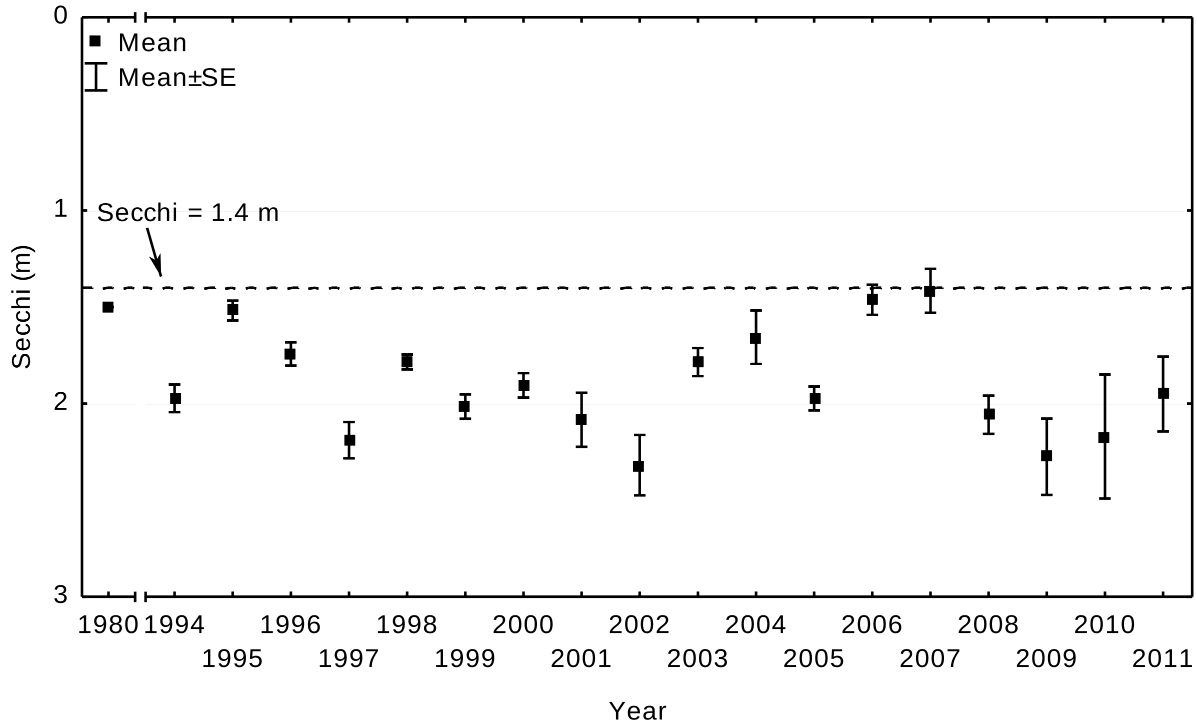


Figure 59. Growing Season Trends of Chl-*a*, TP, and Secchi depth for Lower Twin Lake, 2011

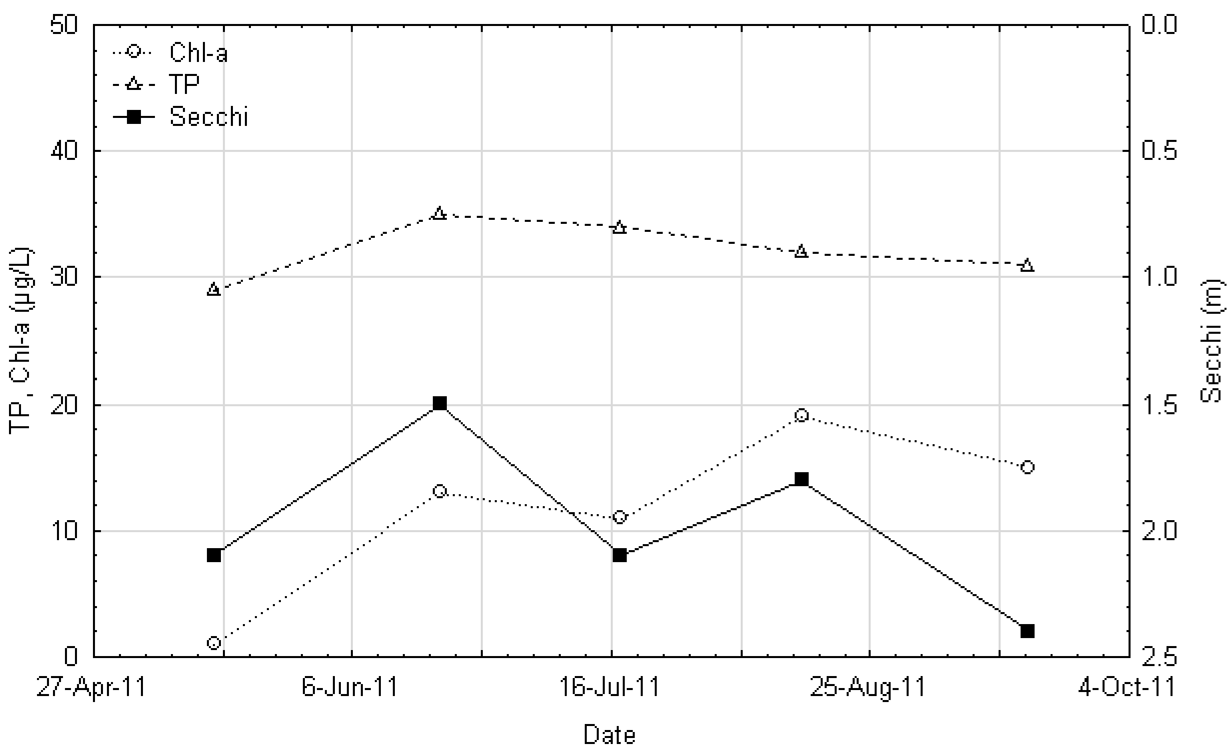


Figure 60. Bottom and surface TP concentrations, Lower Twin Lake, 2005

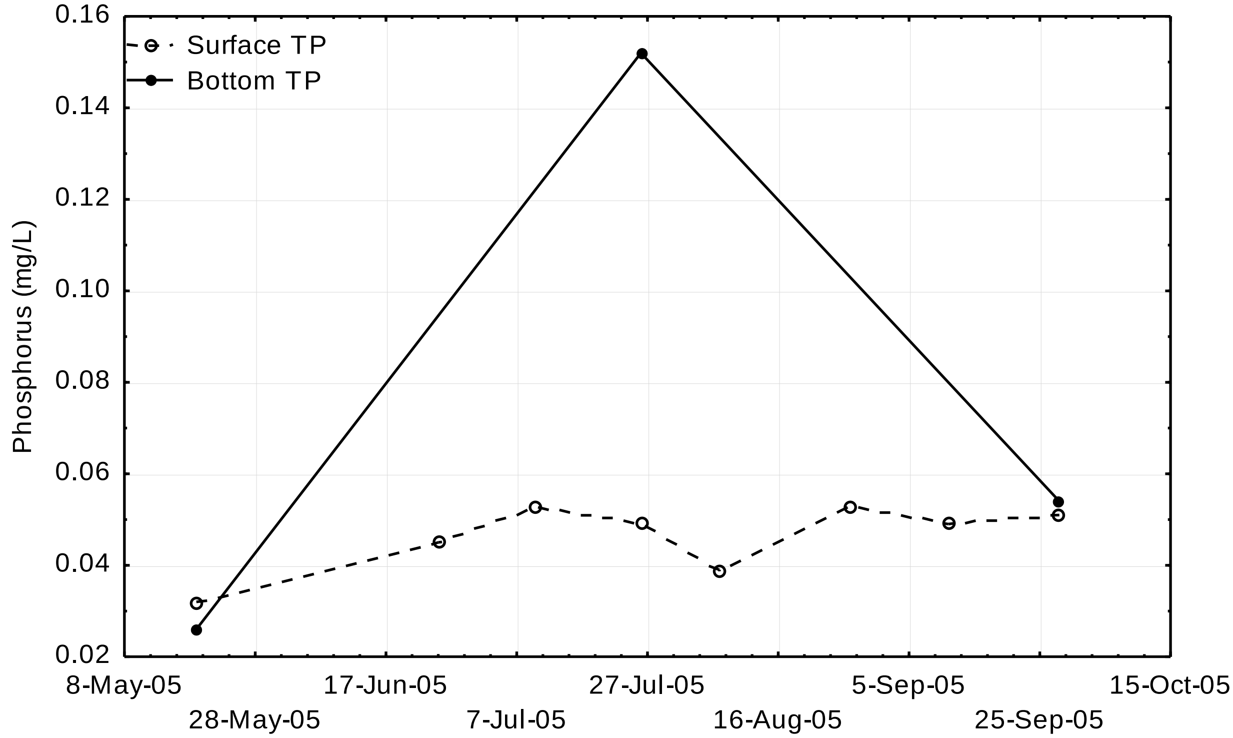


Figure 61. Temperature depth profiles, Lower Twin Lake, 2005

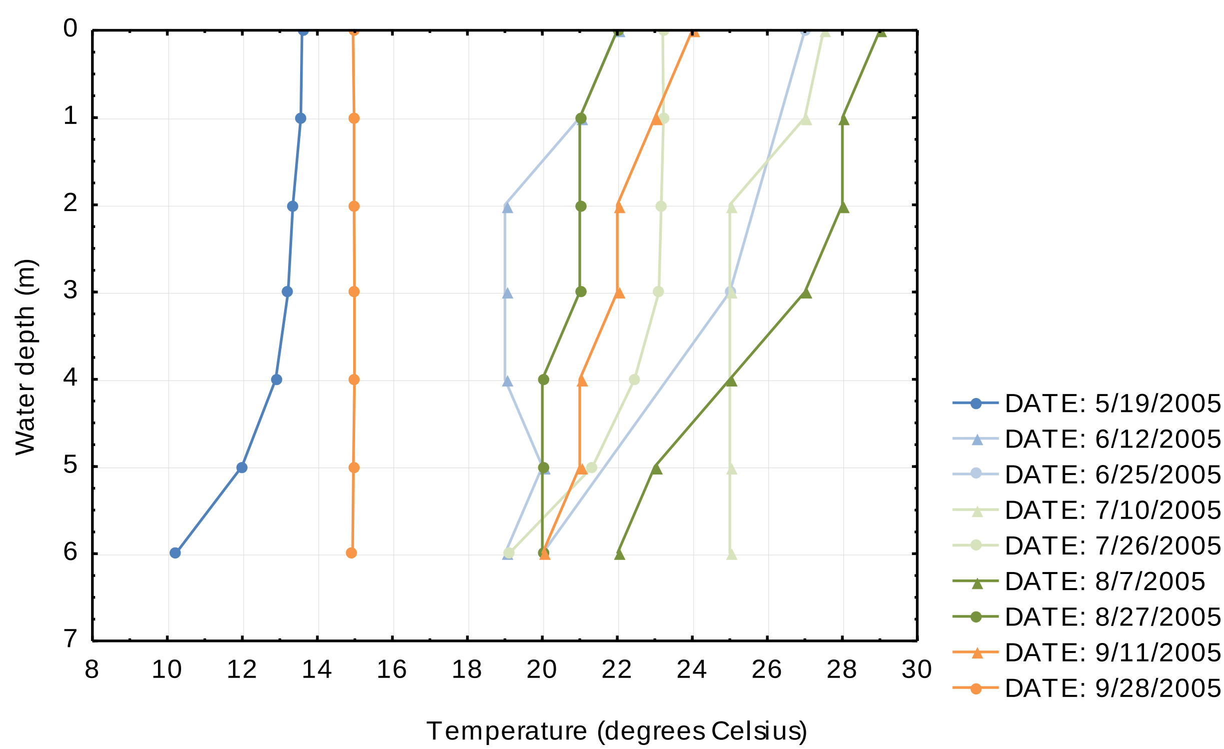


Figure 62. Dissolved oxygen depth profiles, Lower Twin Lake, 2005

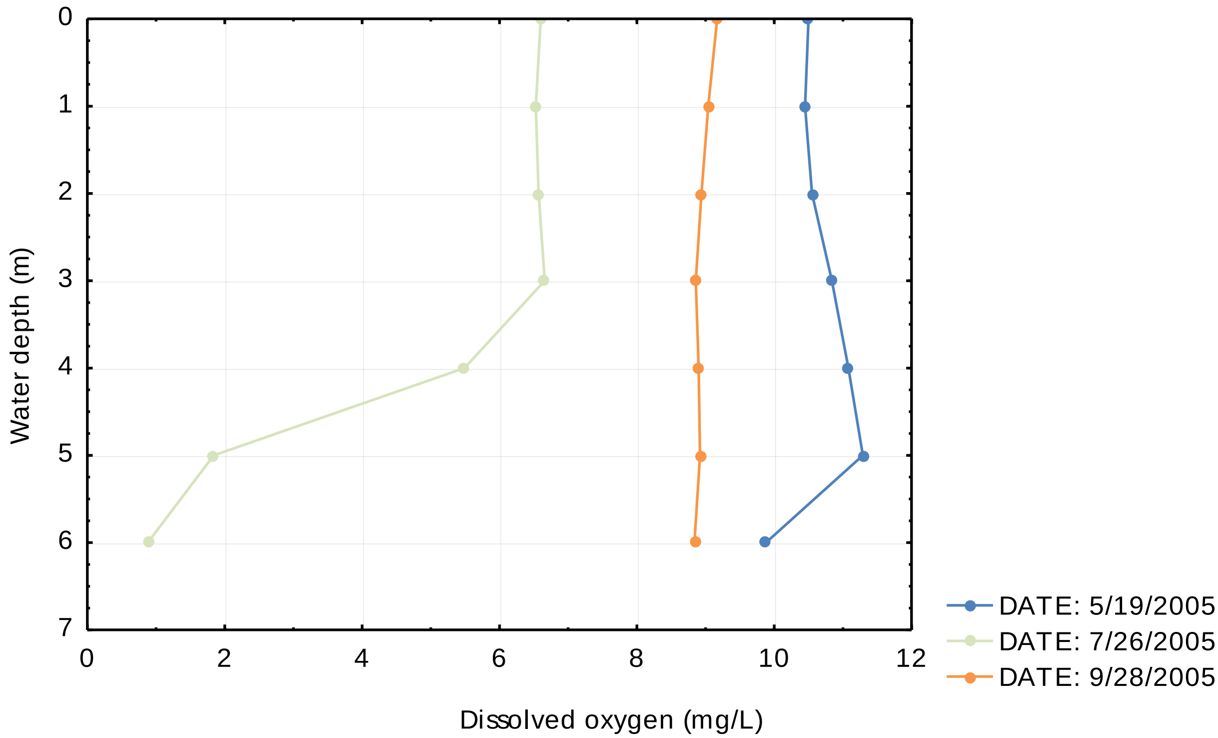


Figure 63. pH depth profiles, Lower Twin Lake, 2005

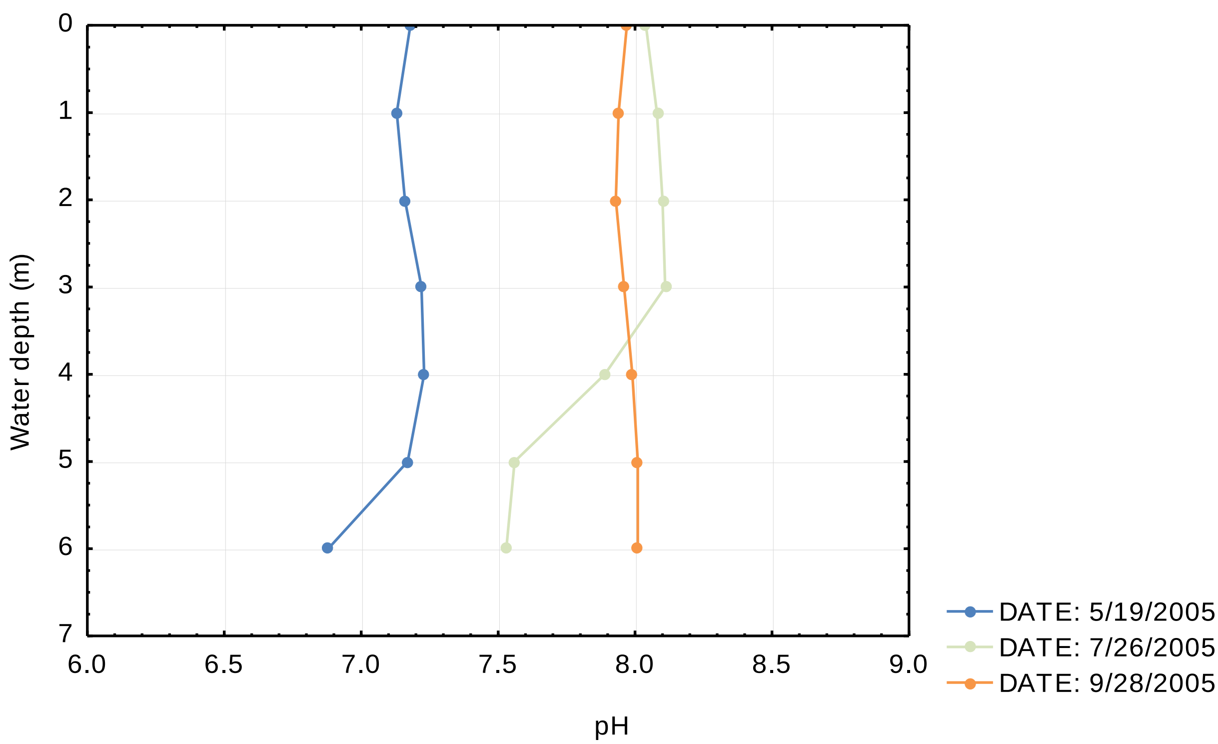
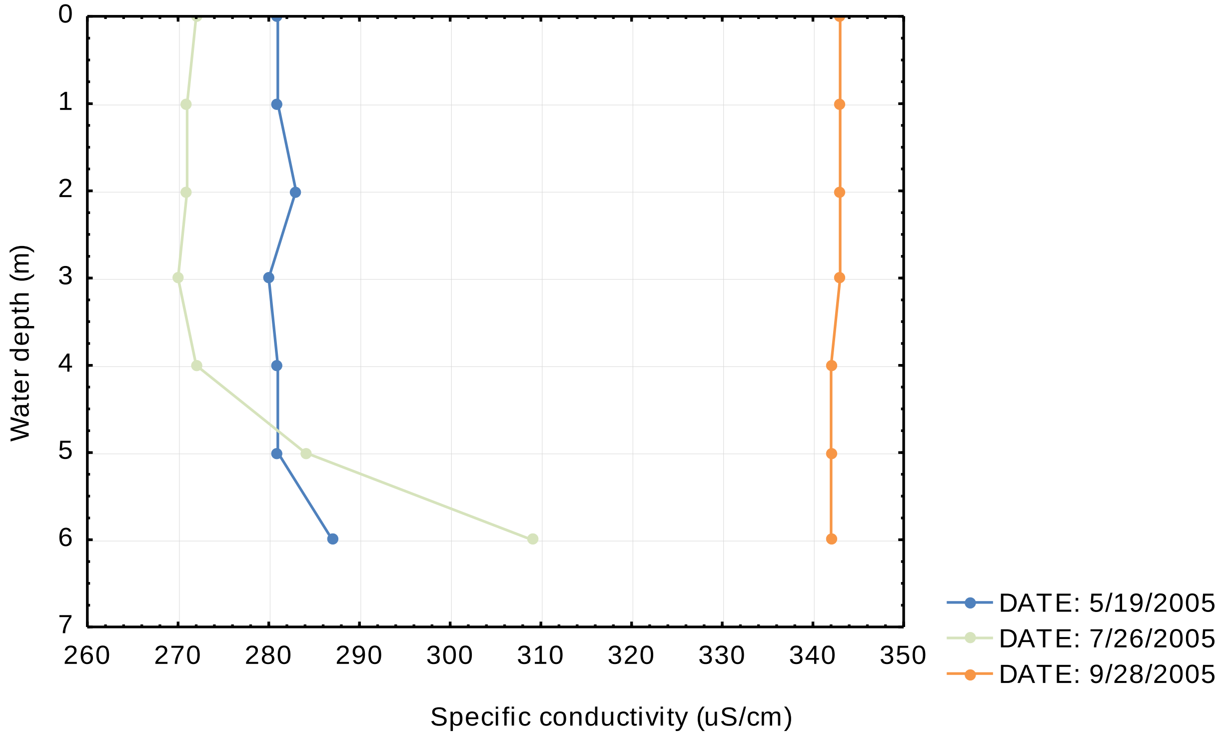


Figure 64. Specific conductivity depth profiles, Lower Twin Lake, 2005

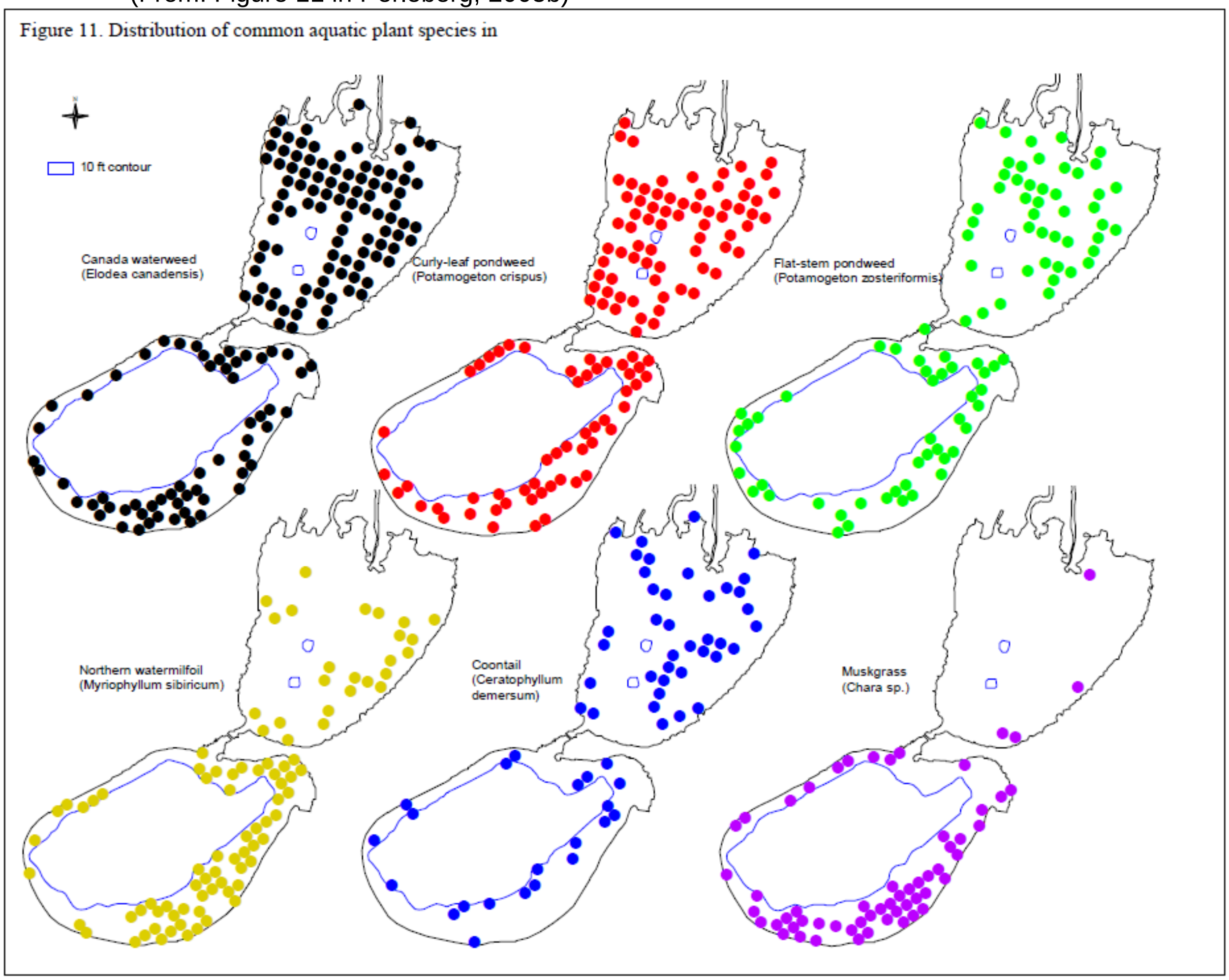


11.4.3 Macrophytes

A vegetation survey was conducted in June 2005 to assess the aquatic plant community of Lower Twin Lake (Perleberg 2005b; Figure 36). According to the report, curly-leaf pondweed (*Potamogeton crispus)* was present and abundant but not the dominant species. Other common submerged plant species were Canada waterweed, flatstem pondweed, northern watermilfoil, coontail, and muskgrass. Wild rice was present in over half of the samples sites and yellow waterlily were common. The lake supports a diversity of native plant species and a mix of emergent, floating, and submerged plant communities.

Heavy development and use of Lower Twin Lake and within its immediate watershed has resulted in removal of riparian vegetation and probably increased contribution of nutrients to the lake. High nutrients and shallow depths make the lake conducive to growth of aquatic vegetation. The invasive plant curly leaf pondweed was first observed in Lower Twin Lake in the mid-1990s. [Excerpt from the 2010 Lake Management Plan]

Figure 65. Distribution of common aquatic plant species in Lower Twin Lake, June 22-23, 2005
(From: Figure 11 in Perleberg, 2005b)



11.4.4 Fish

The most recent MN DNR fish survey was conducted in 2008 (MN DNR Lake Finder). According to this report:

- Northern pike abundance (4.3 pike/gillnet) was down from previous surveys, but still within the range "typical" for this lake class. Historical surveys have shown that the northern pike population in Lower Twin fluctuates from moderate to high numbers. Abundant northern pike spawning habitat of shallow, submerged and emergent vegetation results in excellent reproduction and recruitment of northern pike in Lower Twin.
- Lower Twin is stocked annually with 123,000 walleye fry in the spring.
- Walleye abundance (2.8 walleye/gillnet) was near the current management goal of 2.2 walleye/gillnet.
- Yellow perch are abundant in Lower Twin and provide a plentiful forage base for the walleye population.
- Present and past surveys have shown low to moderate largemouth bass numbers when compared to other area lakes. Smallmouth bass are found in lower numbers and seem to be concentrated in the inlet and outlet areas.
- Panfish, such as bluegill in the 6-8 inch size range and black crappie, are present in Lower Twin.
- Lower Twin supports an abundant white sucker and shorthead redhorse population.
- Carp are found in very low numbers in Lower Twin.

11.5 Mayo Lake

Mayo Lake is located southwest of Pequot Lakes, Minnesota. Mayo Lake receives discharge from Sibley Lake, and then discharges to Upper Gull Lake via Mayo Brook. The lake is moderately developed with 15 homes/cabins per shoreline mile based on 1997 data. The lake fishery is managed for northern pike and bluegill. Beaver dams have historically prevented walleye migration from Upper Gull Lake. The beaver and dams were removed in April 2003 and since then there have been reports of walleye in Sibley Lake.

Contributor(s): MN DNR Lake Management Plan
Melissa Barrick, Crow Wing SWCD

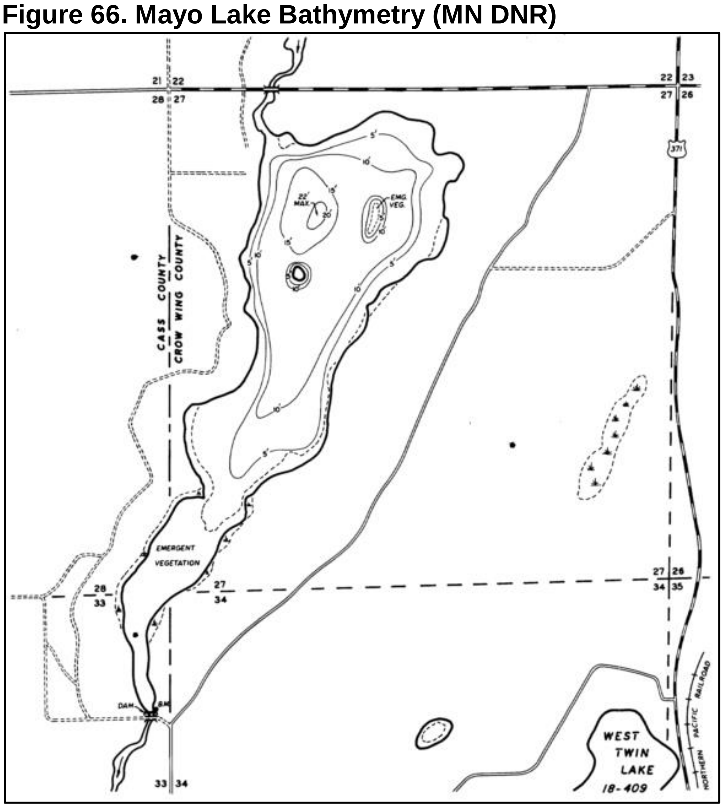
11.5.1 Physical Characteristics

Mayo Lake (MN DNR Lake ID 18-0408-00) is located in Crow Wing County with portions of its watershed located in Cass County (89%) and Crow Wing County (11%). Sibley and Mayo Lakes are located in the south-east portion of the Crow Wing River watershed. Sibley Lake outlets to Mayo Lake; and the Sibley-Mayo Lake watershed outlets into Upper Gull Lake. Water flows from Gull Lake through the Gull River and joins the Crow Wing River at the Sylvan Reservoir just upstream of the Crow Wing River outlet to the Mississippi River. Table summarizes the lake's physical characteristics, Figure 67 shows the 2011 aerial photography, and Figure 66 illustrates the available bathymetry.

Table 56. Mayo Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	151	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	94%	Calculated from MN DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	1,141	
Mean depth (feet)	7.6	Lake volume ÷ surface area
Maximum depth (feet)	22	MN DNR Lake Finder
Drainage area (acre)	35,941	MN DNR Catchments
Watershed area: Lake area	238: 1	Calculated

Figure 66. Mayo Lake Bathymetry (MN DNR)



11.5.2 Water Quality

Water quality monitoring data were available for Mayo Lake from 1987-2009. Only data from the most recent 10 years (2002-2011) were used to determine whether Mayo Lake meets water quality standards. The lake does not meet the Northern Lakes and Forest (NLF) lake water quality standard for TP and Chl-*a* and is at the NLF lake water quality standard for Secchi transparency (Table). Growing season mean TP and Chl-a have exceeded the water quality standards in recent years (Figure 68 and Figure 69). Growing season mean Secchi transparency has been variable during the period of record and has not met the water quality standard in most years (Figure 58). There are no apparent long-term trends in TP, Chl-a, or Secchi transparency during the period of record. However, while growing season mean TP and Chl-a did not vary during 2007-2009, growing season mean Secchi transparency improved from less than 1 meter to greater than 2 meters (Figure 70). Growing season water quality trends in 2009 indicated that peak Chl-a and minimum Secchi transparency occurred in twice, at the end of May and during August (Figure 71). Peak TP, peak Chl-*a* and minimum transparency typically occurs in the middle of the growing season due to rapid algal growth from warm water temperatures and high sunlight.

Table 57. 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Mayo Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NLF Lake Standard
Total phosphorus (µg/L)	36	4%	< 30
Chlorophyll-*a* (µg/L)	18	18%	< 9
Secchi transparency (m)	2.0	6%	> 2.0

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean

Figure 67. Aerial photograph of Mayo Lake (Google Earth, June 2010)

Figure 68. Growing Season Means ± SE of Total Phosphorus for Mayo Lake by Year. The dashed line represents the water quality standard for TP (30 µg/L).

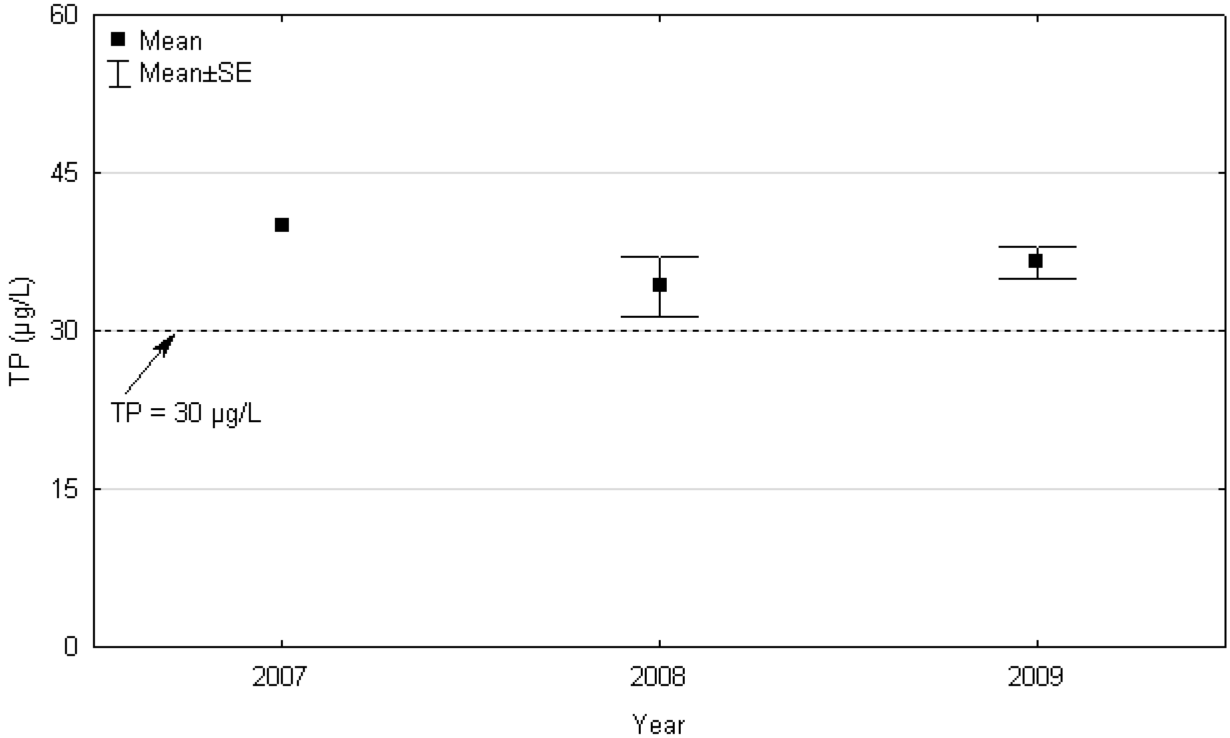


Figure 69. Growing Season Means ± SE of Chlorophyll-*a* for Mayo Lake by Year. The dashed line represents the water quality standard for Chl-*a* (9 µg/L).

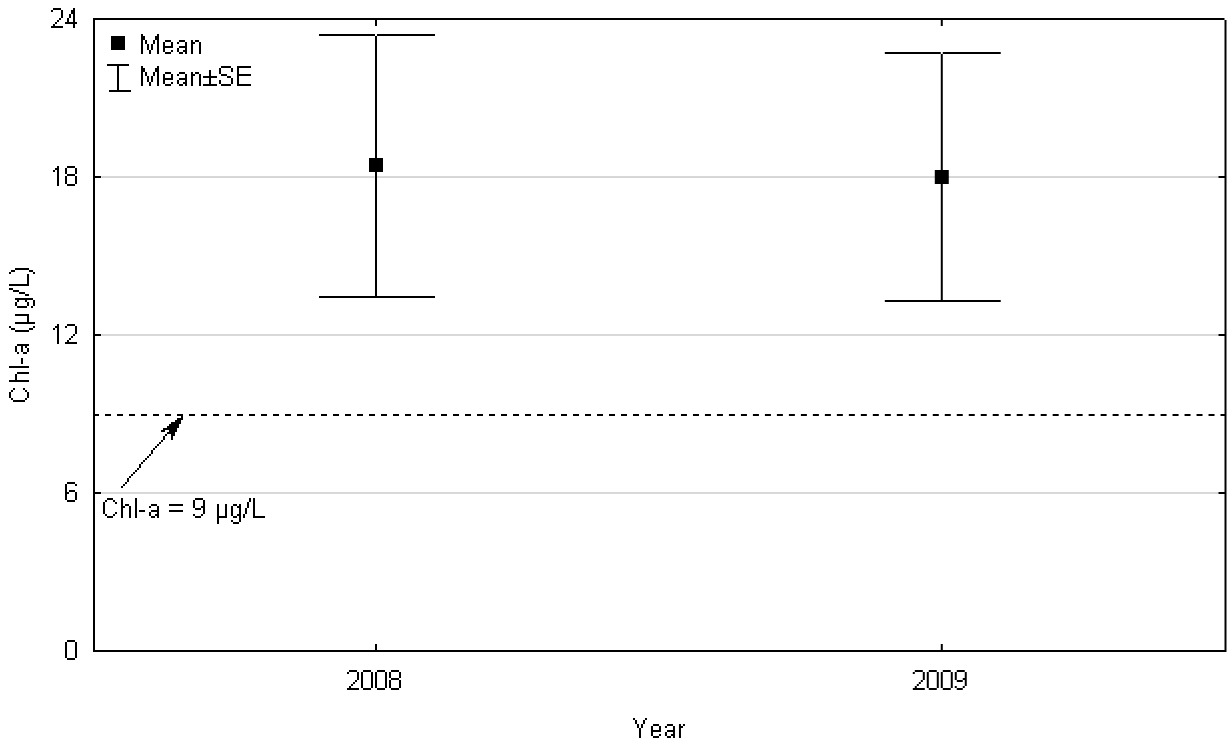


Figure 70. Growing Season Means ± SE of Secchi transparency for Mayo Lake by Year
The dashed line represents the lake water quality standard for transparency (2.0 m).

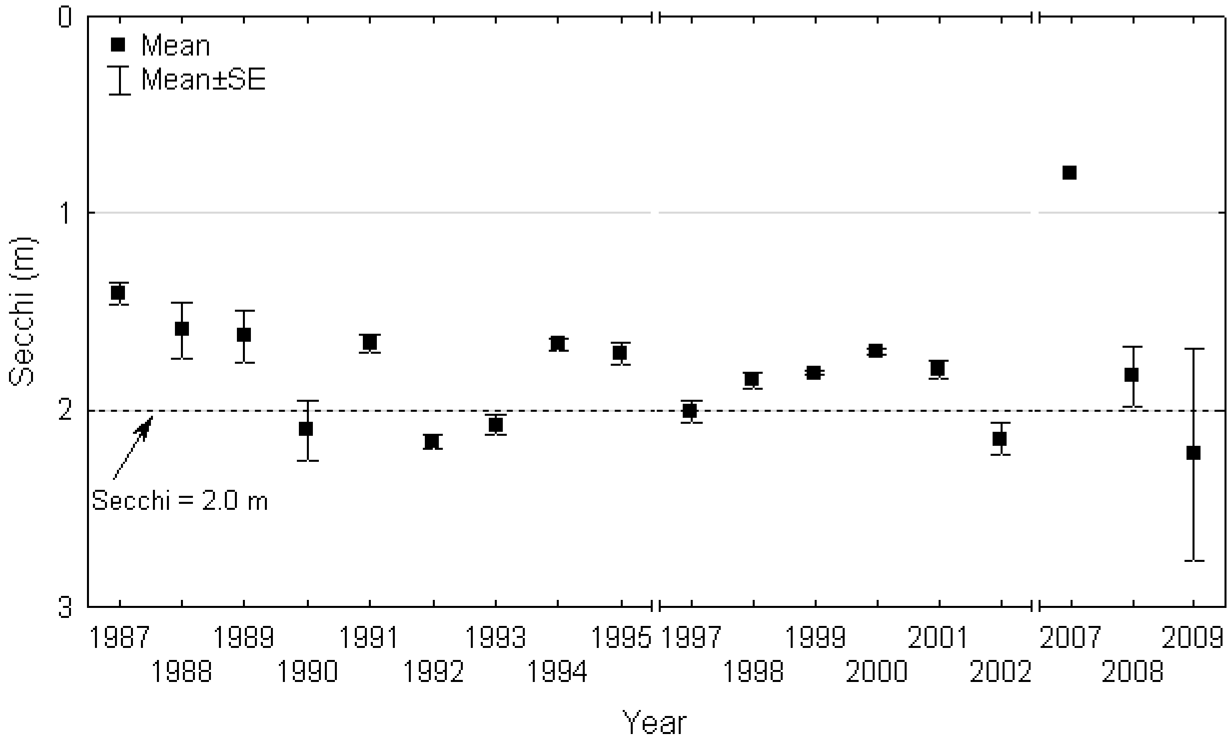
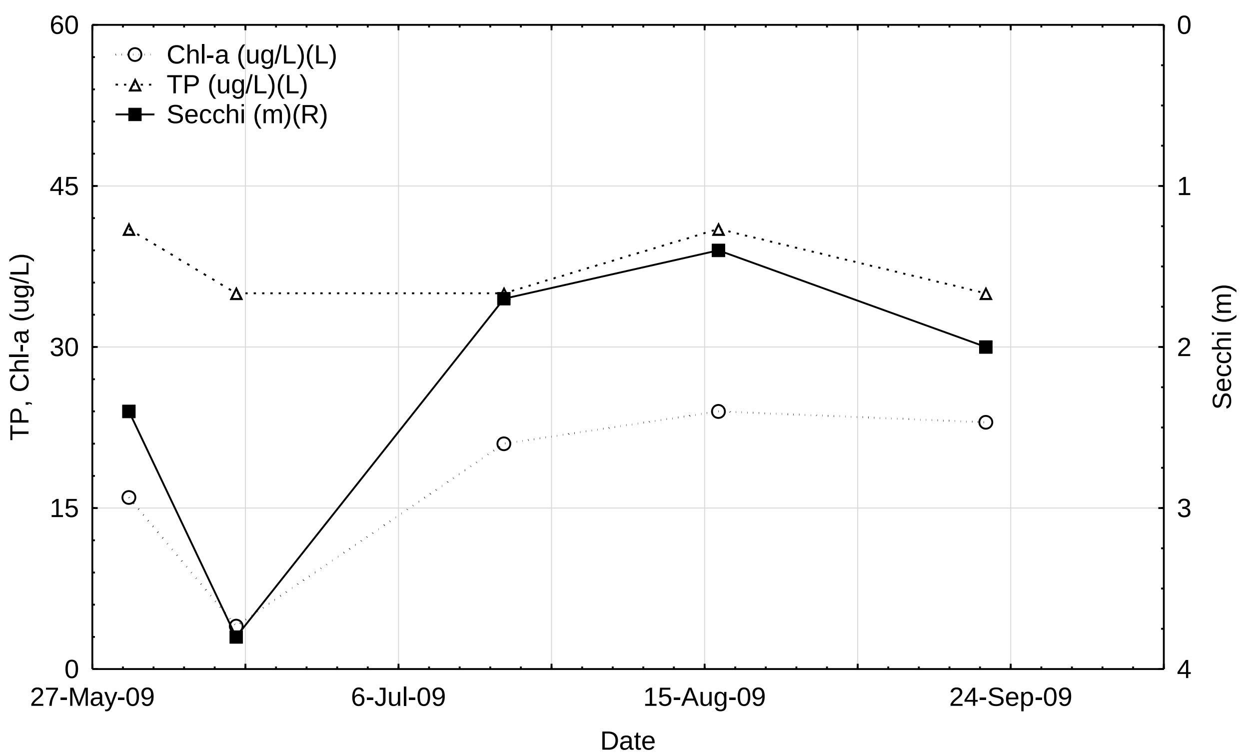


Figure 71. Growing Season Trends of Chl-*a*, TP, and Secchi depth for Mayo Lake, 2009



11.5.3 Macrophytes

The lake's aquatic plant community is moderately diverse with 31 species present in 2003 (MN DNR Lake Finder). Emergent plants such as bulrush and water lilies are common along much of the shoreline (MN DNR Lake Finder); these plants are important for shoreline protection, maintaining water quality, and providing critical habitat for bass and panfish species. There is heavy plant growth at outlet of Mayo Lake.

The non-native curly-leaf pondweed is present in Mayo Lake. Curly-leaf pondweed was present in dense mats up the water surface during a MN DNR Invasives Species Program inspection on June 8, 2010. The heaviest concentrations of curly-leaf pondweed were found in the southern third of the lake. The lake was chemically treated in 2011 and no curly-leaf pondweed was found during a follow-up inspection on June 26, 2012. However, coontail was densely located throughout the lake in depths of 5-11 feet of water. High water levels and dark stained water may have hindered the inspection.

11.5.4 Fish

The most recent MN DNR fish survey was conducted in 2007 (MN DNR Lake Finder). According to this report:

- Northern pike were caught in the highest numbers to date with average length and weight above average.
- Two walleyes were caught in 2007. Only 3 other walleyes have been caught in all previous surveys. The few fish that are present likely migrate upstream via Mayo Creek from Upper Gull Lake.
- The bluegill catch was the highest catch to date, and considered above average when compared to similar lakes.
- Black crappies were present in average numbers.
- No yellow perch were sampled in 2007.

11.6 Portage Lake

Portage Lake is located four miles northwest of Park Rapids, Minnesota. The lake is primarily managed for walleye through supplemental stocking of fry and fingerlings. Secondary species management includes northern pike, black crappie, and bluegill. Portage Lake was reportedly a wild rice marsh before construction of a dam in 1937 raised water levels. Portage Lake has a fair amount of development on the northern and southern shores. U.S. Highway 71 is next to the lake on the eastern shore. Aerial fish house counts have been conducted annually since 1983 to monitor trends in ice fishing pressure. Counts have ranged from 3 to 44 and averaged 22. There were 94 homes/cabins observed during the 2007 assessment (an average of 22.9 homes/cabins per shoreline mile) which is in the 89th percentile of 103 lakes in the Park Rapids area where shoreline development has been recorded. The Portage Lake Association has participated in the Hubbard County Coalition of Lake Associations (COLA) lake water quality monitoring program annually since 1997 and lake water transparency has been recorded through the Citizen Lake Monitoring Program annually since 1986.

In 2007, Portage Lake was included as a Sentinel Lake in the Sustaining Lakes In a Changing Environment (SLICE), long term monitoring project. The SLICE project is designed to use select physical, chemical and biological parameters to detect changes in Minnesota lakes as a result of human activities such as development, agriculture, invasive species or climate change. The first phase of the SLICE project is to monitor a suite of physical, chemical and biological parameters annually, for five years, at a group of 24 "Sentinel" lakes in order to identify the parameters that best predict or describe changes to the lake environment. Those parameters will then be used to expand monitoring on a less frequent basis to a much larger, statewide group of lakes.

Contributor(s): MN DNR 2011 Lake Management Plan
MPCA 2009 Sentinel Lake Assessment Report

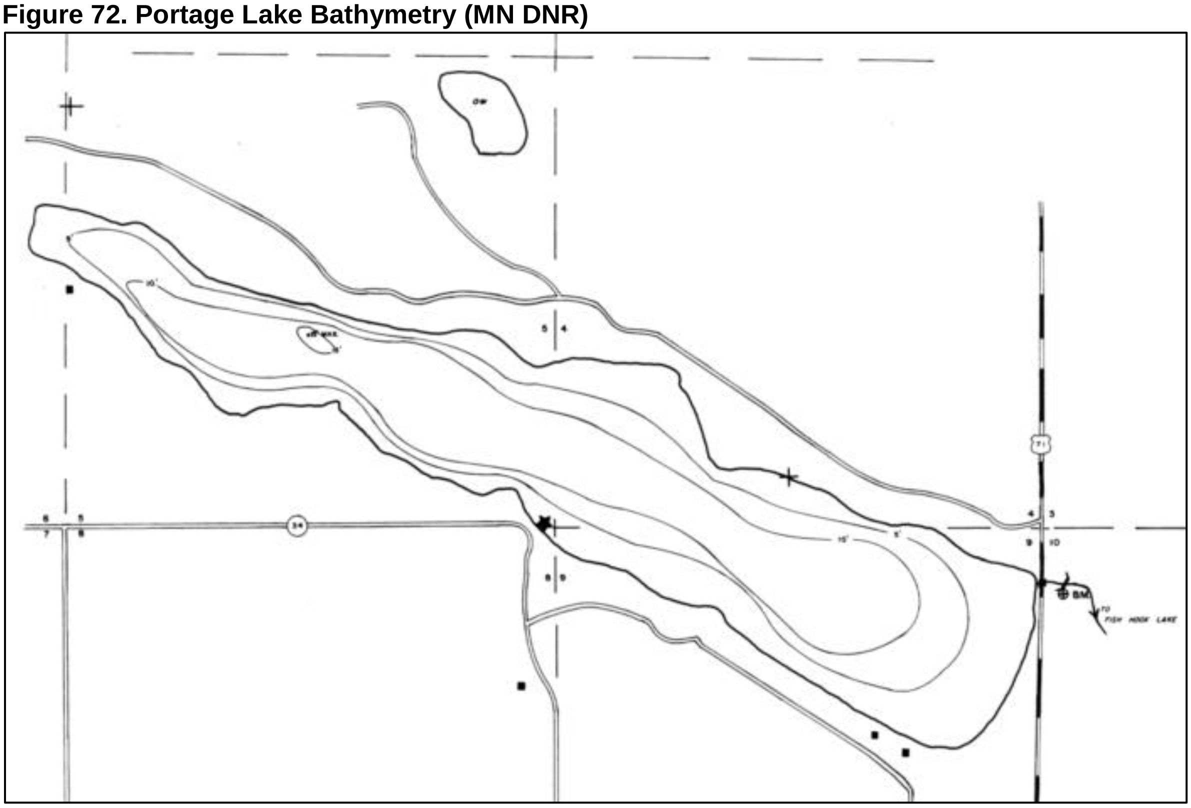
11.6.1 Physical Characteristics

Portage Lake (MN DNR Lake ID 29-0250-00) is located in Hubbard County with roughly half of the watershed located in Becker County (47%) and half located in Hubbard County (53%). The Portage Lake watershed is a small headwater subwatershed located within the eastern portion of the Lower Twin Lake watershed and outlets through a dam via a creek to Fish Hook Lake, then south through the Fish Hook River, east through the Shell River, and then to the Crow Wing River (Perleberg 2006). Table summarizes the lake's physical characteristics, Figure 73 shows the 2011 aerial photography, and Figure 72 illustrates the available bathymetry.

Table 58. Portage Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acres)	417	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	~100%	Calculated from MN DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	3,004	
Mean depth (feet)	7.2	Lake volume ÷ surface area
Maximum depth (feet)	17	MN DNR Lake Finder
Drainage area (acres)	2,996	MN DNR Catchments
Watershed area: Lake area	7: 1	Calculated

Figure 72. Portage Lake Bathymetry (MN DNR)



11.6.2 Water Quality

Water quality monitoring data were available for Portage Lake from 1986-2011. Only data from the most recent 10 years (2002-2011) were used to determine whether Portage Lake meets water quality standards. The lake does not meet the Northern Lakes and Forest (NLF) lake water quality standards for TP, Chl-*a*, or Secchi transparency (Table 72). Growing season mean TP, Chl-a, and Secchi transparency have not met water quality standards during the entire period of record, except TP and Secchi transparency in 2011 (Figure 74, Figure 75, and Figure 76). There are no apparent long-term trends in TP, Chl-a, or Secchi transparency during the period of record. Growing season water quality trends in 2010 indicated that peak Chl-a and minimum Secchi transparency occurred in early August (Figure 77). Peak TP, peak Chl-*a* and minimum transparency typically occurs in the middle of the growing season due to rapid algal growth from warm water temperatures and high sunlight.

Table 72. 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Portage Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NLF Lake Standard
Total phosphorus (µg/L)	51	6%	< 30
Chlorophyll-*a* (µg/L)	22	8%	< 9
Secchi transparency (m)	1.3	3%	> 2.0

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean

Figure 73. Aerial photograph of Portage Lake (Google Earth, September 2011)

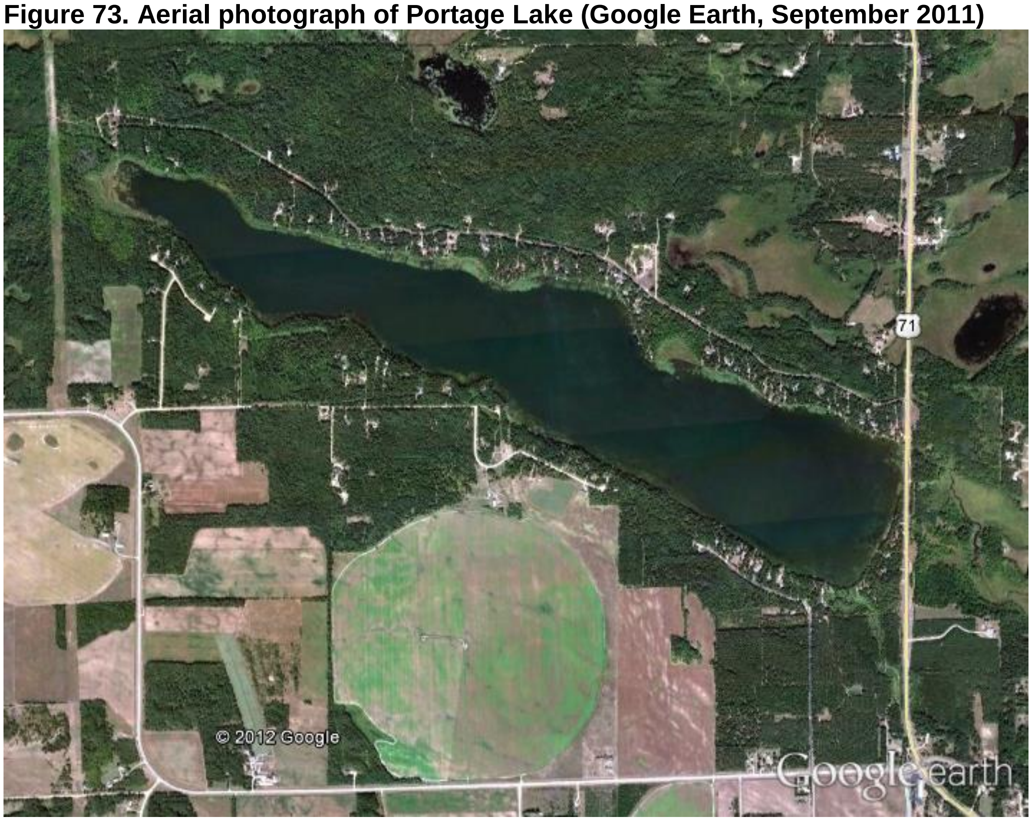


Figure 74. Growing Season Means ± SE of Total Phosphorus for Portage Lake by Year. The dashed line represents the water quality standard for TP (30 µg/L).

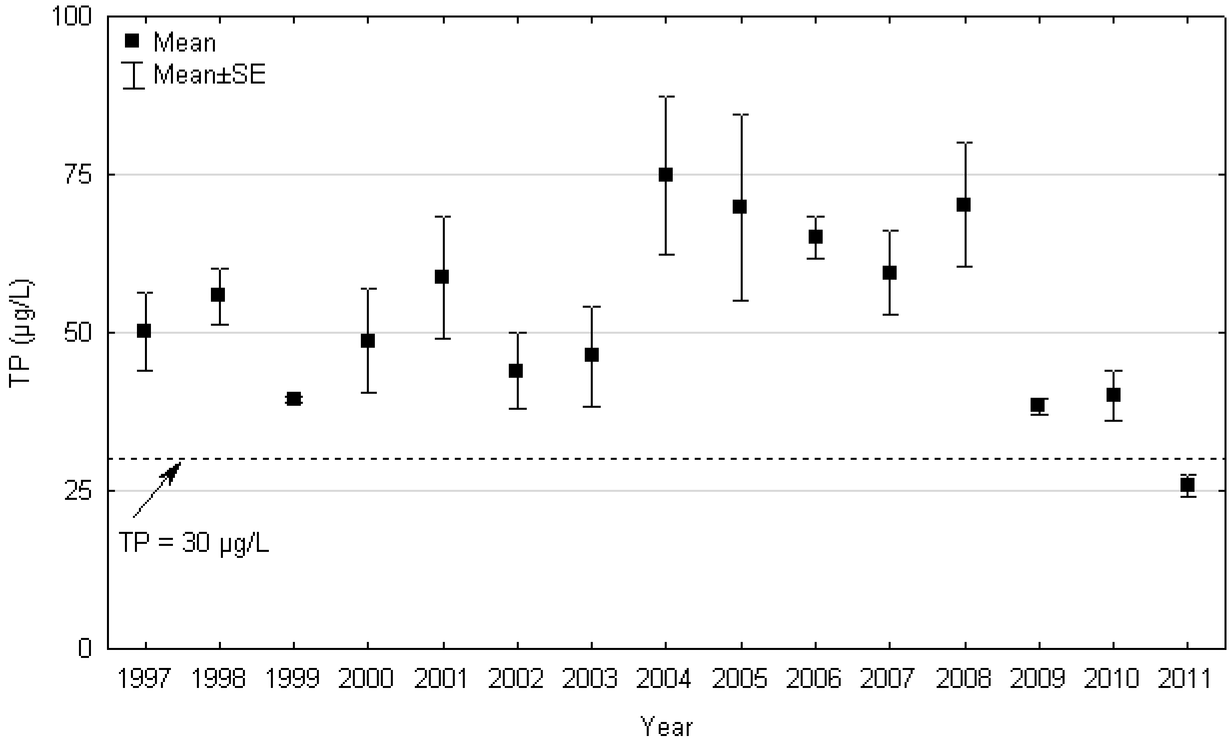


Figure 75. Growing Season Means ± SE of Chlorophyll-*a* for Portage Lake by Year. The dashed line represents the water quality standard for Chl-*a* (9 µg/L).

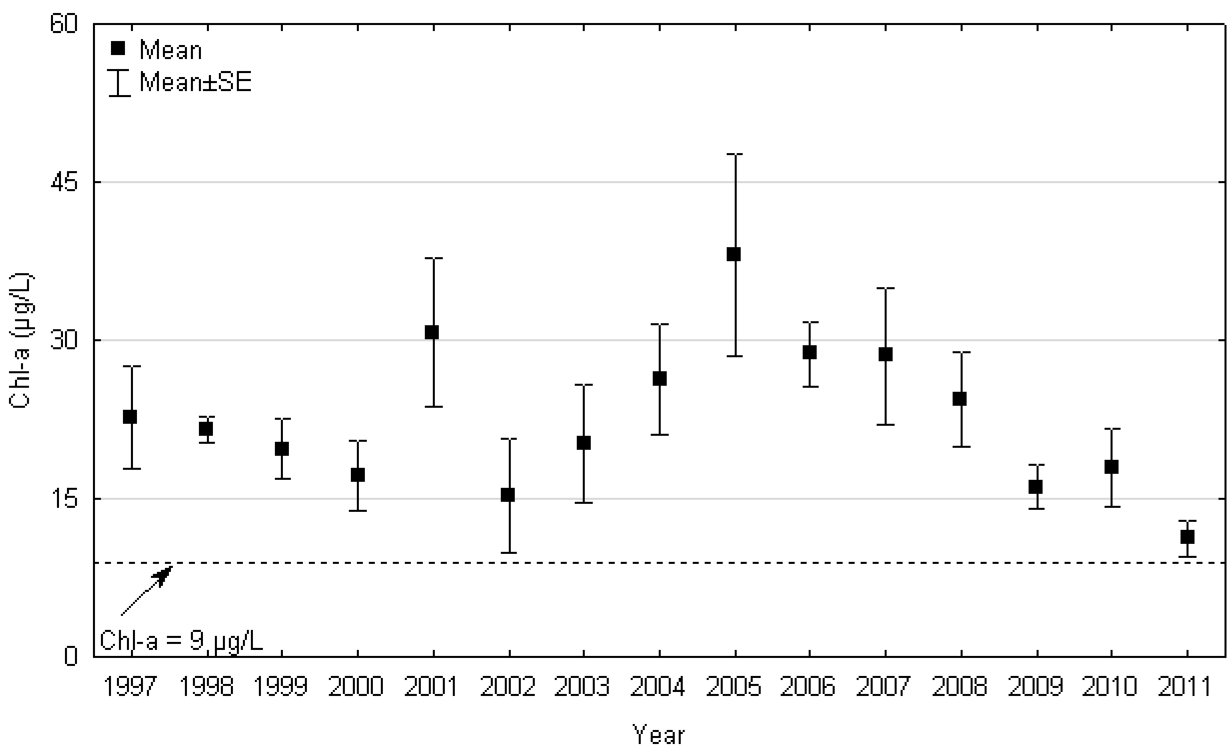


Figure 76. Growing Season Means ± SE of Secchi transparency for Portage Lake by Year The dashed line represents the lake water quality standard for transparency (2.0 m).

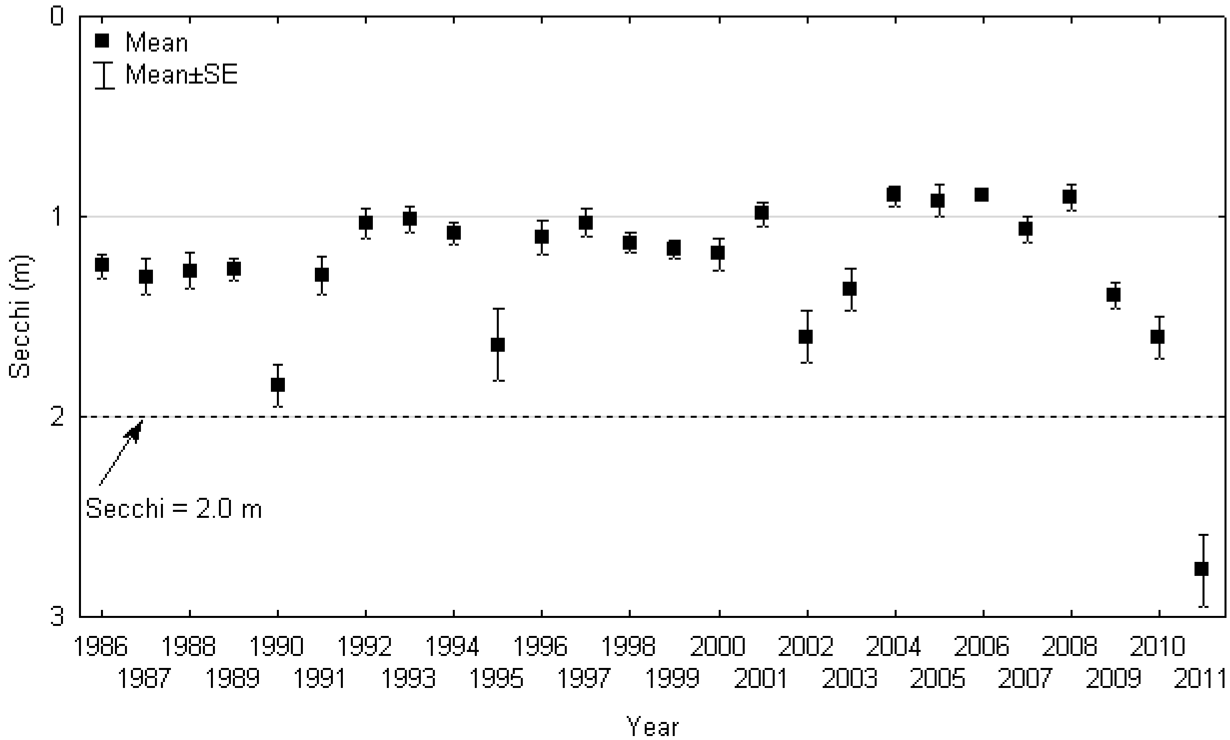
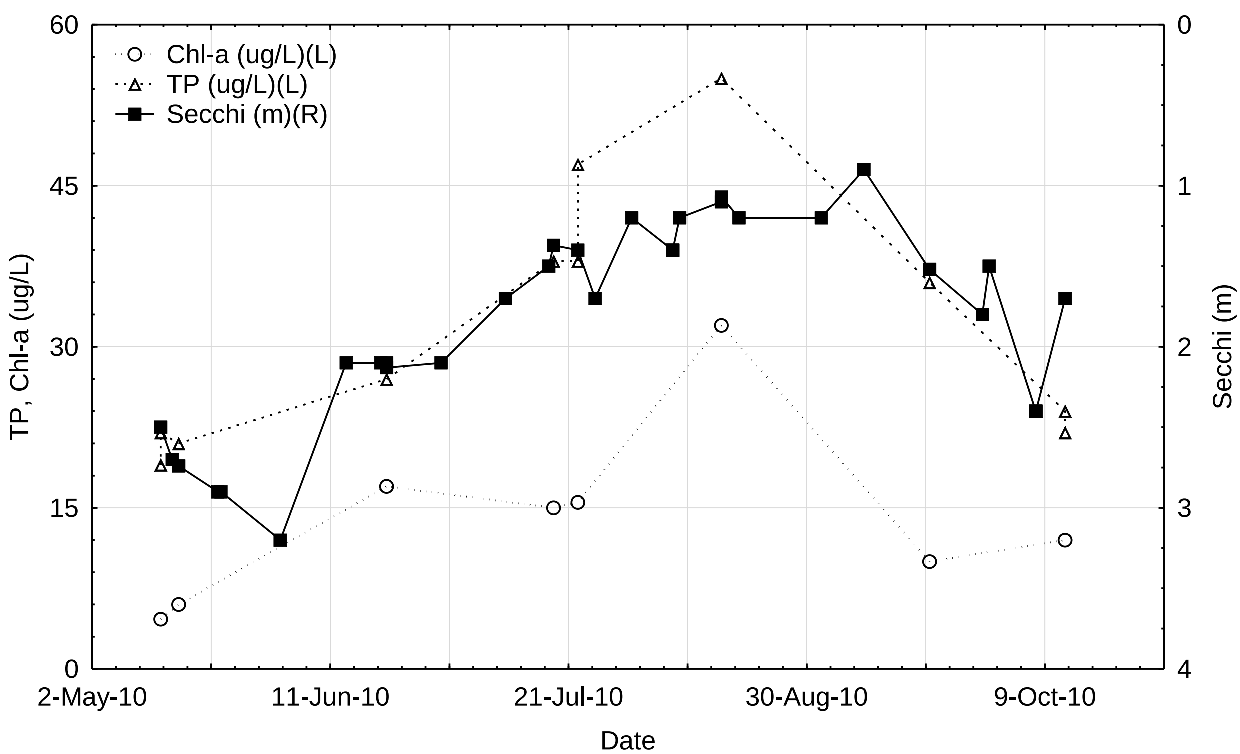


Figure 77. Growing Season Trends of Chl-*a*, TP, and Secchi depth for Portage Lake, 2010



11.6.3 Macrophytes

The invasive submerged aquatic plant, curly-leaf pondweed (Potamogeton crispus) was first observed in Portage Lake in the mid-1990s. By 2002, it had spread to cover nearly 50 acres of the lake. Residents of the lake have elected to control the plant through commercial herbicide applications annually since 2003. Curly-leaf pondweed has increased in cover and abundance in recent years (Figure 78). Muskgrass is also abundant in the lake and appears to be increasing in cover and abundance. Muskgrass is a native bottom-growing plant that promotes clear water. (MPCA and MDNR, 2009)

Vegetation surveys were conducted in August 2004, May 2005, and May 2006 to assess the aquatic plant community of Portage Lake (Perleberg 2006). According to the report, the dominant submerged plant species was coontail (*Ceratophyllum demersum).* Curly-leaf pondweed (*Potamogeton crispus)* was also present, but at low abundance. Other common submerged plant species were muskgrass, Canada waterweed, Bushy pondweed, and other native pondweeds (Figure 78). Common emergent floating-leaf plants included wild rice, bulrush, and yellow waterlily. Non-native pink waterlilies were found at scattered locations around the shoreline.

11.6.4 Fish

Portage Lake infrequently experiences partial winterkills due to low levels of dissolved oxygen in winter. Partial winterkills occurred on Portage in 1985-86, 1988-89 and 1995-96. Those winterkills affect fish abundance and size structure, and appeared to be most detrimental to largemouth bass and bluegill populations. Winter dissolved oxygen levels are closely monitored each year when conditions appear conducive for a fish kill (MN DNR 2011 Lake Management Plan). The size-structure of most game fish populations in the lake is poor. Yellow perch have been particularly low in abundance while black and brown bullheads have increased in abundance in recent years. Several fish species are currently present in Portage Lake that are intolerant to eutrophication: blacknose shiners, banded killifish, and Iowa darter. (MPCA and MDNR, 2009)

The most recent MN DNR fish survey was conducted in 2009 (MN DNR Lake Finder). According to this report:

- Panfish, black crappie, and bluegill abundances are typical for this lake class
- Past surveys have shown a fluctuating northern pike population
- Walleye stocking is maintaining the walleye population with little or sporadic recruitment from natural production
- Yellow perch numbers have been very low since the early 1990’s. Walleye appear to be utilizing other forage species such as bullheads
- The bullhead population is abundance, composed mostly of brown and black bullhead with low numbers of yellow bullhead
- Largemouth bass were present in moderate numbers and above average for this lake class

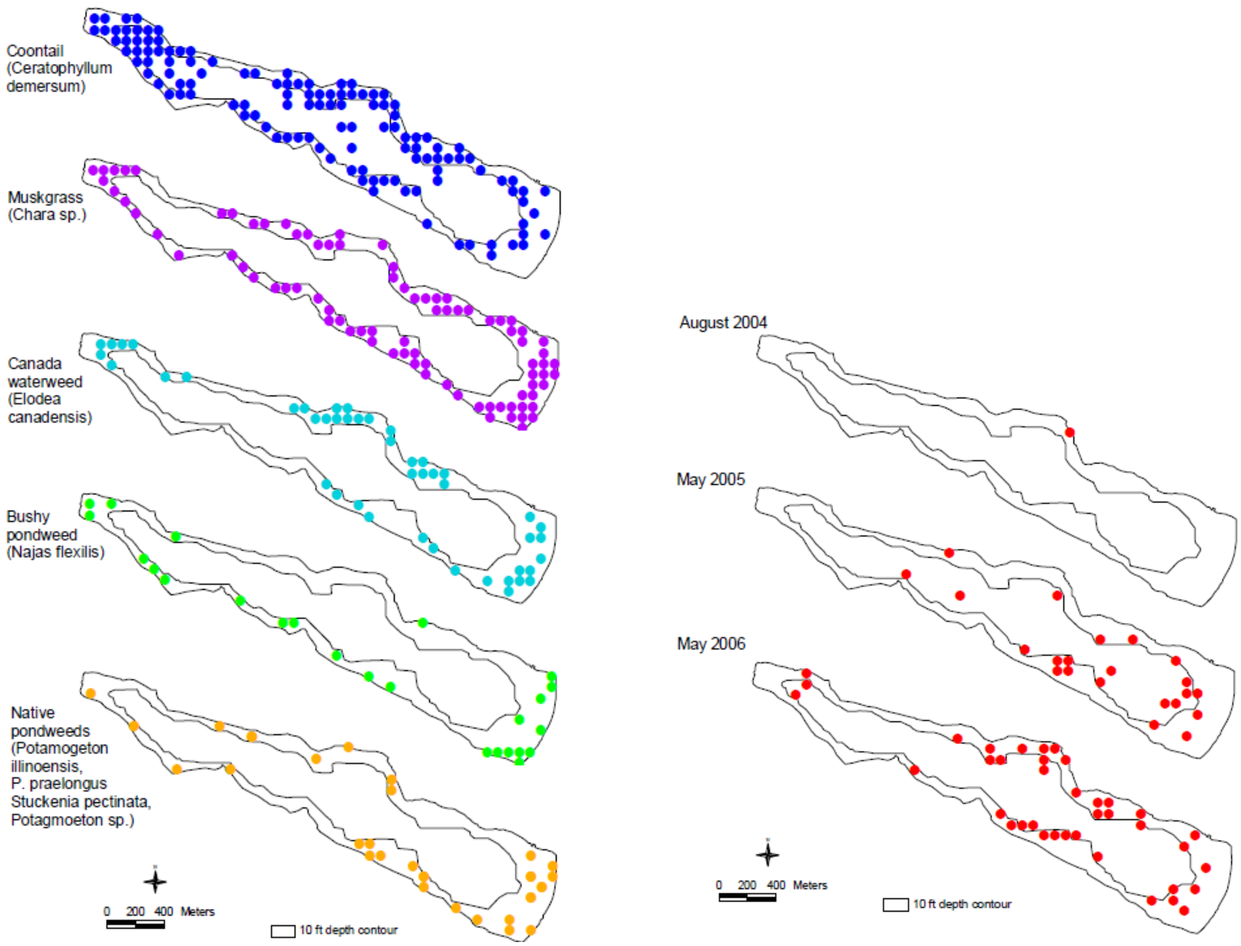


Figure 78. Left: Distribution of common aquatic plant species in Portage Lake, August 10-11, 2004
(From: Figure 10 in Perleberg 2006)
Right: Distribution of curly-leaf pondweed in Portage Lake, Aug 2004, May 2005, May 2006
(From: Figure 13 in Perleberg 2006)

11.7 Sibley Lake

Sibley Lake is located partially within the western municipal boundaries of the City of Pequot Lakes, Minnesota. The greatest development in the Sibley Lake watershed is in the City of Pequot Lakes which borders the east side of Sibley Lake itself. Additional significant development occurs on the upper west side of Sibley Lake and the upper end of Mayo Lake to its south. Sibley Lake lies at the head of the Gull Lake chain. Since 1987, citizen volunteers from Sibley Lake have participated in the MPCA Citizen Lake Monitoring Program recording secchi disc transparency. Radburn & Tina Royer and Dennis R. Meyer have been responsible for these efforts in recent years. In 2008, a Lake Improvement District (LID) was created to provide a more consistent funding mechanism to maintain the quality of the lake and property values, particularly to fight an infestation of curly-leaf pondweed. Lake residents have observed that water levels typically fluctuate ~42 inches per year, and were 16 inches below normal water levels in 2011. In 1997, there were 152 homes/cabins and one resort located along the 8.1 miles of shoreline.

Contributor(s): Sibley Lake Association 2007 Lake Management Plan
MN DNR Lake Management Plan
Melissa Barrick, Crow Wing SWCD

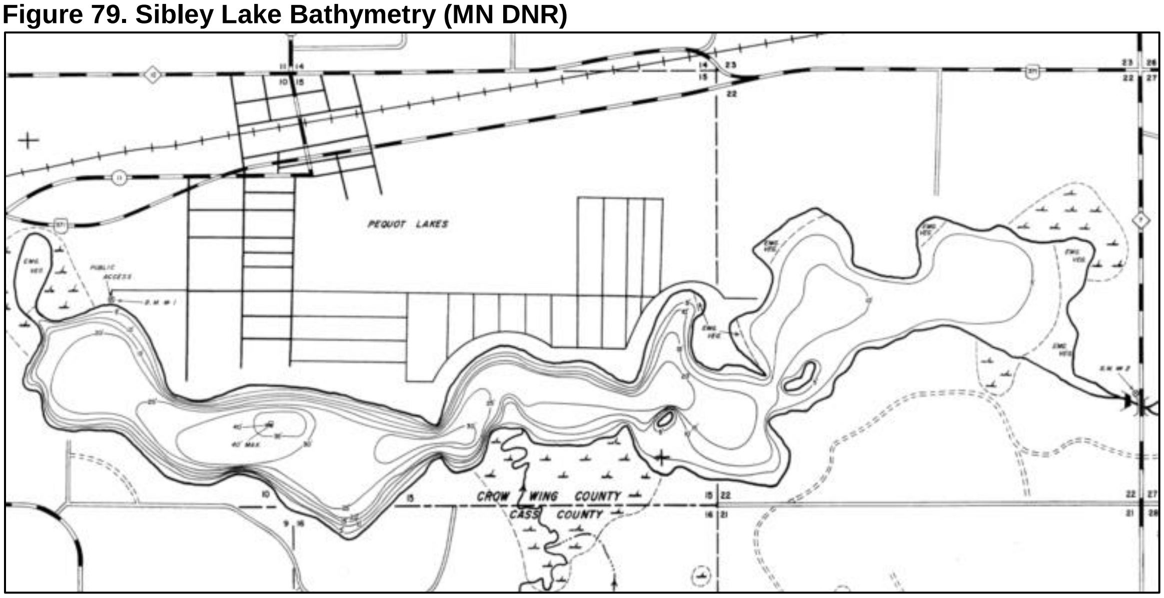
11.7.1 Physical Characteristics

Sibley Lake (MN DNR Lake ID 18-0404-00) is located in Crow Wing County with portions of its watershed located in Cass County (91%) and Crow Wing County (9%). Sibley and Mayo Lakes are located in the south-east portion of the Crow Wing River watershed. Sibley Lake outlets to Mayo Lake, and the Sibley-Mayo Lakes watershed outlets into Upper Gull Lake. Water flows from Gull Lake through the Gull River and joins the Crow Wing River at the Sylvan Reservoir just upstream of the Crow Wing River outlet to the Mississippi River. Table summarizes the lake's physical characteristics, Figure 80 shows the 2011 aerial photography, and Figure 79 illustrates the available bathymetry.

Table 60. Sibley Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acres)	426	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	60%	Calculated from MN DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	5,667	
Mean depth (feet)	13	Lake volume ÷ surface area
Maximum depth (feet)	40	MN DNR Lake Finder
Drainage area (acres)	35,131	MN DNR Catchments
Watershed area: Lake area	82: 1	Calculated

Figure 79. Sibley Lake Bathymetry (MN DNR)



11.7.2 Water Quality

Water quality monitoring data were available for Sibley Lake from 1987-2011. Only data from the most recent 10 years (2002-2011) were used to determine whether Sibley Lake meets water quality standards. The lake does not meet the Northern Lakes and Forest (NLF) lake water quality standards for TP, Chl-*a*, or Secchi transparency (Table). Growing season mean TP, Chl-a, and Secchi transparency have not met water quality standards during the entire period of record, except Secchi transparency in 1989 (Figure 81, Figure 82, and Figure 83). There are no apparent long-term trends in TP during the period of record, but Chl-a appears to be increasing and Secchi transparency decreasing since 2003. Growing season water quality trends in 2010 indicated that peak Chl-a and minimum Secchi transparency occurred twice, once in mid-May and once in mid-August (Figure 84). Peak TP, peak Chl-*a* and minimum transparency typically occurs in the middle of the growing season due to rapid algal growth from warm water temperatures and high sunlight. Dissolved oxygen depth profiles collected in 2004 indicated that Sibley Lake stratifies between 2 and 7 meters during the growing season.

Table 61. 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Sibley Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NLF Lake Standard
Total phosphorus (µg/L)	33	5%	< 30
Chlorophyll-*a* (µg/L)	20	8%	< 9
Secchi transparency (m)	1.5	4%	> 2.0

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean

Figure 80. Aerial photograph of Sibley Lake (Google Earth, June 2010)

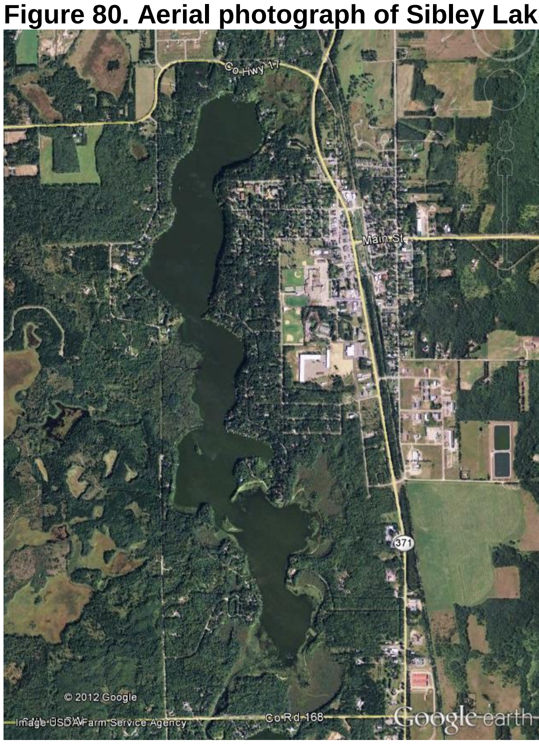


Figure 81. Growing Season Means ± SE of Total Phosphorus for Sibley Lake by Year. The dashed line represents the water quality standard for TP (30 µg/L).

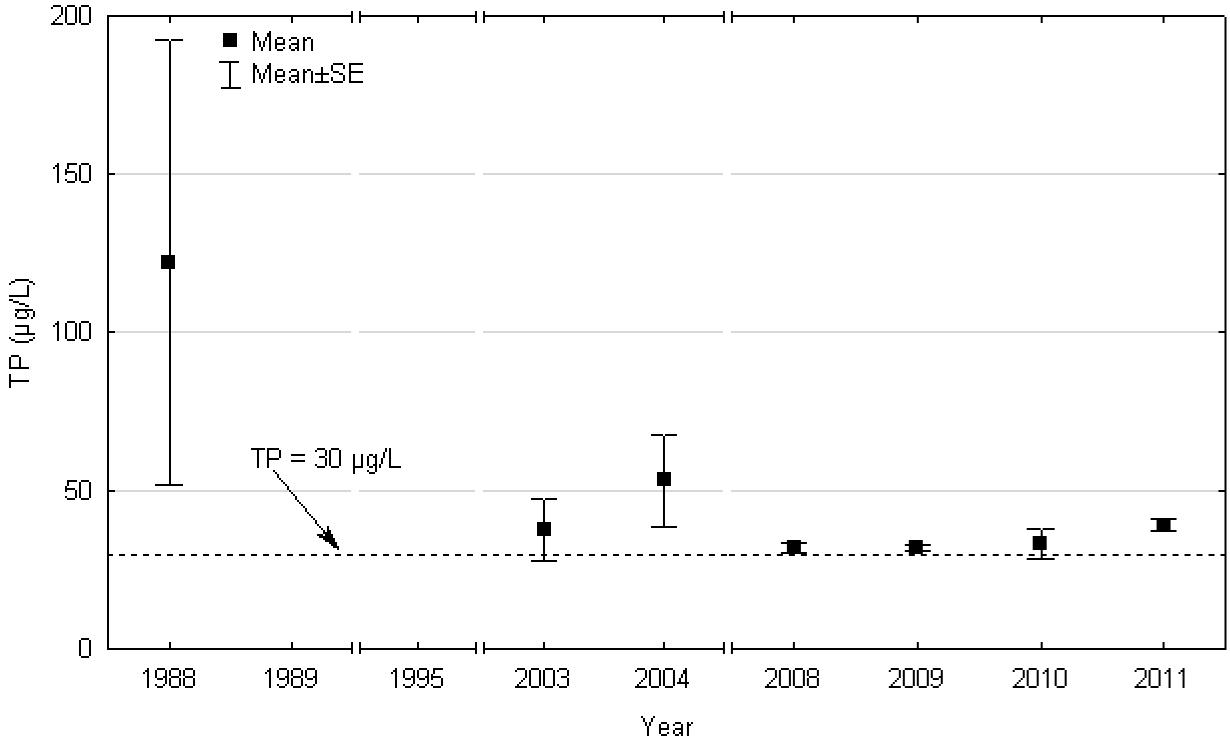


Figure 82. Growing Season Means ± SE of Chlorophyll-*a* for Sibley Lake by Year. The dashed line represents the water quality standard for Chl-*a* (9 µg/L).

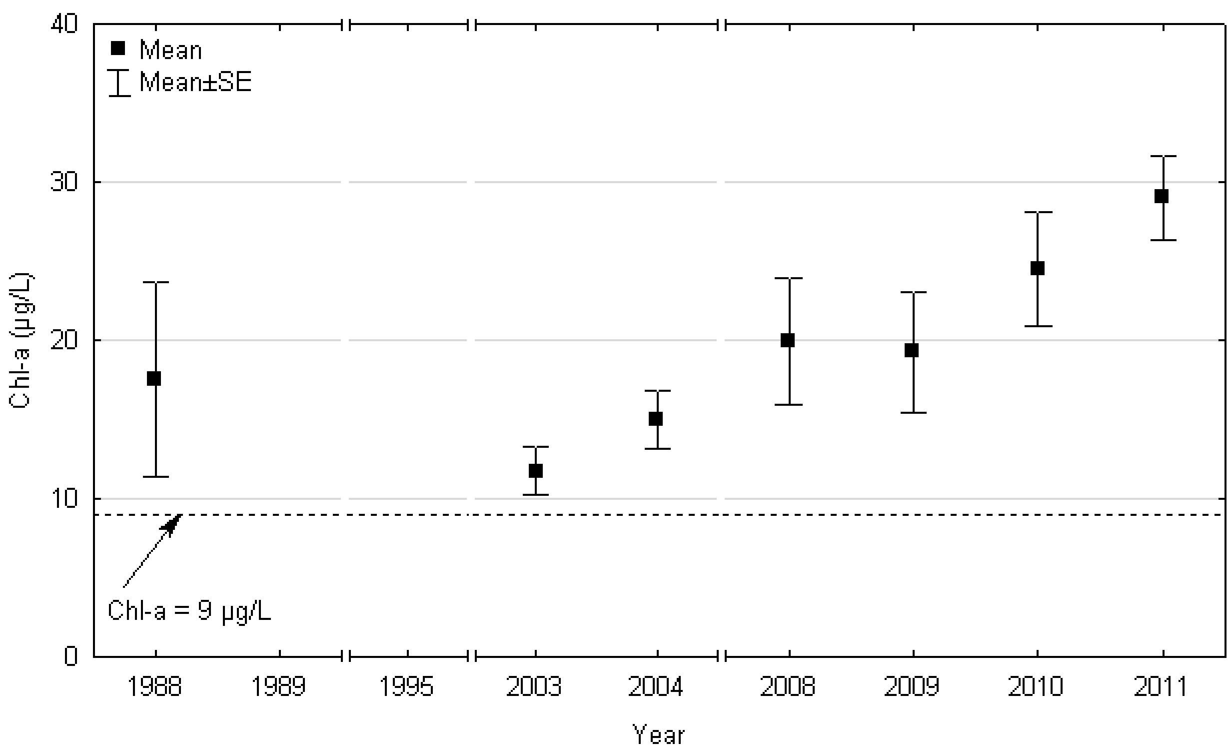


Figure 83. Growing Season Means ± SE of Secchi transparency for Sibley Lake by Year
The dashed line represents the lake water quality standard for transparency (2.0 m).

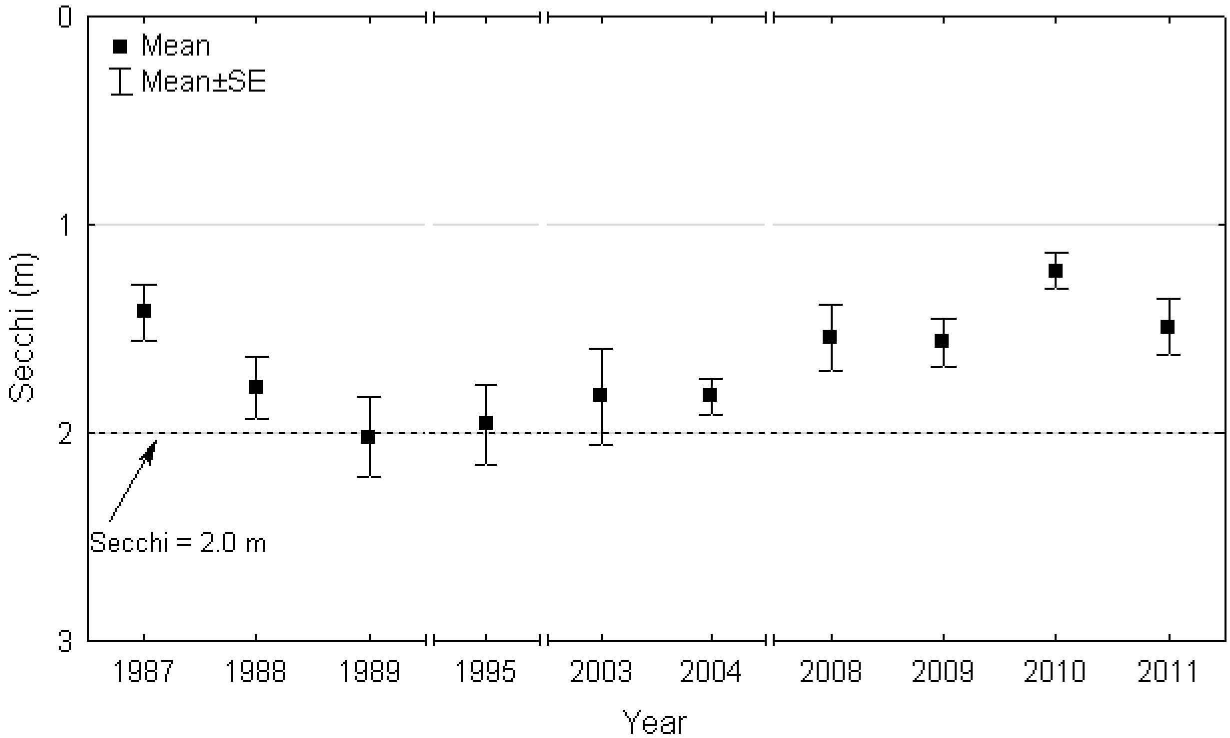


Figure 84. Growing Season Trends of Chl-*a*, TP, and Secchi depth for Sibley Lake, 2010

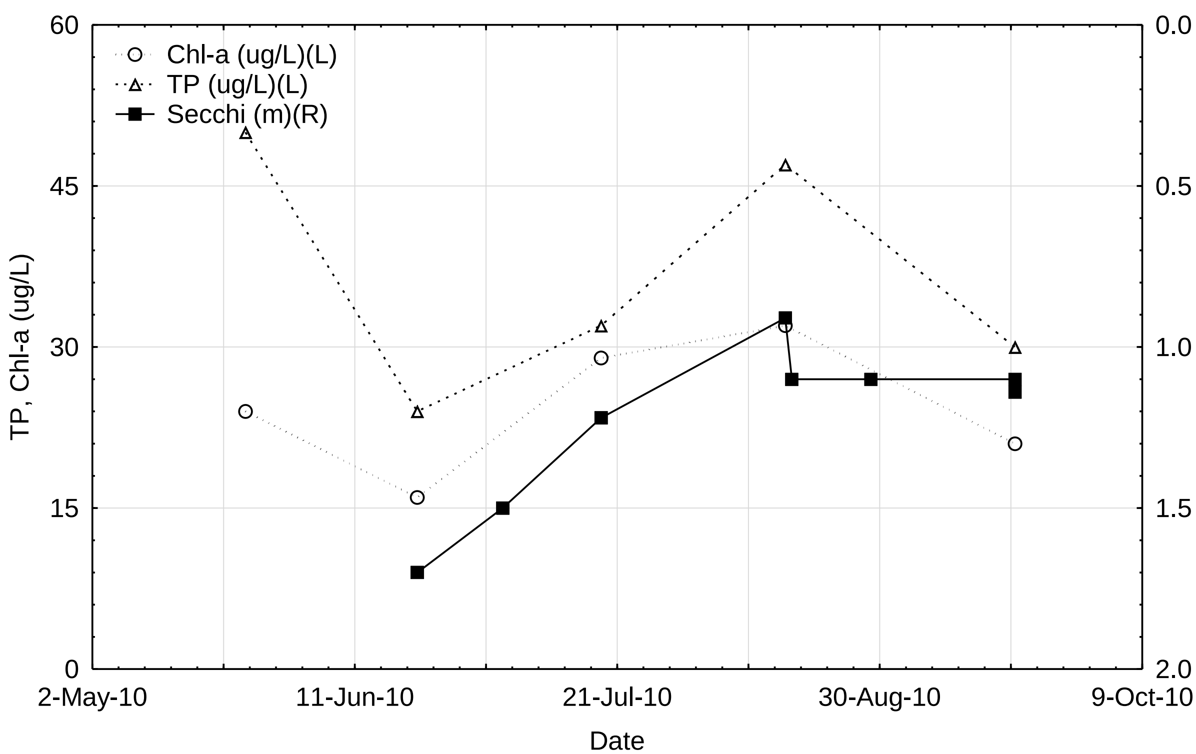


Figure 85. Bottom and surface TP concentrations, Sibley Lake, 2004

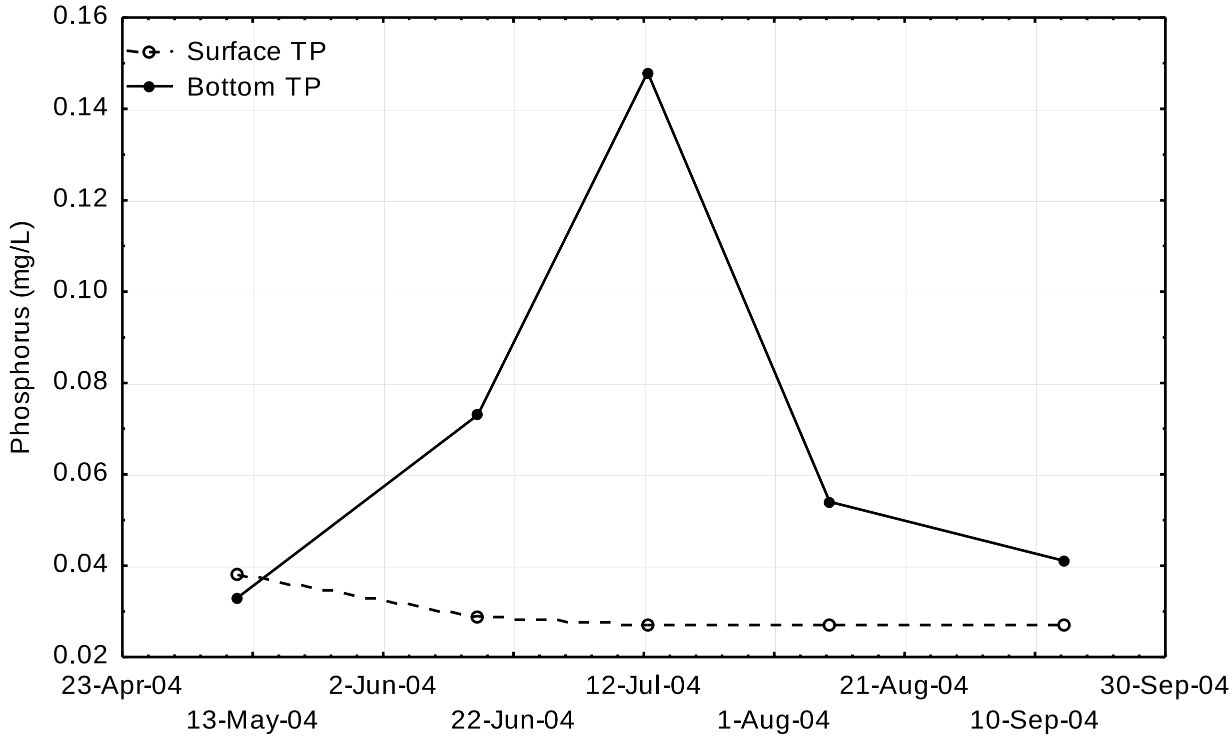


Figure 86. Temperature depth profiles, Sibley Lake, 2004

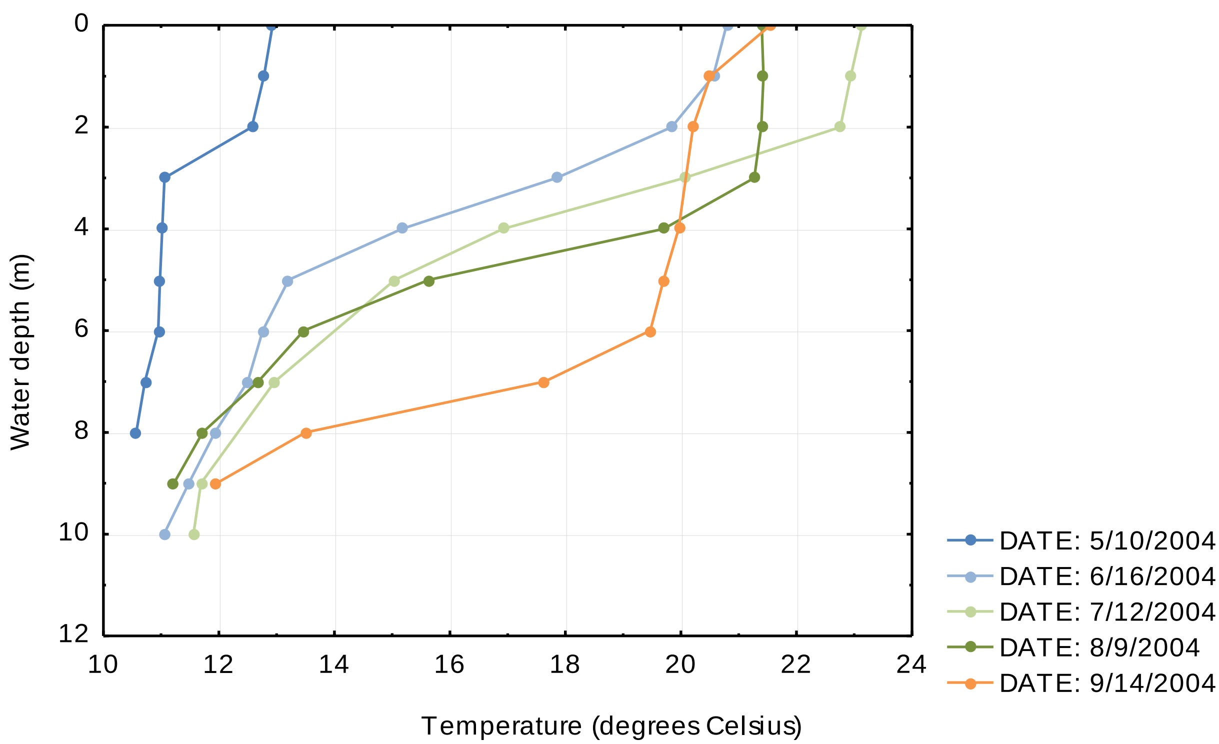


Figure 87. Dissolved oxygen depth profiles, Sibley Lake, 2004

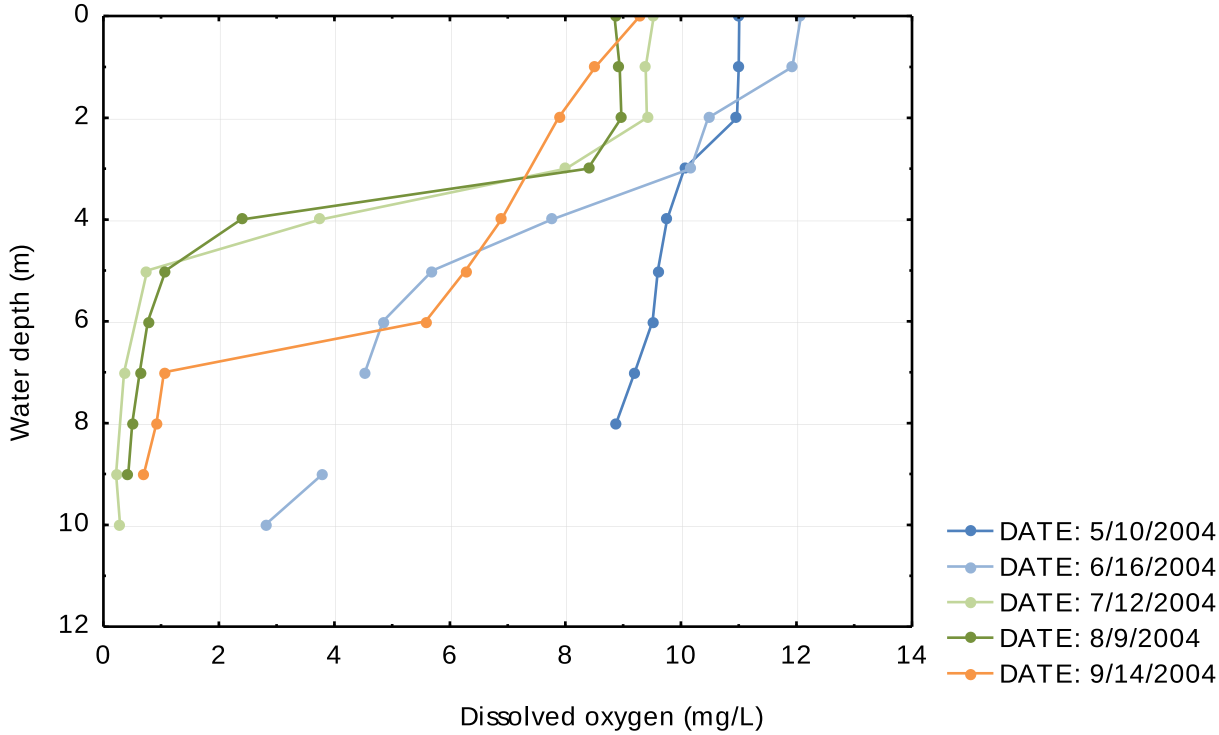


Figure 88. pH depth profiles, Sibley Lake, 2004

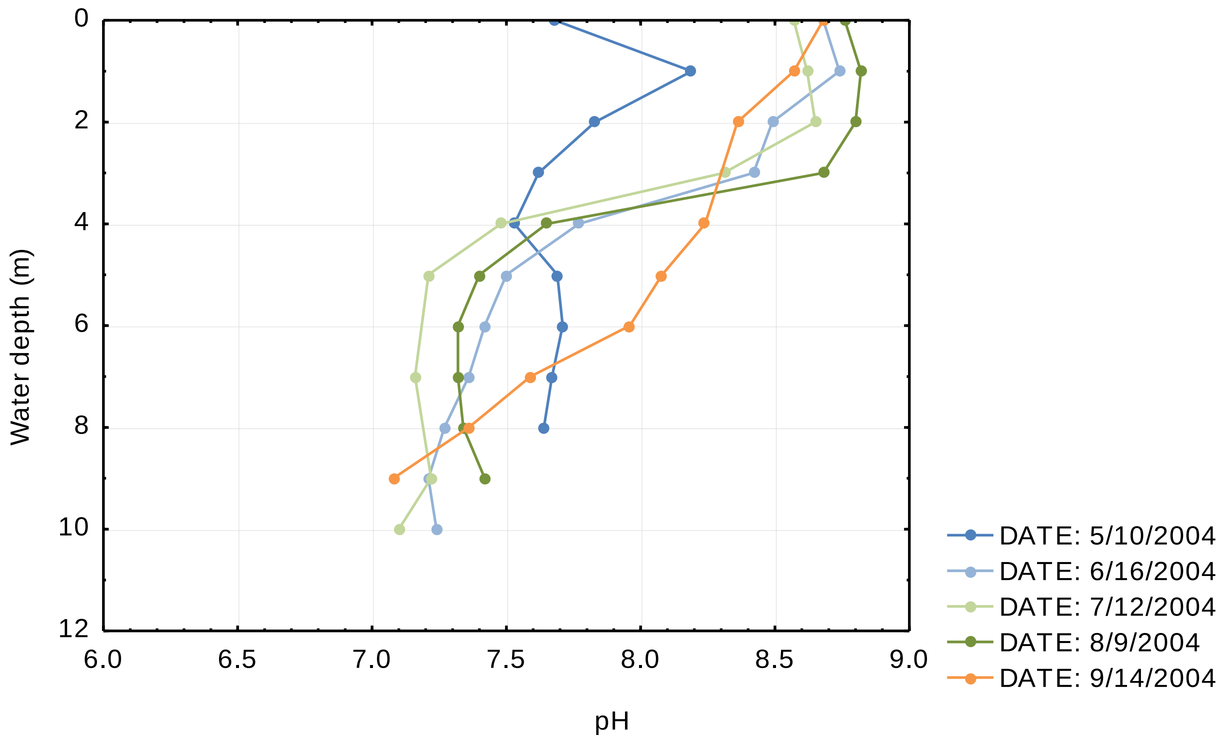
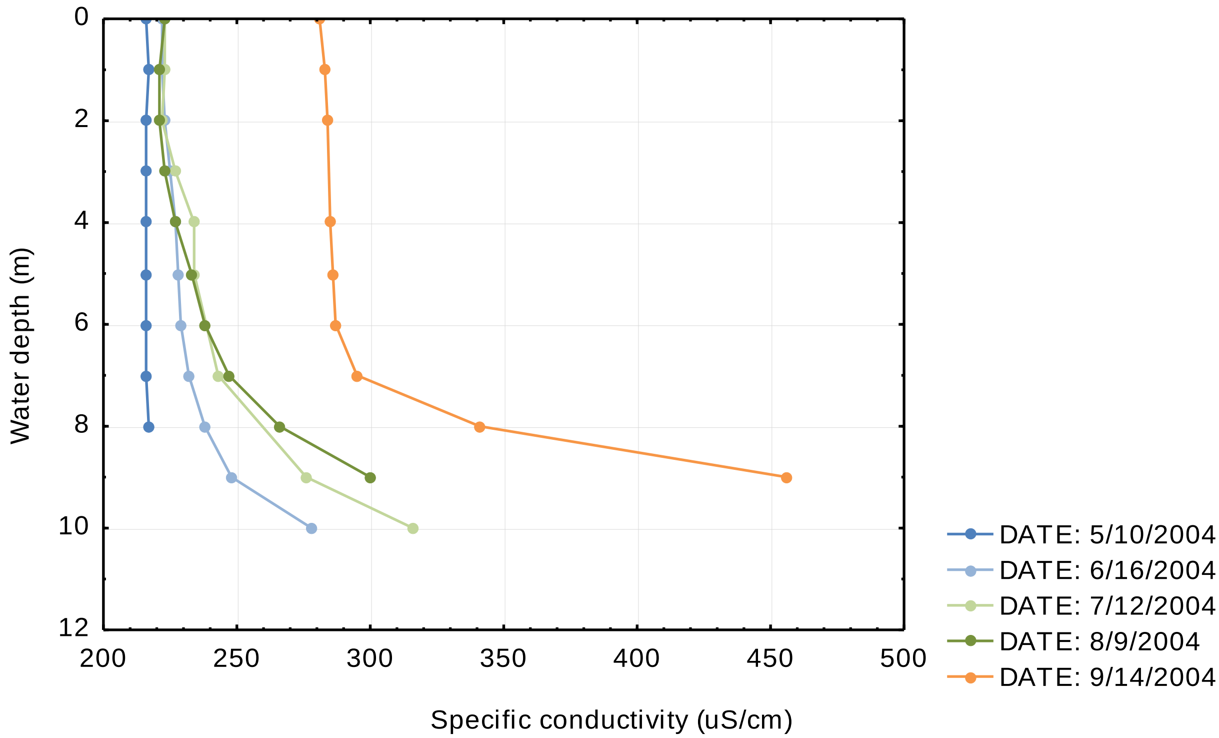


Figure 89. Specific conductivity depth profiles, Sibley Lake, 2004



11.7.3 Macrophytes

The non-native curly-leaf pondweed is present in Sibley Lake. During a MN DNR Invasives Species Program inspection on June 2-3, 2010, the heaviest concentrations of curly-leaf pondweed were found in the very north bay near the public access and the very south bay with nearly all the south bay's littoral zone containing scattered plants and scatter, dense clumps. Approximately 15 and 39 acres of curly-leaf pondweed were chemically treated in 2011 and 2012, respectively. The growth of curly-leaf pondweed in 2012 was greater than normal due to a warm winter and early spring. During a follow-up inspection on June 25, 2012, the heaviest concentrations of curly-leaf pondweed were found along the north-northeast shoreline and the west shoreline south of the boat access. High water levels and low clarity may have hindered the inspection.

11.7.4 Fish

No recent fish surveys have been conducted by the MN DNR in Sibley Lake. The most recent survey is from 1997, outside the period of interest for this TMDL (2002-2011).

12 SIMPLE METHOD SUPPORTING INFORMATION

Table 73. SIMPLE Method Summary for Shell River Tributary

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	98	71.6	4.4
Cultivated Crops	250	10,159	4,173.3	1,287.2
Deciduous Forest	50	29,601	4,719.7	291.2
Developed, High Intensity	200	1	1.6	0.4
Developed, Low Intensity	200	197	117.7	29.0
Developed, Medium Intensity	200	14	14.4	3.6
Developed, Open Space	200	1,999	463.0	114.2
Emergent Herbaceous Wetland	50	5,237	3,582.4	221.0
Evergreen Forest	50	9,932	1,345.4	83.0
Grassland/Herbaceous	50	1,881	234.9	14.5
Mixed Forest	50	4	0.7	0.0
Open Water	50	5,397	7,944.6	490.1
Pasture Hay	100	3,065	736.9	90.9
Shrub/Scrub	50	1,650	243.8	15.0
Woody Wetlands	50	3,445	2,626.6	162.0
Total		**72,681**	**26,277**	**2,807**

Table 74. SIMPLE Method Summary for Blueberry Lake Direct Drainage

Not all of the direct drainage area had sufficient land cover and soil data needed to derive loads

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	-	-	-
Cultivated Crops	250	220	90.6	28.0
Deciduous Forest	50	565	257.0	15.9
Developed, High Intensity	200	-	-	-
Developed, Low Intensity	200	34	45.9	11.3
Developed, Medium Intensity	200	-	-	-
Developed, Open Space	200	68	35.8	8.8
Emergent Herbaceous Wetland	50	56	80.0	4.9
Evergreen Forest	50	338	69.7	4.3
Grassland/Herbaceous	50	76	37.8	2.3
Mixed Forest	50	-	-	-
Open Water	50	13	44.2	2.7
Pasture Hay	100	145	55.0	6.8
Shrub/Scrub	50	137	30.7	1.9
Woody Wetlands	50	131	229.3	14.1
Total		**1,783**	**976**	**101**

Table 75. SIMPLE Method Summary for Blueberry River Tributary

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	36	21.7	1.3
Cultivated Crops	250	5,046	3,296.5	1,016.8
Deciduous Forest	50	23,862	7,586.8	468.0
Developed, High Intensity	200	12	21.0	5.2
Developed, Low Intensity	200	116	87.0	21.5
Developed, Medium Intensity	200	18	23.7	5.8
Developed, Open Space	200	2,284	664.0	163.8
Emergent Herbaceous Wetland	50	3,814	3,359.4	207.2
Evergreen Forest	50	8,129	1,981.9	122.3
Grassland/Herbaceous	50	1,869	546.5	33.7
Mixed Forest	50	4	1.5	0.1
Open Water	50	411	759.3	46.8
Pasture Hay	100	12,754	7,087.4	874.4
Shrub/Scrub	50	1,621	505.9	31.2
Woody Wetlands	50	1,248	1,149.4	70.9
Total		**61,224**	**27,092**	**3,069**

Table 76. SIMPLE Method Summary for Lower Twin Lake Direct Drainage
Not all of the direct drainage area had sufficient land cover and soil data needed to derive loads

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	13	16.8	1.0
Cultivated Crops	250	217	124.9	38.5
Deciduous Forest	50	644	209.3	12.9
Developed, High Intensity	200	-	-	-
Developed, Low Intensity	200	7	13.1	3.2
Developed, Medium Intensity	200	0	0.1	0.0
Developed, Open Space	200	88	68.3	16.8
Emergent Herbaceous Wetland	50	15	16.9	1.0
Evergreen Forest	50	374	115.4	7.1
Grassland/Herbaceous	50	17	5.2	0.3
Mixed Forest	50	-	-	-
Open Water	50	13	66.5	4.1
Pasture Hay	100	80	28.4	3.5
Shrub/Scrub	50	37	10.7	0.7
Woody Wetlands	50	15	17.3	1.1
Total		**1,520**	**693**	**90**

Table 77. SIMPLE Method Summary for Eighth Crow Wing Lake Direct Drainage
Not all of the direct drainage area had sufficient land cover and soil data needed to derive loads

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	-	-	-
Cultivated Crops	250	64	58.2	18.0
Deciduous Forest	50	995	374.1	23.1
Developed, High Intensity	200	-	-	-
Developed, Low Intensity	200	5	11.8	2.9
Developed, Medium Intensity	200	-	-	-
Developed, Open Space	200	82	81.1	20.0
Emergent Herbaceous Wetland	50	6	7.1	0.4
Evergreen Forest	50	179	64.9	4.0
Grassland/Herbaceous	50	46	16.3	1.0
Mixed Forest	50	-	-	-
Open Water	50	7	44.6	2.8
Pasture Hay	100	190	74.1	9.1
Shrub/Scrub	50	22	7.8	0.5
Woody Wetlands	50	-	-	-
Total		**1,597**	**740**	**82**

Table 78. SIMPLE Method Summary for First Crow Wing Lake Direct Drainage
Not all of the direct drainage area had sufficient land cover and soil data needed to derive loads

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	3	3.1	0.2
Cultivated Crops	250	2,703	1,179.2	363.7
Deciduous Forest	50	6,112	2,634.1	162.5
Developed, High Intensity	200	-	-	-
Developed, Low Intensity	200	58	89.4	22.1
Developed, Medium Intensity	200	1	3.0	0.7
Developed, Open Space	200	521	313.1	77.3
Emergent Herbaceous Wetland	50	1,249	2,206.4	136.1
Evergreen Forest	50	5,962	1,416.6	87.4
Grassland/Herbaceous	50	900	228.2	14.1
Mixed Forest	50	2	1.8	0.1
Open Water	50	59	223.5	13.8
Pasture Hay	100	739	180.2	22.2
Shrub/Scrub	50	1,258	383.1	23.6
Woody Wetlands	50	855	1,475.3	91.0
Total		**20,421**	**10,337**	**1,015**

Table 79. SIMPLE Method Summary for Portage Lake Direct Drainage
Not all of the direct drainage area had sufficient land cover and soil data needed to derive loads

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	8	17.1	1.1
Cultivated Crops	250	124	156.6	48.3
Deciduous Forest	50	1,368	391.0	24.1
Developed, High Intensity	200	-	-	-
Developed, Low Intensity	200	18	32.1	7.9
Developed, Medium Intensity	200	4	12.2	3.0
Developed, Open Space	200	91	64.9	16.0
Emergent Herbaceous Wetland	50	13	23.4	1.4
Evergreen Forest	50	362	108.9	6.7
Grassland/Herbaceous	50	73	19.6	1.2
Mixed Forest	50	-	-	-
Open Water	50	15	67.8	4.2
Pasture Hay	100	353	200.1	24.7
Shrub/Scrub	50	108	32.7	2.0
Woody Wetlands	50	22	45.7	2.8
Total		**2,559**	**1,172**	**144**

Table 80. SIMPLE Method Summary for Sibley Lake Direct Drainage
Not all of the direct drainage area had sufficient land cover and soil data needed to derive loads

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	102	145.5	9.0
Cultivated Crops	250	1,152	847.4	261.4
Deciduous Forest	50	11,727	3,884.4	239.6
Developed, High Intensity	200	4	7.9	1.9
Developed, Low Intensity	200	162	150.9	37.2
Developed, Medium Intensity	200	3	4.3	1.1
Developed, Open Space	200	1,043	376.5	92.9
Emergent Herbaceous Wetland	50	1,948	2,113.2	130.4
Evergreen Forest	50	1,099	414.9	25.6
Grassland/Herbaceous	50	995	355.0	21.9
Mixed Forest	50	7	3.0	0.2
Open Water	50	601	1,379.5	85.1
Pasture Hay	100	8,248	5,198.2	641.3
Shrub/Scrub	50	2,298	786.2	48.5
Woody Wetlands	50	5,288	4,891.5	301.7
Total		**34,676**	**20,558**	**1,898**

Table 81. SIMPLE Method Summary for Mayo Lake Direct Drainage
Not all of the direct drainage area had sufficient land cover and soil data needed to derive loads

NLCD 2006 Description	TP EMC (µg/L)	Area (ac)	Flow (ac-ft)	TP (kg/yr)
Barren Land	50	-	-	-
Cultivated Crops	250	9	1.7	0.5
Deciduous Forest	50	389	45.1	2.8
Developed, High Intensity	200	-	-	-
Developed, Low Intensity	200	0	0.0	0.0
Developed, Medium Intensity	200	-	-	-
Developed, Open Space	200	19	5.7	1.4
Emergent Herbaceous Wetland	50	28	27.4	1.7
Evergreen Forest	50	4	0.5	0.0
Grassland/Herbaceous	50	20	2.2	0.1
Mixed Forest	50	-	-	-
Open Water	50	4	8.0	0.5
Pasture Hay	100	29	3.1	0.4
Shrub/Scrub	50	29	3.7	0.2
Woody Wetlands	50	100	79.3	4.9
Total		**630**	**177**	**13**

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Table 82. Blueberry Lake Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Blueberry Lake**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	92.6	0.16	76.8%	92.6	0.08	76.8%

Table 83. Blueberry Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct drainage	7.2763	1.2	1.42E-02	0.10	0.16
2	1	1	Shell River	294.3283	32.1	1.03E+01	0.10	0.11
3	1	1	Blueberry River	247.9553	33.1	1.10E+01	0.10	0.13
PRECIPITATION				2.2	1.4	2.02E-02	0.10	0.66
TRIBUTARY INFLOW				549.6	66.5	2.13E+01	0.07	0.12
***TOTAL INFLOW				551.7	67.9	2.13E+01	0.07	0.12
ADVECTIVE OUTFLOW				551.7	66.5	2.14E+01	0.07	0.12
***TOTAL OUTFLOW				551.7	66.5	2.14E+01	0.07	0.12
***EVAPORATION					1.4	2.02E-02	0.10	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations
Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct drainage	116.9	1.4%	9.92E+02	0.1%	0.27	98.0	16.1
2	1	1	Shell River	2812.9	34.1%	5.74E+05	45.5%	0.27	87.5	9.6
3	1	1	Blueberry River	3075.8	37.2%	6.86E+05	54.4%	0.27	92.8	12.4
PRECIPITATION				58.0	0.7%	8.40E+02	0.1%	0.50	40.8	26.9
INTERNAL LOAD				2196.1	26.6%	0.00E+00		0.00		
TRIBUTARY INFLOW				6005.7	72.7%	1.26E+06	99.9%	0.19	90.4	10.9
***TOTAL INFLOW				8259.8	100.0%	1.26E+06	100.0%	0.14	121.7	15.0
ADVECTIVE OUTFLOW				6154.8	74.5%	1.11E+06		0.17	92.6	11.2
***TOTAL OUTFLOW				6154.8	74.5%	1.11E+06		0.17	92.6	11.2
***RETENTION				2105.0	25.5%	6.19E+05		0.37		

Overflow Rate (m/yr)	30.8	Nutrient Resid. Time (yrs)	0.0503
Hydraulic Resid. Time (yrs)	0.0674	Turnover Ratio	19.9
Reservoir Conc (mg/m3)	92.6	Retention Coef.	0.255

Table 84. Blueberry Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment:	**1**	**Blueberry Lake**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	60.0	0.18	59.9%	92.6	0.08	76.8%

Table 85. Blueberry Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct drainage	7.2763	1.2	1.42E-02	0.10	0.16
2	1	1	Shell River	294.3283	32.1	1.03E+01	0.10	0.11
3	1	1	Blueberry River	247.9553	33.1	1.10E+01	0.10	0.13
PRECIPITATION				2.1551	1.4	2.02E-02	0.10	0.66
TRIBUTARY INFLOW				549.6	66.5	2.13E+01	0.07	0.12
***TOTAL INFLOW				551.7	67.9	2.13E+01	0.07	0.12
ADVECTIVE OUTFLOW				551.7	66.5	2.14E+01	0.07	0.12
***TOTAL OUTFLOW				551.7	66.5	2.14E+01	0.07	0.12
***EVAPORATION					1.4	2.02E-02	0.10	

Overall Mass Balance Based Upon Predicted TOTAL P Component: — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct drainage	95.6	1.9%	6.62E+02	0.1%	0.27	80.1	13.1
2	1	1	Shell River	2222.9	43.8%	3.58E+05	42.7%	0.27	69.2	7.6
3	1	1	Blueberry River	2569.8	50.6%	4.79E+05	57.1%	0.27	77.6	10.4
PRECIPITATION				58.0	1.1%	8.40E+02	0.1%	0.50	40.8	26.9
INTERNAL LOAD				133.8	2.6%	0.00E+00		0.00		
TRIBUTARY INFLOW				4888.3	96.2%	8.38E+05	99.9%	0.19	73.5	8.9
***TOTAL INFLOW				5080.1	100.0%	8.39E+05	100.0%	0.18	74.8	9.2
ADVECTIVE OUTFLOW				3988.3	78.5%	5.99E+05		0.19	60.0	7.2
***TOTAL OUTFLOW				3988.3	78.5%	5.99E+05		0.19	60.0	7.2
***RETENTION				1091.8	21.5%	2.10E+05		0.42		

Overflow Rate (m/yr)	30.8	Nutrient Resid. Time (yrs)	0.0529
Hydraulic Resid. Time (yrs)	0.0674	Turnover Ratio	18.9
Reservoir Conc (mg/m3)	60.0	Retention Coef.	0.215

Table 86. Eighth Crow Wing Lake Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Eighth Crow Wing Lake				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	29.2	0.24	29.1%	29.2	0.08	29.1%

Table 87. Eighth Crow Wing Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct drainage	6.5033	0.9050	8.19E-03	0.10	0.14
2	1	1	Ninth Crow Wing Lake	93.0212	10.1155	1.02E+00	0.10	0.11
PRECIPITATION				1.9959	1.3173	1.74E-02	0.10	0.66
TRIBUTARY INFLOW				99.5245	11.0205	1.03E+00	0.09	0.11
***TOTAL INFLOW				101.5204	12.3378	1.05E+00	0.08	0.12
ADVECTIVE OUTFLOW				101.5204	11.0205	1.07E+00	0.09	0.11
***TOTAL OUTFLOW				101.5204	11.0205	1.07E+00	0.09	0.11
***EVAPORATION					1.3173	1.74E-02	0.10	

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

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct drainage	124.4	18.7%	1.12E+03	43.5%	0.27	137.4	19.1
2	1	1	Ninth Crow Wing Lake	192.2	28.9%	7.39E+02	28.6%	0.14	19.0	2.1
PRECIPITATION				53.7	8.1%	7.21E+02	27.9%	0.50	40.8	26.9
INTERNAL LOAD				295.2	44.4%	0.00E+00		0.00		
TRIBUTARY INFLOW				316.6	47.6%	1.86E+03	72.1%	0.14	28.7	3.2
***TOTAL INFLOW				665.5	100.0%	2.58E+03	100.0%	0.08	53.9	6.6
ADVECTIVE OUTFLOW				322.0	48.4%	6.24E+03		0.25	29.2	3.2
***TOTAL OUTFLOW				322.0	48.4%	6.24E+03		0.25	29.2	3.2
***RETENTION				343.5	51.6%	6.30E+03		0.23		

Overflow Rate (m/yr)	5.5	Nutrient Resid. Time (yrs)	0.4898
Hydraulic Resid. Time (yrs)	1.0124	Turnover Ratio	2.0
Reservoir Conc (mg/m3)	29.2	Retention Coef.	0.516

Table 88. Eighth Crow Wing Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Eighth Crow Wing Lake

Variable		Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P	MG/M3	27.0	0.23	26.1%	29.2	0.08	29.1%

Table 89. Eighth Crow Wing Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Direct drainage	6.5033	0.9050	8.19E-03	0.10	0.14
2	1	1	Ninth Crow Wing Lake	93.0212	10.1155	1.02E+00	0.10	0.11
PRECIPITATION				1.9959	1.3173	1.74E-02	0.10	0.66
TRIBUTARY INFLOW				99.5245	11.0205	1.03E+00	0.09	0.11
***TOTAL INFLOW				101.5204	12.3378	1.05E+00	0.08	0.12
ADVECTIVE OUTFLOW				101.5204	11.0205	1.07E+00	0.09	0.11
***TOTAL OUTFLOW				101.5204	11.0205	1.07E+00	0.09	0.11
***EVAPORATION					1.3173	1.74E-02	0.10	

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

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Direct drainage	57.8	9.7%	2.42E+02	14.2%	0.27	63.9	8.9
2	1	1	Ninth Crow Wing Lake	192.2	32.1%	7.39E+02	43.4%	0.14	19.0	2.1
PRECIPITATION				53.7	9.0%	7.21E+02	42.3%	0.50	40.8	26.9
INTERNAL LOAD				295.2	49.3%	0.00E+00		0.00		
TRIBUTARY INFLOW				250.0	41.7%	9.81E+02	57.7%	0.13	22.7	2.5
***TOTAL INFLOW				599.0	100.0%	1.70E+03	100.0%	0.07	48.5	5.9
ADVECTIVE OUTFLOW				297.0	49.6%	5.05E+03		0.24	27.0	2.9
***TOTAL OUTFLOW				297.0	49.6%	5.05E+03		0.24	27.0	2.9
***RETENTION				301.9	50.4%	4.92E+03		0.23		

Overflow Rate (m/yr)	5.5	Nutrient Resid. Time (yrs)	0.5020
Hydraulic Resid. Time (yrs)	1.0124	Turnover Ratio	2.0
Reservoir Conc (mg/m3)	27.0	Retention Coef.	0.504

Table 90. First Crow Wing Lake Calibrated Model Predicted & Observed Values

Segment:		1 First Crow Wing Lake				
		Predicted Values--->			Observed Values--->	
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	59.5	0.10	59.5%	59.5	0.08	59.5%

Table 91. First Crow Wing Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct drainage	86.7324	12.6422	1.60E+00	0.10	0.15
2	1	1	Second Crow Wing Lake	584.8364	64.7323	4.19E+01	0.10	0.11
PRECIPITATION				2.0611	1.3603	1.85E-02	0.10	0.66
TRIBUTARY INFLOW				671.5688	77.3745	4.35E+01	0.09	0.12
***TOTAL INFLOW				673.6299	78.7348	4.35E+01	0.08	0.12
ADVECTIVE OUTFLOW				673.6299	77.3745	4.35E+01	0.09	0.11
***TOTAL OUTFLOW				673.6299	77.3745	4.35E+01	0.09	0.11
***EVAPORATION					1.3603	1.85E-02	0.10	

Overall Mass Balance Based Upon Predicted Component: TOTAL P — Outflow & Reservoir Concentrations

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct drainage	1036.4	18.5%	7.79E+04	65.3%	0.27	82.0	11.9
2	1	1	Second Crow Wing Lake	1424.1	25.4%	4.06E+04	34.0%	0.14	22.0	2.4
PRECIPITATION				55.4	1.0%	7.68E+02	0.6%	0.50	40.8	26.9
INTERNAL LOAD				3094.1	55.2%	0.00E+00		0.00		
TRIBUTARY INFLOW				2460.5	43.9%	1.18E+05	99.4%	0.14	31.8	3.7
***TOTAL INFLOW				5610.0	100.0%	1.19E+05	100.0%	0.06	71.3	8.3
ADVECTIVE OUTFLOW				4603.2	82.1%	2.26E+05		0.10	59.5	6.8
***TOTAL OUTFLOW				4603.2	82.1%	2.26E+05		0.10	59.5	6.8
***RETENTION				1006.9	17.9%	1.43E+05		0.38		

Overflow Rate (m/yr)	37.5	Nutrient Resid. Time (yrs)	0.0382
Hydraulic Resid. Time (yrs)	0.0466	Turnover Ratio	26.1
Reservoir Conc (mg/m3)	59.5	Retention Coef.	0.179

Table 92. First Crow Wing Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		1	First Crow Wing Lake				
		Predicted Values--->			Observed Values--->		
Variable		Mean	CV	Rank	Mean	CV	Rank
TOTAL P	MG/M3	54.0	0.10	55.3%	59.5	0.08	59.5%

Table 93. First Crow Wing Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct drainage	86.7324	12.6422	1.60E+00	0.10	0.15
2	1	1	Second Crow Wing Lake	584.8364	64.7323	4.19E+01	0.10	0.11
PRECIPITATION				2.0611	1.3603	1.85E-02	0.10	0.66
TRIBUTARY INFLOW				671.5688	77.3745	4.35E+01	0.09	0.12
***TOTAL INFLOW				673.6299	78.7348	4.35E+01	0.08	0.12
ADVECTIVE OUTFLOW				673.6299	77.3745	4.35E+01	0.09	0.11
***TOTAL OUTFLOW				673.6299	77.3745	4.35E+01	0.09	0.11
***EVAPORATION					1.3603	1.85E-02	0.10	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct drainage	632.1	12.5%	2.90E+04	41.2%	0.27	50.0	7.3
2	1	1	Second Crow Wing Lake	1424.1	28.2%	4.06E+04	57.7%	0.14	22.0	2.4
PRECIPITATION				55.4	1.1%	7.68E+02	1.1%	0.50	40.8	26.9
INTERNAL LOAD				2937.5	58.2%	0.00E+00		0.00		
TRIBUTARY INFLOW				2056.2	40.7%	6.95E+04	98.9%	0.13	26.6	3.1
***TOTAL INFLOW				5049.2	100.0%	7.03E+04	100.0%	0.05	64.1	7.5
ADVECTIVE OUTFLOW				4178.3	82.8%	1.63E+05		0.10	54.0	6.2
***TOTAL OUTFLOW				4178.3	82.8%	1.63E+05		0.10	54.0	6.2
***RETENTION				870.9	17.2%	1.07E+05		0.38		

Overflow Rate (m/yr)	37.5	Nutrient Resid. Time (yrs)	0.0386
Hydraulic Resid. Time (yrs)	0.0466	Turnover Ratio	25.9
Reservoir Conc (mg/m3)	54.0	Retention Coef.	0.172

Table 94. Lower Twin Lake Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Lower Twin Lake**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	39.9	0.10	42.0%	39.9	0.05	42.0%

Table 95. Lower Twin Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	**Type**	**Seg**	**Name**	**Area km²**	**Flow hm³/yr**	**Variance (hm3/yr)²**	**CV -**	**Runoff m/yr**
1	1	1	Direct drainage	6.5316	0.8	7.18E-03	0.10	0.13
2	1	1	Upper Twin Lake	1544.9810	212.9	4.53E+02	0.10	0.14
PRECIPITATION				1.0194	0.7	4.53E-03	0.10	0.66
TRIBUTARY INFLOW				1551.5	213.7	4.53E+02	0.10	0.14
***TOTAL INFLOW				1552.5	214.4	4.53E+02	0.10	0.14
ADVECTIVE OUTFLOW				1552.5	213.7	4.53E+02	0.10	0.14
***TOTAL OUTFLOW				1552.5	213.7	4.53E+02	0.10	0.14
***EVAPORATION					0.7	4.53E-03	0.10	

Overall Mass Balance Based Upon Component: **Predicted TOTAL P** — **Outflow & Reservoir Concentrations**

Trb	**Type**	**Seg**	**Name**	**Load kg/yr**	**%Total**	**Load Variance (kg/yr)²**	**%Total**	**CV**	**Conc mg/m³**	**Export kg/km²/yr**
1	1	1	Direct drainage	118.5	1.3%	1.02E+03	0.1%	0.27	139.8	18.1
2	1	1	Upper Twin Lake	8750.1	93.4%	1.53E+06	99.9%	0.14	41.1	5.7
PRECIPITATION				27.4	0.3%	1.88E+02	0.0%	0.50	40.8	26.9
INTERNAL LOAD				476.6	5.1%	0.00E+00		0.00		
TRIBUTARY INFLOW				8868.6	94.6%	1.53E+06	100.0%	0.14	41.5	5.7
***TOTAL INFLOW				9372.6	100.0%	1.53E+06	100.0%	0.13	43.7	6.0
ADVECTIVE OUTFLOW				8528.7	91.0%	1.41E+06		0.14	39.9	5.5
***TOTAL OUTFLOW				8528.7	91.0%	1.41E+06		0.14	39.9	5.5
***RETENTION				843.9	9.0%	1.33E+05		0.43		

Overflow Rate (m/yr)	209.7	Nutrient Resid. Time (yrs)	0.0150
Hydraulic Resid. Time (yrs)	0.0165	Turnover Ratio	66.6
Reservoir Conc (mg/m3)	39.9	Retention Coef.	0.090

Table 96. Lower Twin Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Lower Twin Lake**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	36.1	0.10	37.6%	39.9	0.05	42.0%

Table 97. Lower Twin Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					**Averaging Period =**		**1.00**	**years**
				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Direct drainage	6.5316	0.8	7.18E-03	0.10	0.13
2	1	1	Upper Twin Lake	1544.9810	212.9	4.53E+02	0.10	0.14
PRECIPITATION				1.0194	0.7	4.53E-03	0.10	0.66
TRIBUTARY INFLOW				1551.5	213.7	4.53E+02	0.10	0.14
***TOTAL INFLOW				1552.5	214.4	4.53E+02	0.10	0.14
ADVECTIVE OUTFLOW				1552.5	213.7	4.53E+02	0.10	0.14
***TOTAL OUTFLOW				1552.5	213.7	4.53E+02	0.10	0.14
***EVAPORATION					0.7	4.53E-03	0.10	

Overall Mass Balance Based Upon				**Predicted**		**Outflow & Reservoir Concentrations**				
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Direct drainage	84.8	1.0%	5.21E+02	0.0%	0.27	100.0	13.0
2	1	1	Upper Twin Lake	7846.6	93.0%	1.23E+06	99.9%	0.14	36.9	5.1
PRECIPITATION				27.4	0.3%	1.88E+02	0.0%	0.50	40.8	26.9
INTERNAL LOAD				476.6	5.6%	0.00E+00		0.00		
TRIBUTARY INFLOW				7931.3	94.0%	1.23E+06	100.0%	0.14	37.1	5.1
***TOTAL INFLOW				8435.3	100.0%	1.23E+06	100.0%	0.13	39.3	5.4
ADVECTIVE OUTFLOW				7708.5	91.4%	1.13E+06		0.14	36.1	5.0
***TOTAL OUTFLOW				7708.5	91.4%	1.13E+06		0.14	36.1	5.0
***RETENTION				726.8	8.6%	9.91E+04		0.43		

Overflow Rate (m/yr)	209.7	Nutrient Resid. Time (yrs)	0.0151
Hydraulic Resid. Time (yrs)	0.0165	Turnover Ratio	66.3
Reservoir Conc (mg/m3)	36.1	Retention Coef.	0.086

Table 98. Mayo Lake Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Mayo Lake**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	35.7	0.10	37.2%	35.7	0.04	37.2%

Table 99. Mayo Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct drainage	2.5455	0.6	3.21E-03	0.10	0.22
2	1	1	Sibley Lake	142.2917	26.3	6.91E+00	0.10	0.18
PRECIPITATION				0.6101	0.4	1.62E-03	0.10	0.66
TRIBUTARY INFLOW				144.8	26.9	6.91E+00	0.10	0.19
***TOTAL INFLOW				145.4	27.3	6.92E+00	0.10	0.19
ADVECTIVE OUTFLOW				145.4	26.9	6.92E+00	0.10	0.18
***TOTAL OUTFLOW				145.4	26.9	6.92E+00	0.10	0.18
***EVAPORATION					0.4	1.62E-03	0.10	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations
Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	Load Variance %Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct drainage	38.6	3.4%	1.08E+02	0.7%	0.27	68.1	15.1
2	1	1	Sibley Lake	880.2	77.7%	1.55E+04	98.9%	0.14	33.5	6.2
PRECIPITATION				16.4	1.4%	6.73E+01	0.4%	0.50	40.8	26.9
INTERNAL LOAD				198.3	17.5%	0.00E+00		0.00		
TRIBUTARY INFLOW				918.7	81.1%	1.56E+04	99.6%	0.14	34.2	6.3
***TOTAL INFLOW				1133.5	100.0%	1.57E+04	100.0%	0.11	41.6	7.8
ADVECTIVE OUTFLOW				958.9	84.6%	1.63E+04		0.13	35.7	6.6
***TOTAL OUTFLOW				958.9	84.6%	1.63E+04		0.13	35.7	6.6
***RETENTION				174.6	15.4%	4.76E+03		0.40		

Overflow Rate (m/yr)	44.0	Nutrient Resid. Time (yrs)	0.0444
Hydraulic Resid. Time (yrs)	0.0525	Turnover Ratio	22.5
Reservoir Conc (mg/m3)	35.7	Retention Coef.	0.154

Table 100. Mayo Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Mayo Lake

Variable		Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P	MG/M3	30.0	0.10	30.2%	35.7	0.04	37.2%

Table 101. Mayo Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct drainage	2.5455	0.6	3.21E-03	0.10	0.22
2	1	1	Sibley Lake	142.2917	26.3	6.91E+00	0.10	0.18
PRECIPITATION				0.6101	0.4	1.62E-03	0.10	0.66
TRIBUTARY INFLOW				144.8	26.9	6.91E+00	0.10	0.19
***TOTAL INFLOW				145.4	27.3	6.92E+00	0.10	0.19
ADVECTIVE OUTFLOW				145.4	26.9	6.92E+00	0.10	0.18
***TOTAL OUTFLOW				145.4	26.9	6.92E+00	0.10	0.18
***EVAPORATION					0.4	1.62E-03	0.10	

Overall Mass Balance Based Upon Predicted TOTAL P Component: — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct drainage	37.2	4.0%	1.00E+02	0.8%	0.27	65.7	14.6
2	1	1	Sibley Lake	788.7	83.9%	1.24E+04	98.7%	0.14	30.0	5.5
PRECIPITATION				16.4	1.7%	6.73E+01	0.5%	0.50	40.8	26.9
INTERNAL LOAD				98.0	10.4%	0.00E+00		0.00		
TRIBUTARY INFLOW				825.9	87.8%	1.25E+04	99.5%	0.14	30.8	5.7
***TOTAL INFLOW				940.3	100.0%	1.26E+04	100.0%	0.12	34.5	6.5
ADVECTIVE OUTFLOW				805.7	85.7%	1.23E+04		0.14	30.0	5.5
***TOTAL OUTFLOW				805.7	85.7%	1.23E+04		0.14	30.0	5.5
***RETENTION				134.6	14.3%	2.95E+03		0.40		

Overflow Rate (m/yr)	44.0	Nutrient Resid. Time (yrs)	0.0450
Hydraulic Resid. Time (yrs)	0.0525	Turnover Ratio	22.2
Reservoir Conc (mg/m3)	30.0	Retention Coef.	0.143

Table 102. Portage Lake Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment:	**1**	**Portage Lake**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	50.9	0.35	52.7%	50.9	0.06	52.7%

Table 103. Portage Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	**Type**	**Seg**	**Name**	**Area** km^2	**Flow** hm^3/yr	**Variance** $(hm3/yr)^2$	**CV** -	**Runoff** m/yr
1	1	1	Direct drainage	10.4492	1.4	2.05E-02	0.10	0.14
PRECIPITATION				1.6873	1.1	1.24E-02	0.10	0.66
TRIBUTARY INFLOW				10.4	1.4	2.05E-02	0.10	0.14
***TOTAL INFLOW				12.1	2.5	3.29E-02	0.07	0.21
ADVECTIVE OUTFLOW				12.1	1.4	4.53E-02	0.15	0.12
***TOTAL OUTFLOW				12.1	1.4	4.53E-02	0.15	0.12
***EVAPORATION					1.1	1.24E-02	0.10	

Overall Mass Balance Based Upon Component: **Predicted TOTAL P** — **Outflow & Reservoir Concentrations**

Trb	**Type**	**Seg**	**Name**	**Load** kg/yr	**%Total**	**Load Variance** $(kg/yr)^2$	**%Total**	**CV**	**Conc** mg/m^3	**Export** $kg/km^2/yr$
1	1	1	Direct drainage	183.9	60.8%	2.45E+03	82.6%	0.27	128.3	17.6
PRECIPITATION				45.4	15.0%	5.15E+02	17.4%	0.50	40.8	26.9
INTERNAL LOAD				73.3	24.2%	0.00E+00		0.00		
TRIBUTARY INFLOW				183.9	60.8%	2.45E+03	82.6%	0.27	128.3	17.6
***TOTAL INFLOW				302.6	100.0%	2.97E+03	100.0%	0.18	118.8	24.9
ADVECTIVE OUTFLOW				72.9	24.1%	7.66E+02		0.38	50.9	6.0
***TOTAL OUTFLOW				72.9	24.1%	7.66E+02		0.38	50.9	6.0
***RETENTION				229.7	75.9%	2.60E+03		0.22		

Overflow Rate (m/yr)	0.8	Nutrient Resid. Time (yrs)	0.6242
Hydraulic Resid. Time (yrs)	2.5897	Turnover Ratio	1.6
Reservoir Conc (mg/m3)	50.9	Retention Coef.	0.759

Table 104. Portage Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Portage Lake

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	30.0	0.34	30.2%	50.9	0.06	52.7%

Table 105. Portage Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct drainage	10.4492	1.4	2.05E-02	0.10	0.14
PRECIPITATION				1.6873	1.1	1.24E-02	0.10	0.66
TRIBUTARY INFLOW				10.4	1.4	2.05E-02	0.10	0.14
***TOTAL INFLOW				12.1	2.5	3.29E-02	0.07	0.21
ADVECTIVE OUTFLOW				12.1	1.4	4.53E-02	0.15	0.12
***TOTAL OUTFLOW				12.1	1.4	4.53E-02	0.15	0.12
***EVAPORATION					1.1	1.24E-02	0.10	

Overall Mass Balance Based Upon Component: **Predicted TOTAL P** — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct drainage	71.7	52.2%	3.72E+02	42.0%	0.27	50.0	6.9
PRECIPITATION				45.4	33.0%	5.15E+02	58.0%	0.50	40.8	26.9
INTERNAL LOAD				20.3	14.8%	0.00E+00		0.00		
TRIBUTARY INFLOW				71.7	52.2%	3.72E+02	42.0%	0.27	50.0	6.9
***TOTAL INFLOW				137.4	100.0%	8.87E+02	100.0%	0.22	53.9	11.3
ADVECTIVE OUTFLOW				43.0	31.3%	2.39E+02		0.36	30.0	3.5
***TOTAL OUTFLOW				43.0	31.3%	2.39E+02		0.36	30.0	3.5
***RETENTION				94.4	68.7%	7.04E+02		0.28		

Overflow Rate (m/yr)	0.8	Nutrient Resid. Time (yrs)	0.8110
Hydraulic Resid. Time (yrs)	2.5897	Turnover Ratio	1.2
Reservoir Conc (mg/m3)	30.0	Retention Coef.	0.687

Table 106. Sibley Lake Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Sibley Lake**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	33.5	0.31	34.6%	33.5	0.05	34.6%

Table 107. Sibley Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct drainage	140.5678	26.3	6.91E+00	0.10	0.19
PRECIPITATION				1.7229	1.1	1.29E-02	0.10	0.66
TRIBUTARY INFLOW				140.6	26.3	6.91E+00	0.10	0.19
***TOTAL INFLOW				142.3	27.4	6.92E+00	0.10	0.19
ADVECTIVE OUTFLOW				142.3	26.3	6.94E+00	0.10	0.18
***TOTAL OUTFLOW				142.3	26.3	6.94E+00	0.10	0.18
***EVAPORATION					1.1	1.29E-02	0.10	

Overall Mass Balance Based Upon Predicted TOTAL P Component: — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct drainage	2024.0	97.8%	2.97E+05	99.8%	0.27	77.0	14.4
PRECIPITATION				46.3	2.2%	5.37E+02	0.2%	0.50	40.8	26.9
TRIBUTARY INFLOW				2024.0	97.8%	2.97E+05	99.8%	0.27	77.0	14.4
***TOTAL INFLOW				2070.4	100.0%	2.98E+05	100.0%	0.26	75.5	14.6
ADVECTIVE OUTFLOW				881.4	42.6%	8.83E+04		0.34	33.5	6.2
***TOTAL OUTFLOW				881.4	42.6%	8.83E+04		0.34	33.5	6.2
***RETENTION				1188.9	57.4%	1.79E+05		0.36		

Overflow Rate (m/yr)	15.3	Nutrient Resid. Time (yrs)	0.1133
Hydraulic Resid. Time (yrs)	0.2661	Turnover Ratio	8.8
Reservoir Conc (mg/m3)	33.5	Retention Coef.	0.574

Table 108. Sibley Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Sibley Lake

Variable		Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P	MG/M3	30.0	0.31	30.2%	33.5	0.05	34.6%

Table 109. Sibley Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct drainage	140.5678	26.3	6.91E+00	0.10	0.19
PRECIPITATION				1.7229	1.1	1.29E-02	0.10	0.66
TRIBUTARY INFLOW				140.6	26.3	6.91E+00	0.10	0.19
***TOTAL INFLOW				142.3	27.4	6.92E+00	0.10	0.19
ADVECTIVE OUTFLOW				142.3	26.3	6.94E+00	0.10	0.18
***TOTAL OUTFLOW				142.3	26.3	6.94E+00	0.10	0.18
***EVAPORATION					1.1	1.29E-02	0.10	

Overall Mass Balance Based Upon Component: Predicted TOTAL P — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct drainage	1735.1	97.4%	2.18E+05	99.8%	0.27	66.0	12.3
PRECIPITATION				46.3	2.6%	5.37E+02	0.2%	0.50	40.8	26.9
TRIBUTARY INFLOW				1735.1	97.4%	2.18E+05	99.8%	0.27	66.0	12.3
***TOTAL INFLOW				1781.5	100.0%	2.19E+05	100.0%	0.26	65.0	12.5
ADVECTIVE OUTFLOW				788.6	44.3%	6.85E+04		0.33	30.0	5.5
***TOTAL OUTFLOW				788.6	44.3%	6.85E+04		0.33	30.0	5.5
***RETENTION				992.9	55.7%	1.28E+05		0.36		

Overflow Rate (m/yr)	15.3	Nutrient Resid. Time (yrs)	0.1178
Hydraulic Resid. Time (yrs)	0.2661	Turnover Ratio	8.5
Reservoir Conc (mg/m3)	30.0	Retention Coef.	0.557

14 DISSOLVED OXYGEN STRESSOR IDENTIFICATION

14.1 Swan Creek

14.1.1 Current Conditions

Swan Creek (AUID 07010106-527) and its watershed are located in Cass County. Water quality was monitored at one station (S006-293) on Swan Creek and one station (S006-246) on Iron Creek (07010106-593), a tributary to Swan Creek. Data available from the most recent ten years (2002-2011) were used to assess dissolved oxygen levels and potential relationships with other stream mechanisms, such as nutrients, flow, and water temperature.

Table 110. Dissolved Oxygen (mg/L) for Swan Creek and Iron Creek, 2002-2011.
The daily minimum water quality standard for these waters is 5 mg/L. Bold red font highlights samples below the standard.

Waterbody	Station	Month	No. of Samples	Minimum DO (mg/L)	No. Samples < 5 mg/L
Swan Creek (07010106-527)	S006-293	May	3	5.2	0
		June	4	5.3	0
		July	2	**4.0**	**1**
		August	5	**2.4**	**3**
		September	4	**4.3**	**1**
Iron Creek (07010106-593)	S006-246	April	4	6.6	0
		May	4	6.8	0
		June	5	**1.3**	**3**
		July	5	**0.6**	**5**
		August	4	**0.0**	**4**
		September	2	**2.9**	**2**
		October	2	**3.3**	**1**

14.1.2 Candidate Causes

14.1.2.1 Nutrients

Stream eutrophication standards are under development based on several studies and data collection efforts that have demonstrated significant and predictable relationships among summer levels of nutrients, sestonic chlorophyll-a, and biochemical oxygen demand in several medium to large Minnesota rivers (Heiskary & Markus 2001, Heiskary & Markus 2003). Consistent with USEPA guidance, criteria are being developed for three “River Nutrient Regions (RNR)”. The draft phosphorus standard for Central Region streams is 100 µg/L as a growing season (June-September) mean (for more information, refer to the draft Minnesota Nutrient Criteria Development for Rivers report online:

http://www.pca.state.mn.us/index.php?option=com_k2&Itemid=131&id=3312&layout=item&view=item#draft-water-quality-standards-technical-support-documents).

Phosphorus data was only available in 2010 for Swan Creek, and in 2010-2011 for Iron Creek (Table 111). One sample from Swan Creek barely exceeded the target in-stream TP goal of 100 µg/L in 2010, though other TP measurements show samples just below 100 µg/L. Individual phosphorus concentrations in Iron Creek exceeded 100 µg/L in June and July of 2010 and 2011.

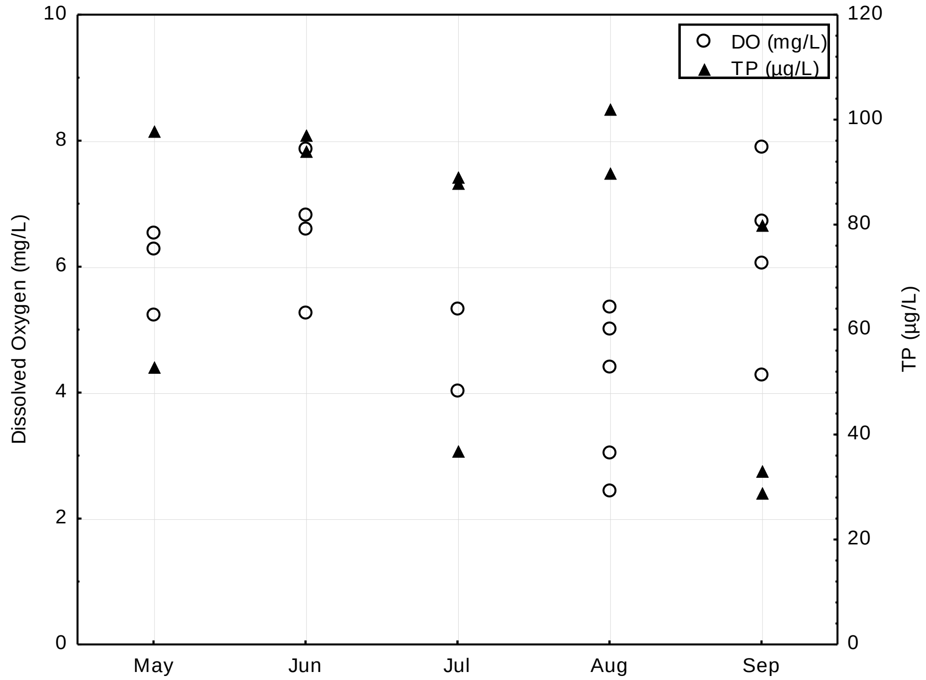
Table 111. Growing season TP (µg/L) for Swan Creek and Iron Creek, 2002-2011.
Bold red font highlights samples that exceed the in-stream TP goal of 100 µg/L.

Waterbody	Year	Month	Mean TP (µg/L)	No. of Samples
Swan Creek (07010106-527)	2010	June	96	2
		July	71	3
		August	96	2
		September	47	3
Iron Creek (07010106-593)	2010	June	143	2
		July	97	2
		August	53	3
		September	70	3
	2011	June	18	2
		July	154	2
		August	202	2

There are two registered feedlots in operation in the Swan Creek watershed, both of which are adjacent to tributaries flowing into Swan Creek. The total number of dairy and beef cattle animal units at both feedlots is 398 according to the MPCA registered feedlot database. Using assumptions based on the variations in TP generated by different feedlot species and the average flow of TP actually lost to surface waters, we estimated that these AUs contribute approximately 22 lb/yr of phosphorus to Swan Creek, a small fraction (2%) of the total phosphorus load of 1,045 lb/yr. In addition, there was no significant correlation between in-stream DO and TP concentrations that would suggest a relationship between the two parameters (Figure 90). TP concentrations were variable with no consistent trends throughout the year, while DO concentrations were generally lower in the summer months. But even so, in some parts of the drainage area feedlot animals have unrestricted access to tributaries, and have caused bank erosion (MPCA 2013b).

There was also no apparent correlation between in-stream nitrogen and dissolved oxygen concentrations. Nitrate/nitrite concentrations in Swan Creek were low. Only one sample was above 0.10 mg/L (0.13 mg/L) in 2010, and many below the detection limit of 0.03 mg/L.

Figure 90. Dissolved oxygen (mg/L) and TP (µg/L) by month for Swan Creek for 2010.



14.1.2.2 Iron Oxidation

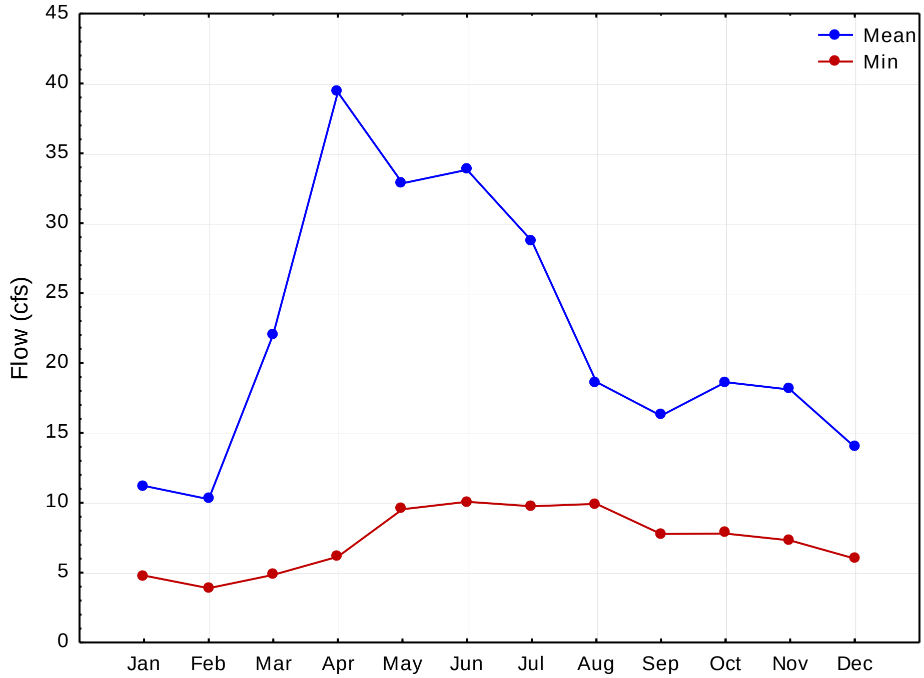
Iron is dissolved in high quantities in the groundwater of much of the Crow Wing Watershed, including Swan Creek's subwatersheds (MPCA 2013b). As this groundwater feeds into Swan Creek and its tributaries, the iron is oxidized by dissolved oxygen and forms an iron floc, leading to lower DO levels in the water and staining the stream water an orange color. This has been identified as a mechanism for lowering dissolved oxygen in other streams as well (USEPA 2001b), and is likely a strong cause of the low DO concentrations in Swan Creek.

Figure 91. Iron Creek, a tributary to Swan Creek (MPCA 2013b).
The orange color results from the high iron content.

14.1.2.3 Stream Flow

Dissolved oxygen levels can be greatly affected by water agitation. Decreased stream flow and water movement may result in lower levels of DO due to lower rates of diffusion from the air. In Swan Creek, the highest mean and min flows occur during the spring and early summer (Figure 92), while the lowest DO levels occur throughout the summer (Table 110), but especially in August and September. Notice the low mean flows for those two months (Figure 92).

Figure 92. Mean and minimum flows by month for Swan Creek, 2000-2009.

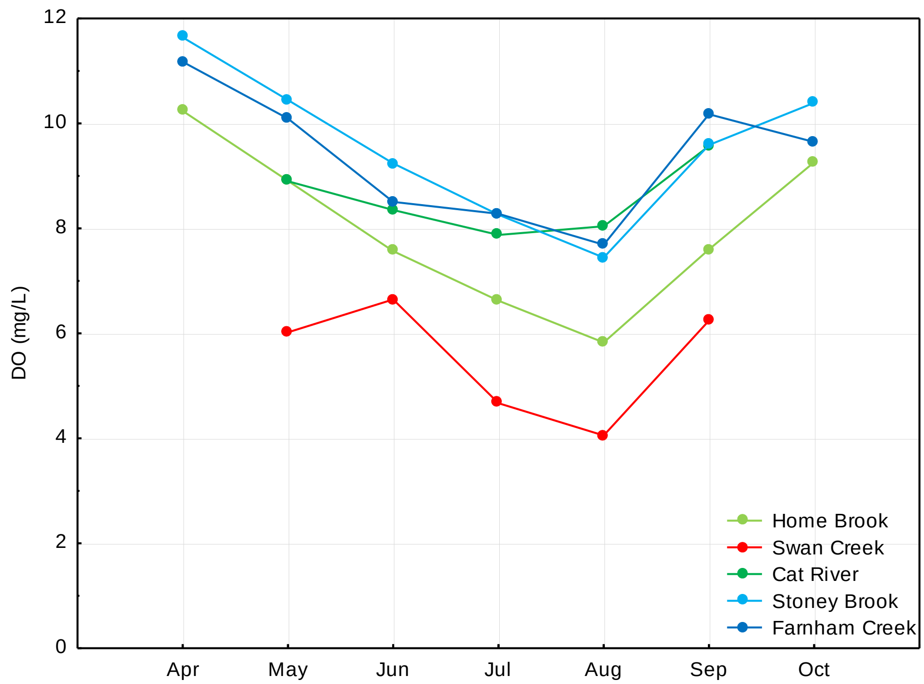


When compared to other stream reaches in the Crow Wing watershed, Swan Creek shows similar flow patterns (Table 112), yet each of those reaches has higher monthly DO trends (Figure 93). Besides flow, natural stream conditions in Swan Creek likely lead to less water agitation. There is little wooded area along the reach, leading to a lack of woody debris in the streambed. Also, the streambed lacks rocky substrates that help to form riffles (MPCA 2013b). Those riffles agitate stream waters, helping to aerate the water and increase DO levels. Instead, the streambed sediment is silty, which is increased by the upstream erosion at pasture sites (MPCA 2013b). Overall, decreased flow may be a small factor influencing lower DO levels, but these other natural stream conditions likely also play a role.

Table 112. Full 10 yr (2000-2009) flow comparison and critical DO months (June-August) comparison across reaches with flows similar to Swan Creek.

Stream Reach	AUID	10 yr Flow (cfs)			10 yr Flow (cfs) June-September		
		Mean	Min	Max	Mean	Min	Max
Home Brook	07010106-524	26.13	4.38	633.48	30.94	4.38	633.48
Swan Creek	07010106-527	22.03	3.89	257.95	24.37	7.77	257.95
Cat River	07010106-544	23.01	2.45	230.81	24.46	5.62	221.36
Stoney Brook	07010106-698	20.19	3.59	365.88	20.89	4.46	189.43
Farnham Creek	07010106-702	22.99	4.19	255.20	25.56	8.00	237.17

Figure 93. Dissolved oxygen monthly mean reach comparison to Swan Creek, 2002-2011.



14.1.2.4 Wetland-dominated drainage area

Swan Creek is surrounded by wetlands and sedge meadows, with those land types accounting for roughly 37% of its watershed (Table 10). Dissolved oxygen levels are naturally low in wetlands due to stagnant, warm waters and the decomposition of large amounts of organic matter. With over one third of waters contributing to Swan Creek flowing through these wetlands and sedge meadows, it is likely that the low DO levels can be largely attributed to natural conditions.

14.1.2.5 Water Temperature

Warmer waters hold less oxygen than cooler waters. In addition, warmer waters have increased rates of organic matter decomposition, which consumes oxygen. The seasonal variation of dissolved oxygen concentrations in Swan Creek and Iron Creek correlates strongly with seasonal variations in water temperature (Figure 94, Figure 95). Increased temperatures are likely a major stressor for low dissolved oxygen levels during the summer months. However, dissolved oxygen concentrations are still less than 8 mg/L when water temperatures are colder indicating that water temperature alone is not the only stressor to dissolved oxygen in Swan Creek.

Figure 94. Water temperature (°C) and DO (mg/L) by month for Swan Creek in 2010.

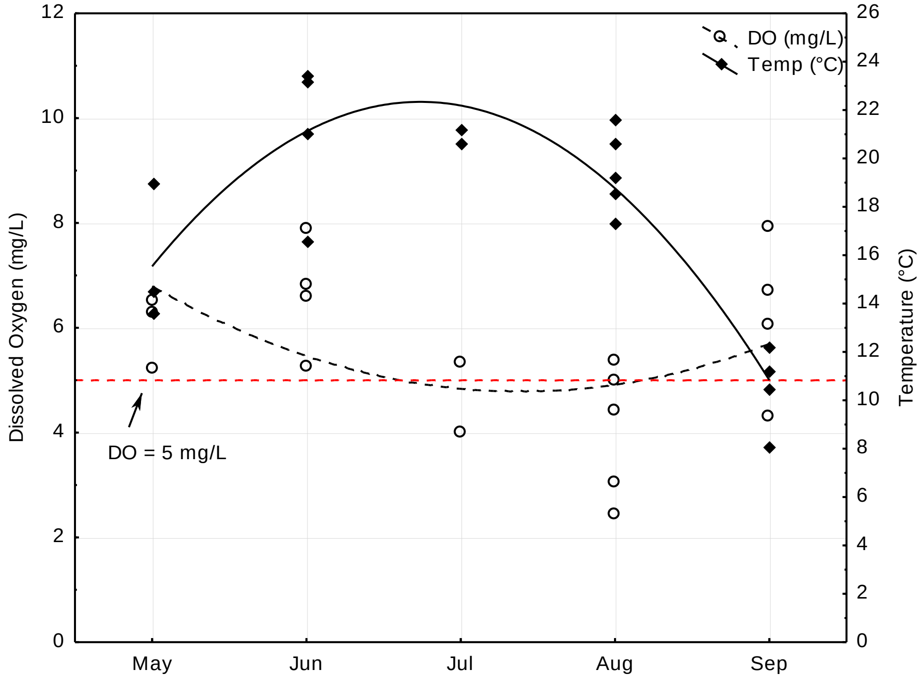
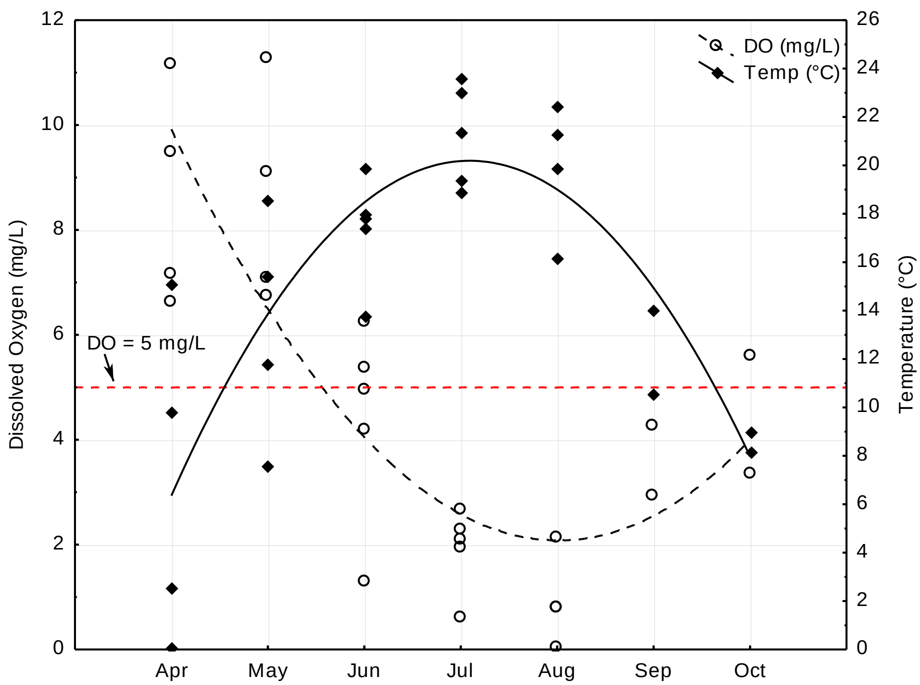


Figure 95. Water temperature (°C) and DO (mg/L) by month for Iron Creek 2010-2011.



Water temperatures may be high during the summer months in Swan Creek due to insufficient shading from riparian vegetation (MPCA 2013b). Without shade from stream canopy, increased sunlight warms stream waters, decreasing the solubility of oxygen and also potentially increasing organic matter decomposition rates, which further decreases DO levels (Allan 1995). Although a decrease in riparian zones can be associated with agriculture, in the Swan Creek watershed natural wetlands with low riparian cover occur in high proportions (37%; Table 10).

14.1.2.6 Habitat Alteration

The stressor identification study conducted by the MPCA (MPCA 2013a) states:

> An overall analysis of the data strongly suggests that the biological impairments in Swan Creek are partly the result of localized human (animal husbandry related) physical alterations to the stream channel. Cattle influence on stream channel geomorphology is evident at both of the impaired sites. Overwidening of stream channels is a common result of cattle having access to stream riparian areas and channels, and this has clearly occurred at the downstream site. As is also typical for unfenced stream channels, the upper pasture has bank erosion from animal trampling, and thus excess sediment in the stream. The MSHA metrics also substantiate the degraded habitat in these pastured reaches.

Personal communication from Kevin Stroom, the principal investigator of the MPCA stressor identification study, also indicated that there may be elevated plant growth in the reach adjacent to the lower pasture site (10EM086) due to lost riparian shading, channel over-widening, and siltation from cattle trampling of the channel. Respiration from this elevated plant growth may be reducing dissolved oxygen levels at night. Restricting livestock access to the stream channel should also allow the stream to eventually narrow and deepen, be more shaded, be cooler, and allow for less plant growth – all of which would improve the dissolved oxygen levels in this lower reach.

14.1.3 Conclusions/Summary

Dissolved oxygen levels are low year-round in Swan Creek, and drop below the daily minimum 5 mg/L standard during the summer months (Table 110). The primary stressors to low dissolved oxygen in Swan Creek identified in this study were:

- Iron oxidation/ peatland-derived phosphorus
- Habitat alteration

Iron oxidation and peatland-derived phosphorus were identified as key stressors to dissolved oxygen in Swan Creek. In addition, the high fraction of the upper watershed covered by peatland soils likely contributes low DO waters to Swan Creek. Pasturing animals were observed in the stream which may be contributing to localized areas of stream trampling (habitat alteration) resulting in lost riparian shading, channel over-widening, siltation, and ultimate elevated plant growth that reduces dissolved oxygen levels at night.

14.2 Straight River

14.2.1 Current Conditions

Straight River (AUID 07010106-558) originates in Straight Lake and flows to the confluence with Fish Hook River near Park Rapids, MN. Water quality data available from the most recent ten years (2002-2011) at three stations (S004-793, S002-960, and S004-788) were used to assess dissolved oxygen levels and potential relationships with other stream mechanisms, such as nutrients, flow, and water temperature.

Table 113. Dissolved Oxygen (mg/L) for Straight River for available data from 2002-2011. The daily minimum water quality standard for 2A waters is 7 mg/L. Bold red font highlights samples below the standard. Stations are listed in order from upstream to downstream.

AUID (07010106 -XXX)	Water body	Station	Month	No. of Samples	Minimum DO (mg/L)	No. of Samples < 7 mg/L
-558	Straight River	S004-793	April	1	10.2	0
			May	1	8.9	0
			June	1	**5.8**	**1**
			July	2	8.3	0
			August	1	12.3	0
		S002-960	January	1	14.9	0
			March	2	11.8	0
			April	6	9.9	0
			May	8	8.9	0
			June	11	7.4	0
			July	9	**6.2**	**4**
			August	7	**6.5**	**1**
			September	6	**4.1**	**1**
			October	2	8.3	0
			November	1	12.3	0
		S004-788	April	1	10.2	0
			May	1	10.0	0
			June	2	7.2	0
			July	2	8.7	0
			August	2	9.2	0
			September	2	9.5	0

14.2.2 Candidate Causes

14.2.2.1 Nutrients

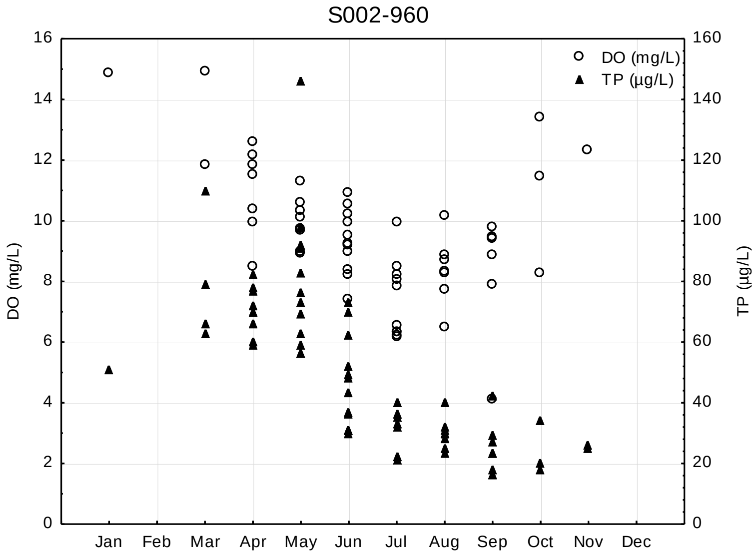
Stream eutrophication standards are under development based on several studies and data collection efforts that have demonstrated significant and predictable relationships among summer levels of nutrients, sestonic chlorophyll-a, and biochemical oxygen demand in several medium to large Minnesota rivers (Heiskary & Markus 2001, Heiskary & Markus 2003). Consistent with USEPA guidance, criteria are being developed for three "River Nutrient Regions (RNR)". The draft phosphorus standard for Central Region streams is 100 µg/L as a growing season (June-September) mean (for more information, refer to the draft Minnesota Nutrient Criteria Development for Rivers report online:
http://www.pca.state.mn.us/index.php?option=com_k2&Itemid=131&id=3312&layout=item&view=item#draft-water-quality-standards-technical-support-documents).

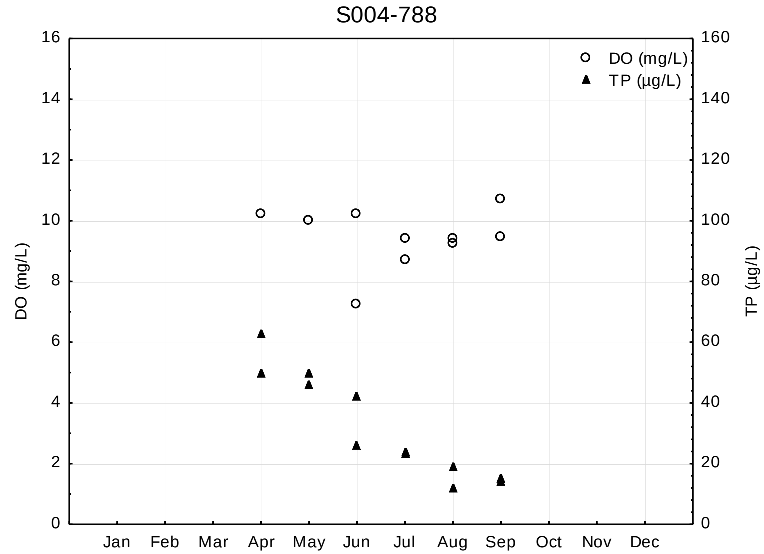
No monitored TP concentrations exceeded the in-stream TP target of 100 µg/L during the growing season (Table 114). There are three registered feedlots in close proximity to the impaired section of Straight River. The total number of animal units between all feedlots is 1,000, with 95% swine and 5% beef cattle according to the MPCA registered feedlot database. Using assumptions based on the variations in TP generated by feedlot species and the average flow of TP actually lost to surface waters, we estimated that these AUs contribute approximately 41 lb/yr of phosphorus to Straight River, a small fraction (<1%) of the total phosphorus load of 5,245 lb/yr. There is a consistent forest buffer along the Straight River that may help to absorb runoff phosphorus before it can reach the water. In addition, there was no significant correlation between in-stream DO and TP concentrations that would suggest a relationship between the two parameters (Figure 96). Although the patterns vary across stations, DO was generally higher in spring and fall and lowest in summer, while TP was typically highest in spring and then decreased throughout the rest of the year, likely due to snowmelt. Nitrate concentrations were high in the Straight River, and may contribute to lower DO levels through nitrification and eutrophication. However, because phosphorus is the limiting nutrient in freshwater bodies and TP shows no relationship with DO, and because concentrations of the available chlorophyll-a data are low, it is unlikely that low DO levels are due to eutrophication issues.

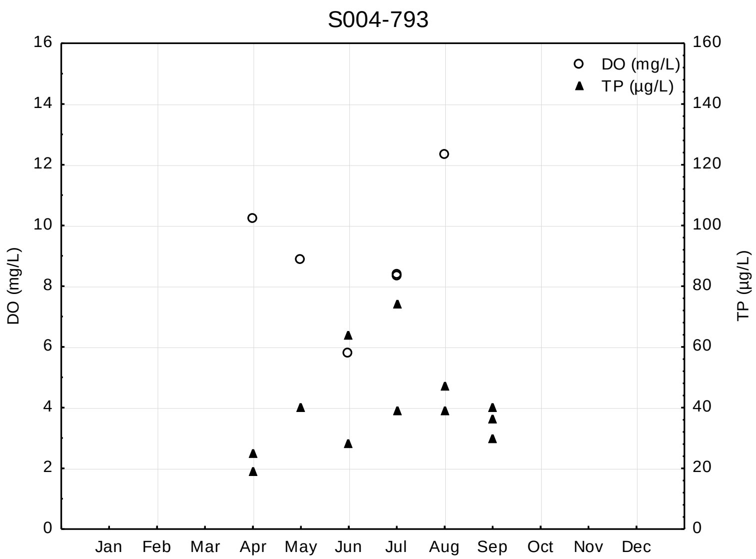
Table 114. Growing season TP (µg/L) for Straight River from data available 2002-2011.
No samples exceeded the in-stream TP goal of 100 µg/L.

Station	Year	Mean TP (µg/L)	No. of Samples
S002-960	2004	43	9
	2005	33	8
	2006	35	8
	2010	28	11
S004-788	2007	19	4
	2008	25	4
S004-793	2007	44	5
	2008	44	4

Figure 96. Dissolved oxygen (mg/L) and TP (µg/L) by month for each station on Straight River for data available 2002-2011.



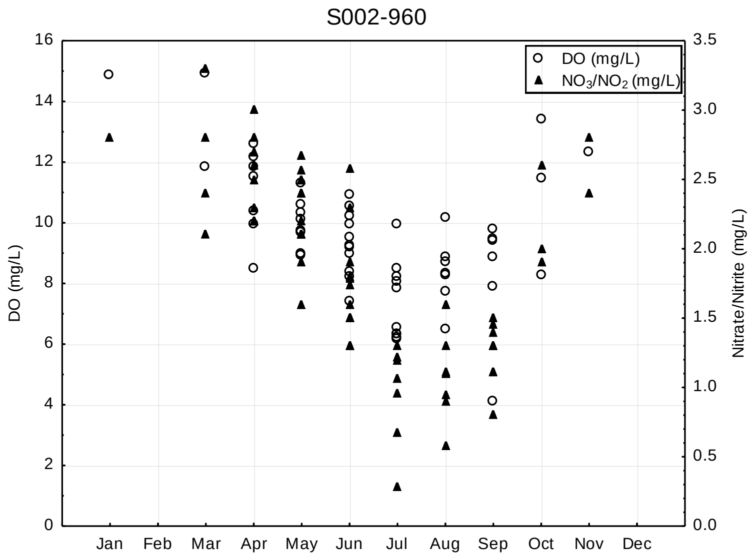


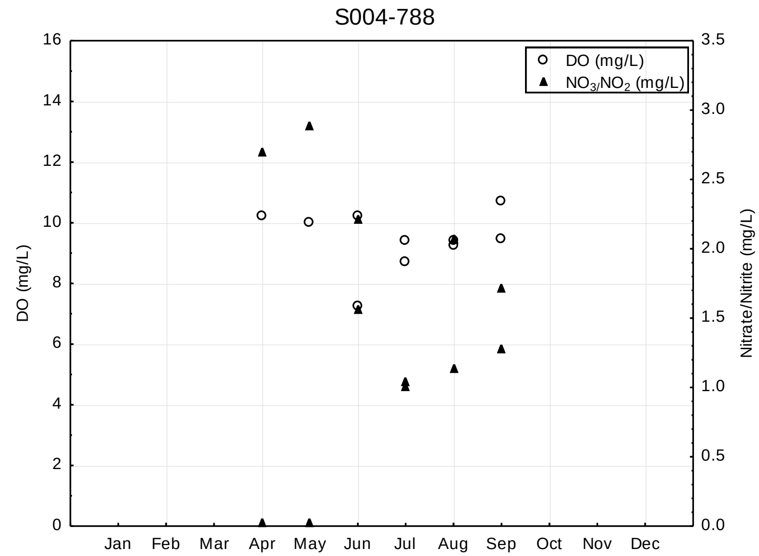


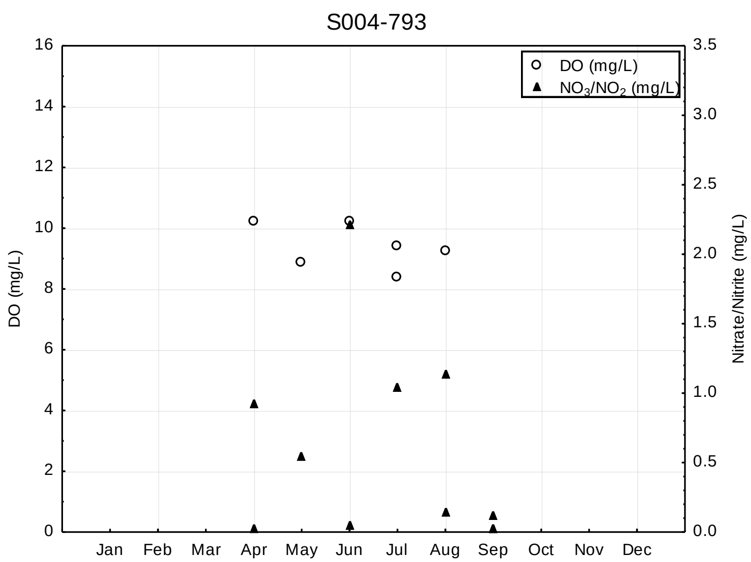
Nitrate concentrations were highest in spring and fall, and lowest during summer months (Figure 97). Overall, nitrate concentrations were very elevated in Straight River compared to other streams and rivers in central Minnesota (MPCA 2013a). This is likely due to the watershed's large proportion of cropland (25%; Table 10), which throughout streams and rivers in the rest of the state accounts for roughly 75% of nitrogen sources (MPCA 2013a). Also, in a USGS study by Ruhl (1995) based on groundwater measurements from monitoring wells and isotope analyses, cropland fertilizer was found to be a primary source of nitrates for Straight River.

This influx of nitrogen sources may be contributing to low DO levels in Straight River. The high nitrate concentrations in the water are likely caused by high rates of DO-consuming nitrification. Then, with higher rates of primary production in the summer months, those nitrates are used much more readily. Subsequent increases in plant and algal growth may result in increased organic matter decomposition and further decreased DO levels. However, there is very little chlorophyll-a data, and for the data that is available all chlorophyll-a concentrations are low (< 12 µg/L). Also, phosphorus is the limiting nutrient for primary production in freshwater bodies, so it is unlikely that DO levels are significantly affected by the nitrate concentrations.

Figure 97. Dissolved oxygen (mg/L) and Nitrate/Nitrite (mg/L) by month for each station on Straight River for data available 2002-2011



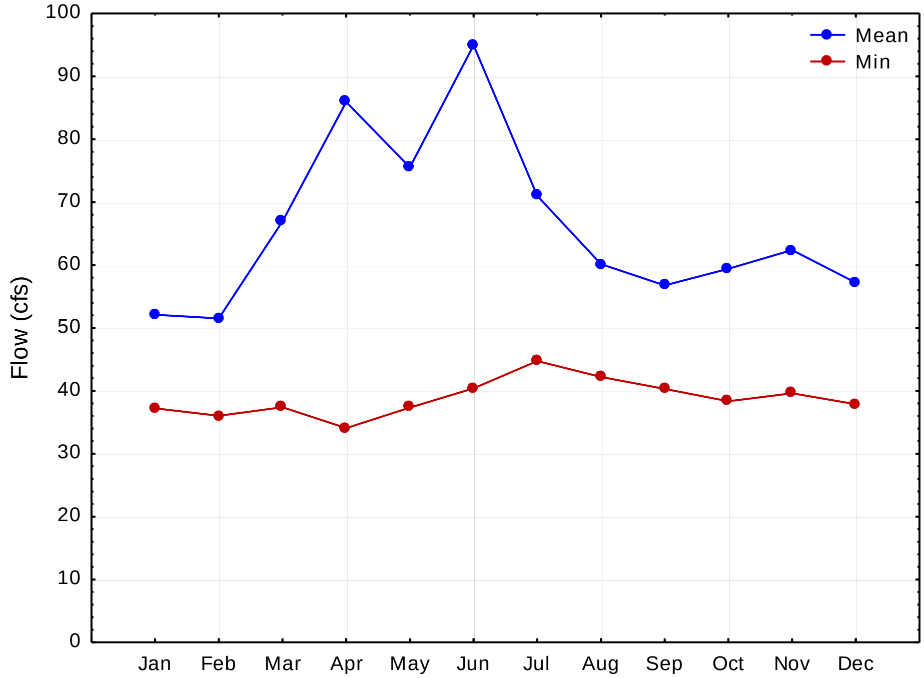




14.2.2.2 Stream Flow

Dissolved oxygen levels can be greatly affected by water agitation. Decreased stream flow and water movement may result in lower levels of DO due to lower rates of diffusion from the air. Straight River had a naturally higher baseflow (Figure 98), with flow highest in spring and early summer, then dropping through the summer back to baseflow levels. DO patterns were independent of flow patterns, and it is unlikely that flow is an important DO stressor.

Figure 98. Mean and minimum flows by month for Straight River, 2000-2009.

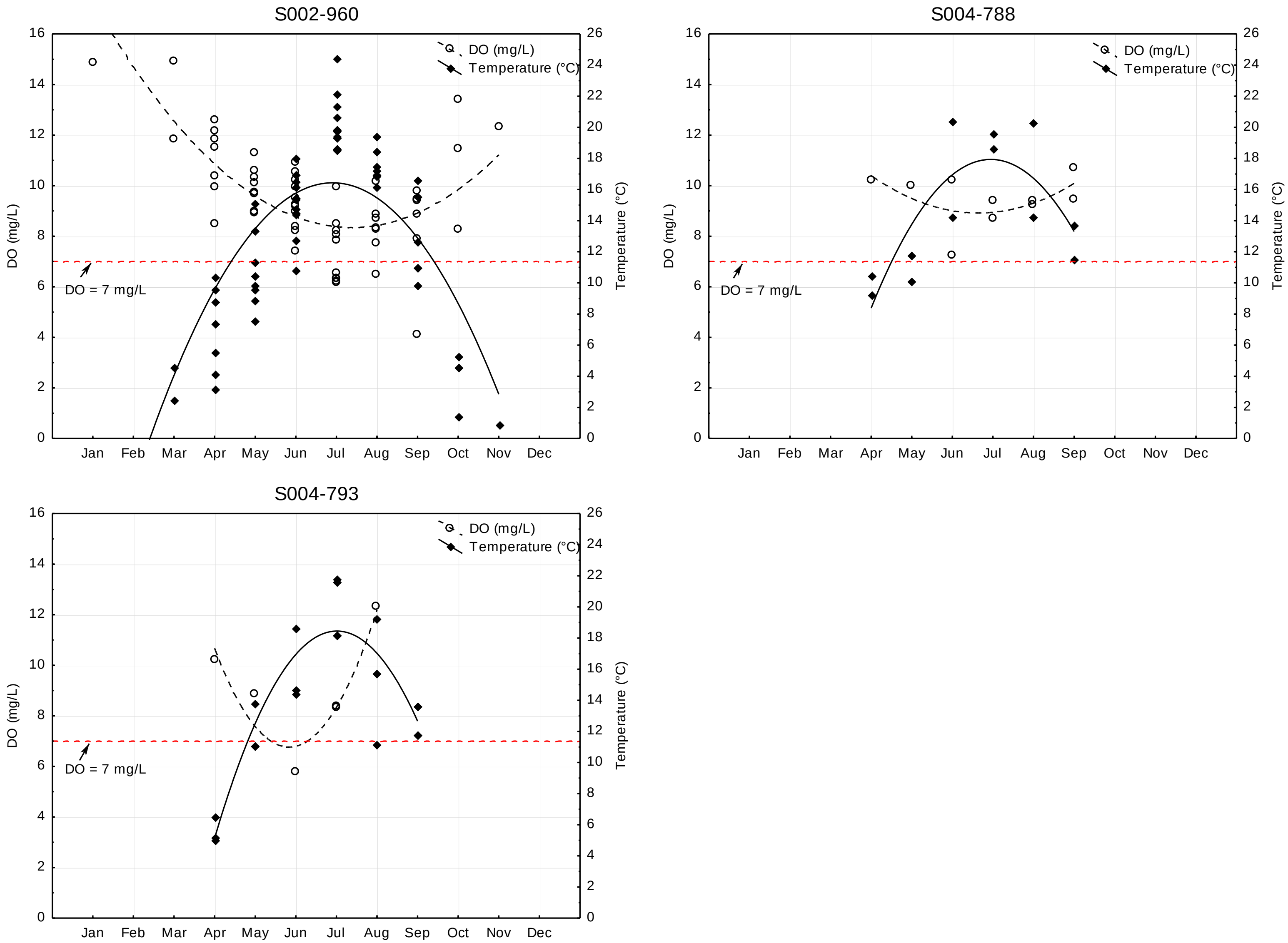


14.2.2.3 Water Temperature

Warmer waters hold less oxygen than cooler waters. In addition, warmer waters have increased rates of organic matter decomposition, which consumes oxygen. Seasonal DO variations coincided strongly with seasonal variations in water temperature for Straight River (Figure 99). Increased temperatures are likely a major stressor for low DO levels during the summer months.

In addition, there are known groundwater appropriations in the Straight River watershed. Based on MN DNR records, total water use has been increasing since 1988, primarily due to increases in agricultural irrigation. The Straight River drainage area alone has 74 groundwater appropriation well sites, 68, of which, are used for agricultural irrigation. The sources of high heat inputs to these rivers are linked to decreased groundwater flows, resulting primarily from increased groundwater appropriations for surface crop irrigation. Since groundwater is cooler than surface water in summer months, the application of cool groundwater to the land surface lead to higher surface water temperatures. Higher water temperatures decrease the solubility of DO and therefore lead to decreased DO concentrations.

Figure 99. Water temperature (°C) and DO (mg/L) by month for each station on Straight River from available data 2002-2011.



14.2.3 Conclusions/Summary

Water temperature was identified as the primary stressor to low dissolved oxygen levels in the Straight River. Patterns of DO in the Straight River coincided strongly with seasonal variations in water temperature (Figure 99), with the lowest dissolved oxygen levels occurring at the warmest water temperatures during the summer months. Moreover, increased groundwater appropriations for surface crop irrigation since 1988 in the Straight River area have been linked to increased water temperatures in the Straight River by the Minnesota DNR[5].

[5] Minnesota Department of Natural Resources – Division of Waters. July 2002. *Surface Water and Ground Water Interaction and Thermal Changes in the Straight River in North Central Minnesota.*

14.3 Shell River

14.3.1 Current Conditions

Shell River (AUID 07010106-681) originates in Lower Twin Lake and flows to the confluence with the Crow Wing River. Water quality data available from the most recent 10 years (2002-2011) at three stations (S002-962, S003-442, and S003-833) were used to assess dissolved oxygen levels and potential relationships with other stream mechanisms, such as nutrients, flow, and water temperature.

Table 115: Dissolved Oxygen (mg/L) for Shell River for available data from 2002-2011. The daily minimum water quality standard for 2B waters is 5 mg/L. Bold red font highlights samples below the standard.

Water body	Station	Month	No. of Samples	Minimum DO (mg/L)	No. of Samples < 5 mg/L
Shell River (07010106-681)	S002-962	January	1	15.4	0
		March	2	11.7	0
		April	6	10.8	0
		May	6	9.6	0
		June	6	6.9	0
		July	3	**4.4**	**1**
		August	4	5.9	0
		September	4	**4.4**	**1**
		October	2	9.6	0
	S003-442	April	1	11.1	0
		May	5	8.0	0
		June	6	**3.9**	**1**
		July	6	**4.0**	**2**
		August	7	**4.9**	**1**
		September	6	7.0	0
	S003-833	April	1	11.0	0
		May	1	9.3	0
		June	2	**3.7**	**1**
		July	2	**4.7**	**1**
		August	2	**4.4**	**1**
		September	2	6.5	0

14.3.2 Candidate Causes

14.3.2.1 Nutrients

No monitored TP concentrations exceeded the in-stream TP target of 100 µg/L during the growing season (Table 116). No registered animal feedlots are within close proximity of the Shell River that could contribute a substantial amount of TP. There was no significant correlation between in-stream DO and TP concentrations that would suggest a relationship between the two parameters (Figure 100, Figure 101, and Figure 102).

Table 116: Growing season TP (µg/L) for Shell River from data available 2002-2011. No samples exceeded the in-stream TP goal of 100 µg/L.

Station	Year	Mean TP (µg/L)	Number of Samples
S002-962	2004	38	13
	2005	39	10
	2006	42	9
S003-442	2007	29	4
	2008	25	4
	2009	24	9
	2010	27	9
S003-833	2007	25	4
	2008	23	4

Figure 100: Dissolved oxygen (mg/L) and TP (µg/L) by month at station S002-962 on Shell River. Data available from 2002-2011.

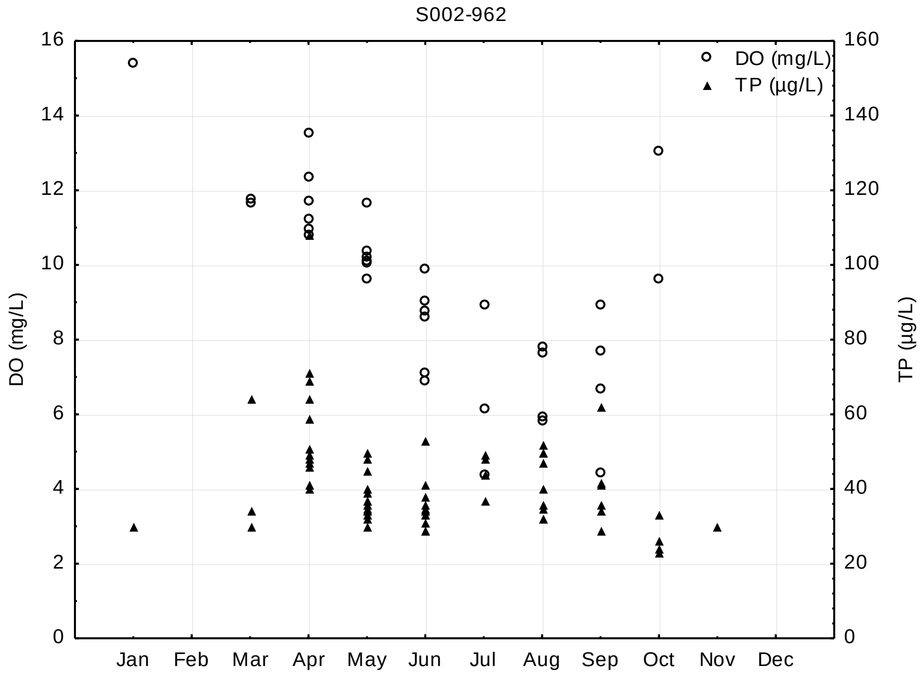


Figure 101: Dissolved oxygen (mg/L) and TP (µg/L) by month at station S003-442 on Shell River. Data available from 2002-2011.

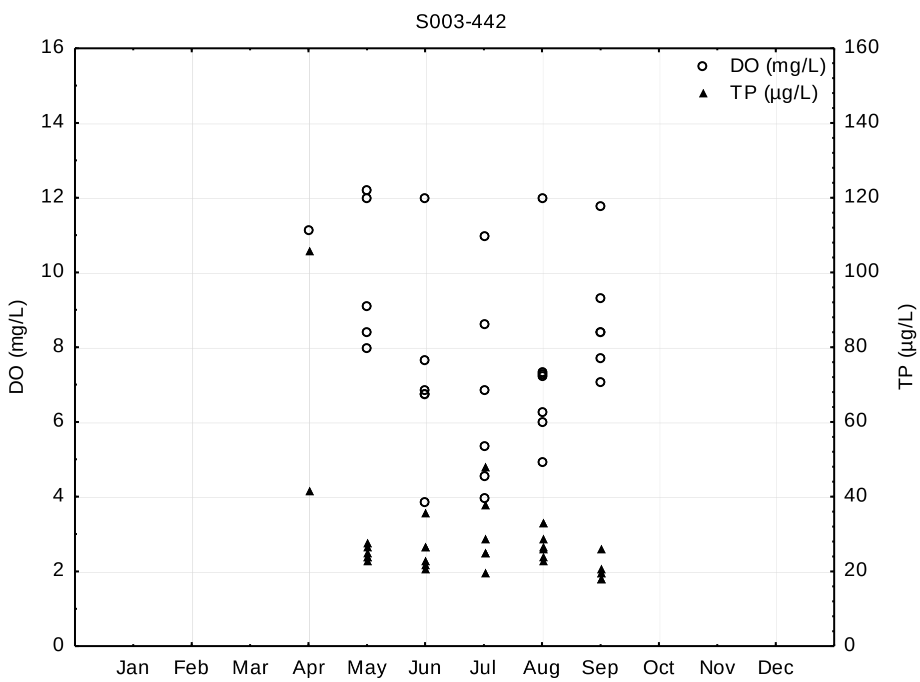
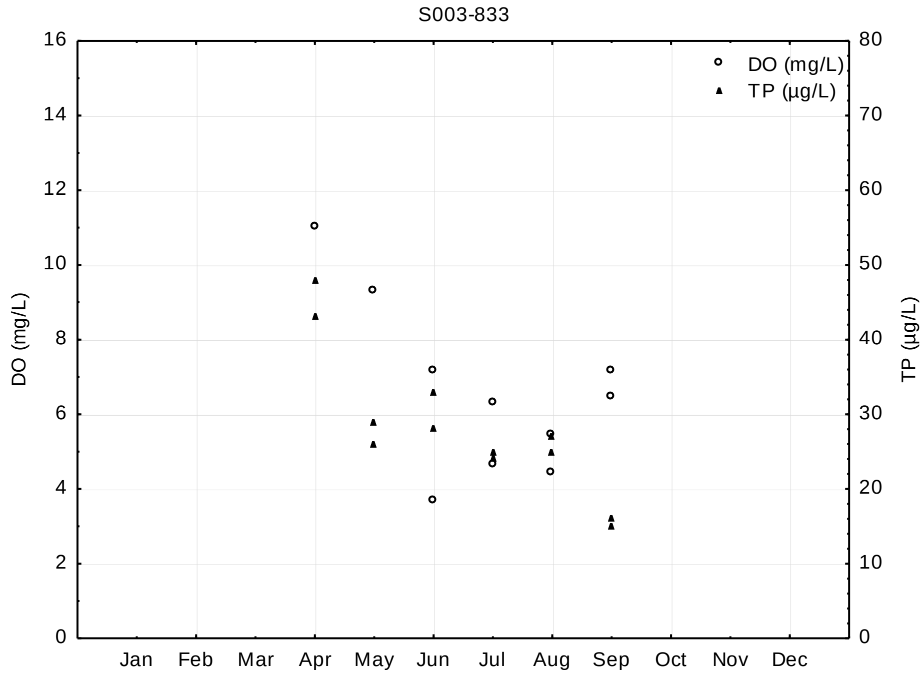


Figure 102: Dissolved oxygen (mg/L) and TP (µg/L) by month at station S003-833 on Shell River. Data available from 2002-2011.



14.3.2.2 Biochemical Oxygen Demand

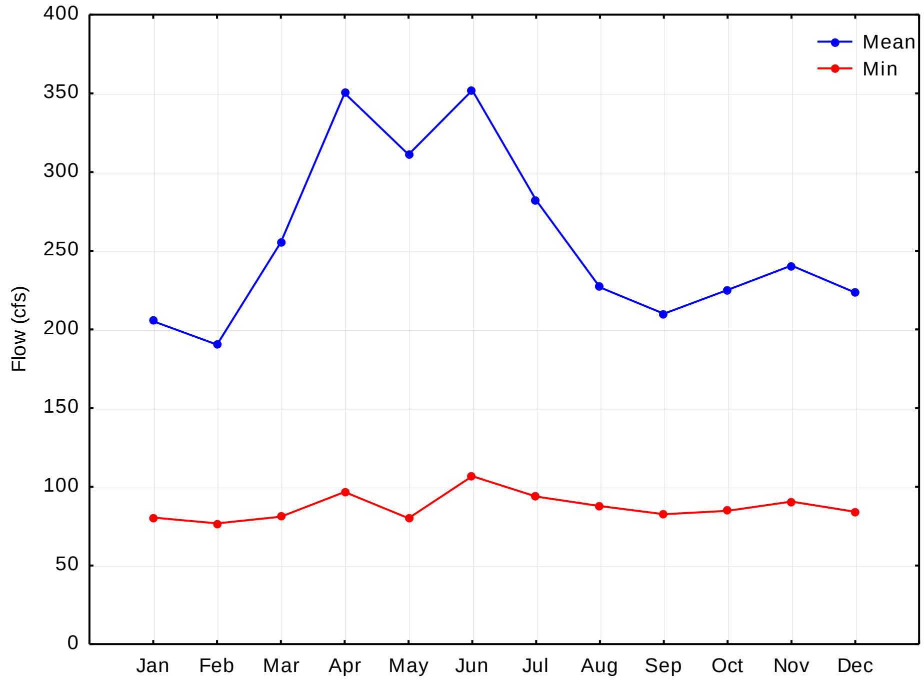
Biochemical oxygen demand (BOD) was monitored at three stations along Shell River (S002-962, S003-442, and S003-833) with a maximum value of 3.0 mg/L. Shell River is wide and shallow with an average depth of approximately 1.5 feet across the channel (Figure 103). The streambed consists mostly of softly-packed sand and fine gravel. Submerged vegetation cover of the streambed ranges from 33-40% during the growing season with dense macrophytes (mainly cattails) located on the streambanks. Oxygen depletion for decomposing organic sediment is thought to be negligible.

Figure 103. Photograph of Shell River taken from the Highway 24 bridge facing upstream. The photograph was taken on September 9, 2009.

14.3.2.3 Stream Flow

Dissolved oxygen levels can be greatly affected by water agitation. Decreased stream flow and water movement may result in lower levels of DO due to lower rates of diffusion from the air. Shell River had a naturally higher baseflow (Figure 104), with flow highest in spring and early summer. Baseflow was less than half of the mean flow for each month throughout the year. DO patterns were independent of flow patterns, and it is unlikely that flow is an important DO stressor.

Figure 104. Mean and minimum flows by month for the Shell River. Data available from 2000-2009.



14.3.2.4 Water Temperature

Warmer waters hold less oxygen than cooler waters. In addition, warmer waters have increased rates of organic matter decomposition, which consumes oxygen. Seasonal DO variations coincided strongly with seasonal variations in water temperature for Straight River (Figure 105, Figure 106, and Figure 107). Increased temperatures are likely a major stressor for localized low DO levels during the summer months.

In addition, there are known groundwater appropriations in the Shell River watershed. Based on MN DNR records, total water use has been increasing since 1988, primarily due to increases in agricultural irrigation. The lower Shell River drainage area downstream of Lower Twin Lake has 59 groundwater appropriation well sites, 58, of which, are used for agricultural irrigation. The sources of high heat inputs to these rivers are linked to decreased groundwater flows, resulting primarily from increased groundwater appropriations for surface crop irrigation. Since groundwater is cooler than surface water in summer months, the application of cool groundwater to the land surface lead to higher surface water temperatures. Higher water temperatures decrease the solubility of DO and therefore lead to decreased DO concentrations.

Figure 105. Water temperature (°C) and DO (mg/L) by month at station S002-962 on Shell River. Data available from 2002-2011.

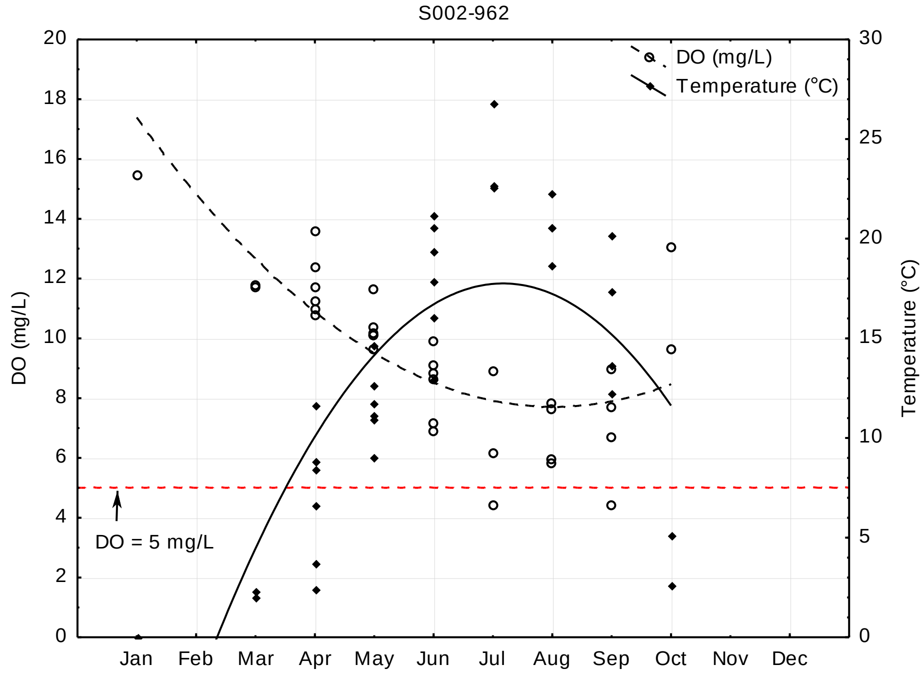


Figure 106. Water temperature (°C) and DO (mg/L) by month at station S003-442 on Shell River. Data available from 2002-2011.

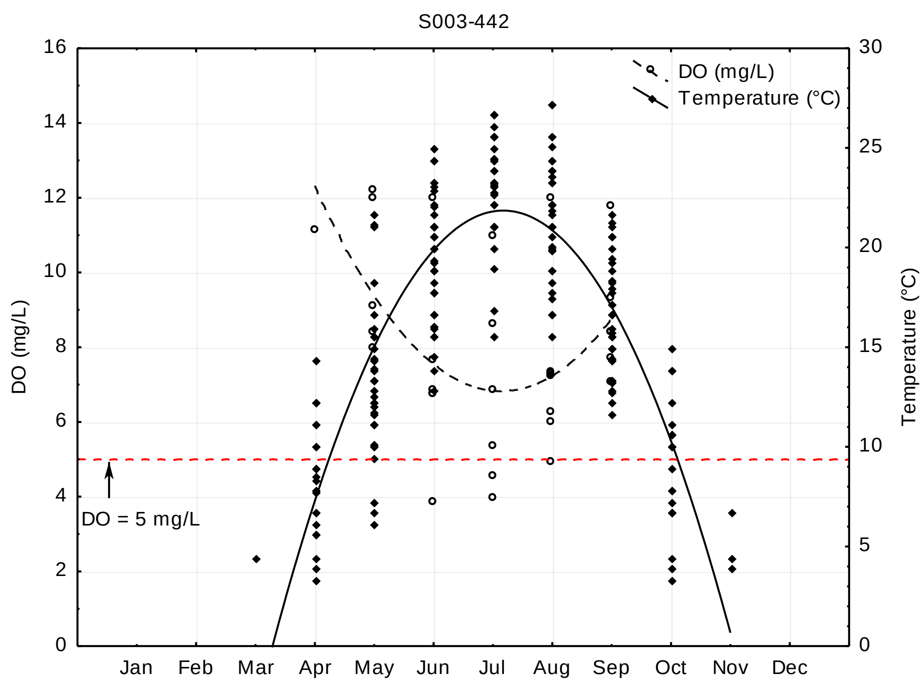
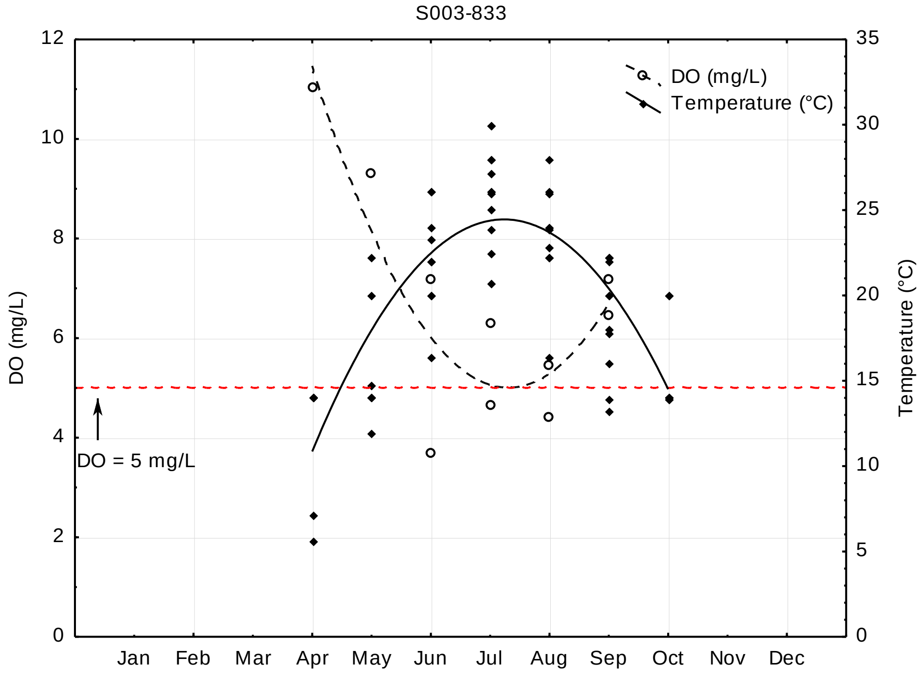


Figure 107. Water temperature (°C) and DO (mg/L) by month at station S003-833 on Shell River. Data available from 2002-2011.



14.3.3 Conclusions/Summary

Water temperature was identified as the primary stressor to low dissolved oxygen levels in the Shell River. Patterns of DO in the Shell River coincided strongly with seasonal variations in water temperature (Figure 105, Figure 106, and Figure 107), with the lowest dissolved oxygen levels occurring at the warmest water temperatures during the summer months. Moreover, increased groundwater appropriations for surface crop irrigation since 1988 in the Straight River area have been linked to increased water temperatures in the nearby Straight River by the Minnesota DNR[6].

[6] Minnesota Department of Natural Resources – Division of Waters. July 2002. *Surface Water and Ground Water Interaction and Thermal Changes in the Straight River in North Central Minnesota.*

15 LOAD DURATION CURVE SUPPORTING INFORMATION

15.1 Flow and Water Quality Data Sources

In the development of load duration curves, gaged flows or HSPF modeled stream flows were used with overlapping *E. coli* monitoring data wherever possible. In most cases, however, overlapping water quality and stream flow data were not available for one or both years of the monitoring record. To estimate missing flow records, regression equations were developed using 2000-2009 mean daily flow records for USGS gage #05347500 (Sylvan Dam outlet), and the corresponding flow records (gaged or HSPF modeled) for each impaired reach. Regression equations where then used to predict missing flow records using the 2010-2011 record at USGS gage #05347500. The sources of all water quality and stream flow data used in the development of phosphorus, heat capacity, and *E. coli* load duration curves are described in the following tables.

Table 117. Phosphorus LDC Flow and Water Quality Data Sources

Impaired Reach Name/AUID	Flow Data Location	Flow Data Range	Water Quality Station	Water Quality Data Range	Extrapolated flow regression equations[§]	Comments
Swan Creek 07010106-527	HSPF basin 575	2000-2009	S006-293	2010	$0.1055x^{0.7225}$	WQ station located approx. 2.4 km upstream of HSPF 575 outlet.
Iron Creek 07010106-593	Area weighted HSPF 575	2000-2009	S006-246	2010-2011	Area weighted from Swan Creek extrapolated flows	Area weighted flows based on Iron Creek drainage of 9.89 mi^2 and Swan Creek drainage = 47.3 mi^2

[§]Extrapolated flow based on regressions between 2000-2009 flows at the applicable HSPF basins and USGS gage #05247500 at the Sylvan Dam Outlet

Table 118. Temperature LDC Flow and Water Quality Data Sources

Impaired Reach Name/AUID	Flow Data Location	Flow Data Range	Water Quality Station	Water Quality Data Range	Extrapolated flow regression equations[§]	Comments
Shell River 07010106-981	DNR/MPCA gage #12021001 (CSAH23)	2004-2012	S002-962	2004, 2006-2007	N/A	Gage and WQ station are at the same location.
	Area weighted HSPF basin 530	2000-2009	S003-442	2004-2009	N/A	Area weighted flows based on HSPF basin 530 total area of 3,652 acres and the area above S003-442 of 1,920 acres
	HSPF basin 530	2000-2009	S002-833	2005-2008	N/A	
Straight River 07010106-558	USGS 05243725		S002-960	2001, 2004, 2006-2007, 2010-2011	N/A	
			S004-788	2007-2008	N/A	

[§]Extrapolated flow based on regressions between 2000-2009 flows at the applicable HSPF basins and USGS gage #05247500 at the Sylvan Dam Outlet

Table 119. *E. coli* LDC Flow and Water Quality Data Sources

Impaired Reach Name/AUID	Flow Data Location	Flow Data Range	Water Quality Station	Water Quality Data Range	Extrapolated flow regression equations§	Comments
Partridge River 07010106-518	HSPF basin 572	2000-2009	S002-961	2009-2010	$0.0423x^{0.9238}$	WQ station is located approximately 1.9 km upstream of the outlet of HSPF subbasin 572.
Home Brook 07010106-524	MPCA gage H12107001	2005-2012 (provisional data)	S004-728*	2010-2011	N/A	WQ station same approx. location at gage. Located in lower portion of impairment
	Area weighted MPCA gage H12107001	2005-2012 (provisional data)	S006-384	2010-2011	N/A	WQ station located at outlet of HSPF basin 587 (Upper Home Brook) Area weighted flow*= (0.545)(IMPCA gage H12107001)
Swan Creek 07010106-527	HSPF basin 575	2000-2009	S006-293	2010-2011	$0.1055x^{0.7225}$	WQ station located approx. 2.4 km upstream of HSPF 575 outlet.
Cat River 07010106-544	HSPF basin 559	2000-2009	S002-408	2009-2010	$0.0854x^{0.7483}$	WQ station located approx. 1.4 km upstream of confluence with Crow Wing River.
Pillager Creek 07010106-577	HSPF basin 584	2000-2009	S006-249	2010-2011	$0.0483x^{0.679}$	WQ station located approx. 1.5 km upstream of confluence with Crow Wing River.
Mayo Creek 07010106-604	HSPF 590 basin plus HSPF basin 591 less components upstream of Sibley Lake	2000-2009	S006-245	2010-2011	$0.0531x^{0.6994}$	WQ station is located 3.9 km upstream of inlet to Sibley Lake (HSPF basin 591)
Unnamed Creek 07010106-684	Area weighted HSPF basin 577 less upstream HSPF basin 576	2000-2009	S006-255	2010-2011	$1.4238x^{0.7993}$	WQ station located approx. 1.9 km upstream of confluence with Crow Wing River Area weighted flow§§= (0.516)(HSPF basin 577 – HSPF basin 576)
Stoney Brook 07010106-698	HSPF basin 589	2000-2009	S006-254	2010-2011	$0.1844x^{0.6294}$	WQ station located approx. 4 km upstream of outlet to HSPF 589 (300m from basin outlet to Upper Gull Lake).

Impaired Reach Name/AUID	Flow Data Location	Flow Data Range	Water Quality Station	Water Quality Data Range	Extrapolated flow regression equations§	Comments
Corey Brook 07010106-700	Area weighted MPCA gage H12107001	2005-2012	S006-248	2010-2011	N/A	WQ station approximately 440 meters upstream of confluence with Home Brook Area weighted flow*= (0.28)(MPCA gage H12107001)
Farnham Creek 07010106-702	HSPF basin 267 plus area weighted components of HSPF basin 568	2000-2009	S006-253	2010-2011	Area weighted§§ flow from MN DNR/MPCA Coop. Stream Gage #12082001	Gaging located approx. 0.7 km upstream of outlet to basin 568. WQ stations located approx. 16.5 km & 15 km and impaired reach approx. 5 km to 18 km upstream of the gaging station. HSPF area weighted flow**= (0.202)(HSPF 568 components) Gaged area weighted flow**= (0.377)(DNR/MPCA #12082001)

§Extrapolated flow based on regressions between 2000-2009 flows at the applicable HSPF basins and USGS gage #05247500 at the Sylvan Dam Outlet
§§Watershed areas: HSPF Subbasin 577 = 18,606 acres, Unnamed at WQ station = 9,600 acres.
*Watershed areas: Home Brook at MPCA gage H12107001 = 24,052 acres, Home Brook at HSPF 587 outlet = 13,117 acres, Corey Brook = 6,447 acres (located in 588, within portion upstream of Home Brook MPCA gage H12107001).
**Watershed areas: HSPF 568 = 26,386, Farnham Creek total = 33,812.5 acres, Farnham Creek downstream of impaired reach = 21,049 acres (portion of HSPF 568).

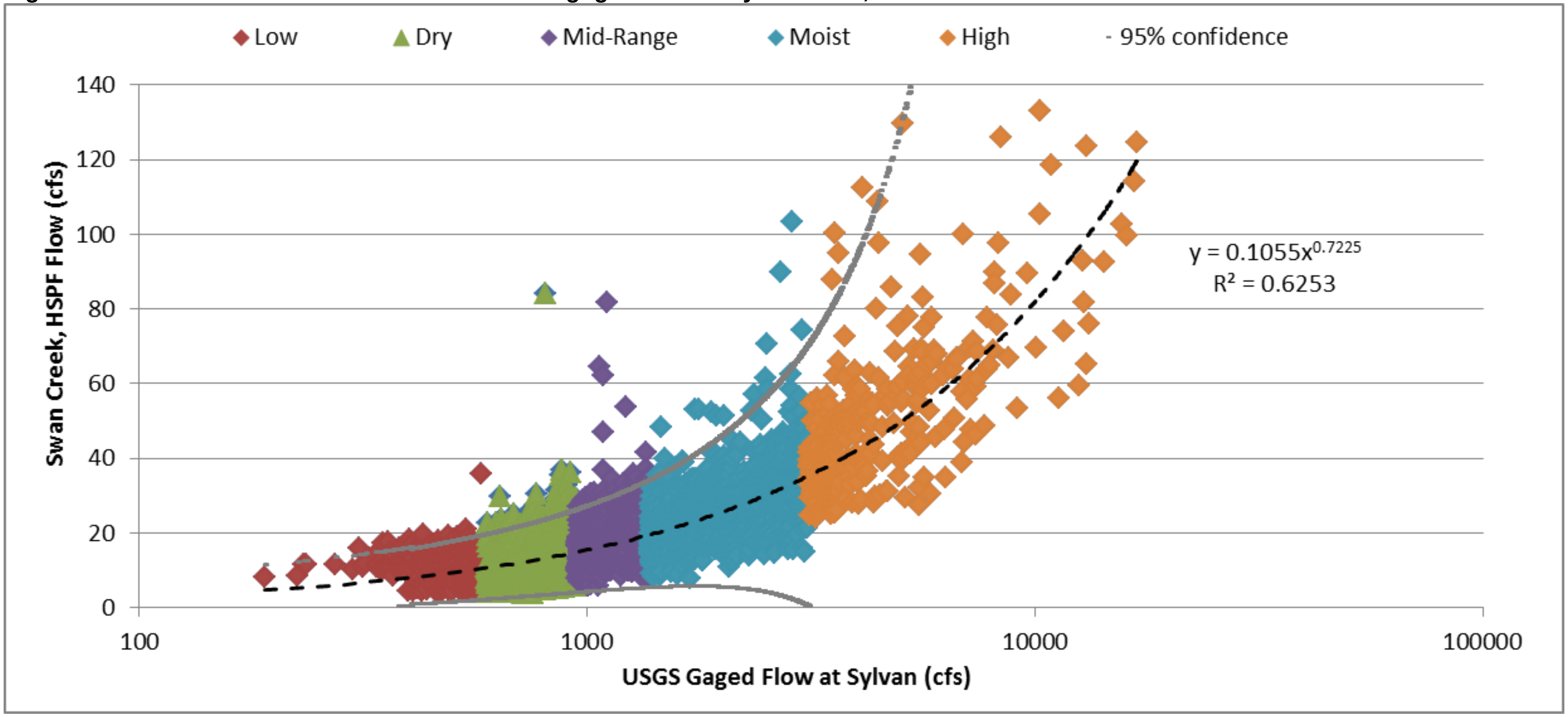
15.2 Flow Extrapolation Error Analysis

HSPF modeled flow data for only the years 2000-2009 was available for the Crow Wing River watershed. In subwatersheds for which 2010, 2011, or both years of flow records could not be reasonably estimated based on nearby gage station records, regressions were developed to estimate HSPF flows based on flow records from USGS gage #05347500 for the years 2000-2009 (the period of record overlap). As an example, Figure 108 shows the regression for Swan Creek HSPF flows on the USGS gage. Ninety-five percent confidence intervals for the regression are shown in grey. On average, the regression tends to underestimate the highest flow events and standard deviations increase from low to high flow regimes. This pattern and the relative magnitude of the 95% confidence interval are typical of all regressions developed to estimate missing flow records. See Table 117, Table 118, and Table 119 for a list of flow estimation methods used in the development of load duration curves.

Since the existing loads written in many of the stream TMDLs are based on flows extrapolated from regression equations, there is a corresponding uncertainty in the estimates of these existing loads. Additional sources of error in flow (and therefore load) estimates include:

- Uncertainty inherent in HSPF modeled flow data
- Uncertainty in gaged flow records
- Uncertainty introduced by area-weighting flows where this was required
- Uncertainty in reported monitoring data

Figure 108. Swan Creek HSPF flow versus USGS gaged flow at Sylvan Dam, 2000-2009.



16 HSPF MODEL CALIBRATION AND VALIDATION

The following report detailing the calibration and validation of hydrology, sediment, and water quality constituents for the Crow Wing River Watershed HSPF model will be publicly available on the Crow Wing River Watershed webpage: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/crow-wing-river.html

HSPF Watershed Modeling Phase 3 for the Crow Wing, Redeye, and Long Prairie Rivers Watersheds: Calibration and Validation of Hydrology, Sediment, and Water Quality Constituents Final Report

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EXECUTIVE SUMMARY

The United States Environmental Protection Agency (USEPA) requires the Minnesota Pollution Control Agency (MPCA) to carry out the Total Maximum Daily Load (TMDL) Program in the state of Minnesota. In an effort to expedite the completion of TMDL projects, MPCA has decided to construct watershed models to support the simultaneous development of TMDL studies for multiple listings within a cataloging unit or 8-digit Hydrologic Unit Code (HUC) watershed. As part of the model development process AQUA TERRA Consultants was contracted to develop watershed models for the Crow Wing River (HUC - 07010106), the Redeye River (HUC - 07010107), and the Long Prairie River (HUC - 07010108). Both the Long Prairie and Redeye Rivers flow into the Crow Wing River which flows into the Mississippi River.

This project was divided into multiple phases where the first two phases required the compilation and processing of geographical, meteorological, point source, and observed data for model development; proposal of model calibration approach; and completion of initial hydrologic calibration. In this final phase of the project, AQUA TERRA Consultants was contracted to finalize the hydrologic and water quality calibration and validation.

This report documents the final phase of the modeling project that includes:

- the results of hydrology calibration and validation,
- the review for sediment apportionment, and
- the results of water quality calibration and validation that include water temperature, sediment, nitrogen, phosphorus, organics, and chlorophyll-a.

Overall, the model performance for hydrology calibration and validation was satisfactory based on the model performance criteria, except at the most upstream gage, Straight River in Crow Wing watershed. This station is affected significantly by groundwater flow from outside the watershed, and the management of an upstream lake. Additional data collection and groundwater study may be required to improve the calibration at this location.

The water quality data was available at multiple locations in the watersheds and the model simulated water quality constituents close to the observed data. The observed data was not sufficient to conduct detailed statistical analysis, and therefore the quality of calibration and validation was based on the visual assessment of various graphs.

The watershed model for these three watersheds was developed at a scale so that all the waterbodies included in the draft 2010 TMDL list were modeled explicitly. Thus, the final model can be successfully used for TMDL development of smaller waterbodies in the watershed, and the model outputs can be used for finer scale assessments, or as input to other waterbody models.

As reported by MPCA, additional water quality data was collected after the calibration period (2003 to 2009) and significant water quality data was collected in 2011. Extending the model calibration period to include the additional years could improve model performance and increase the confidence in model results. Model extension should also provide enough data to analyze the model performance statistically. The Crow Wing watersheds have a significant number of lakes, and the water quality simulation of lakes can be improved with better hydraulic information.