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Ann River Watershed Bacteria, Nutrient, and Biota TMDL

Prepared for:

KANABEC COUNTY SOIL AND WATER CONSERVATION DISTRICT

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TMDL Summary Table

EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
Loading Capacity (expressed as daily load)	Bacteria: *See Section 3.4.1* Lake Nutrients: *See Section 4.7.1* Biotic Integrity: *See Section 5.3.4*	Bacteria P. 3-5 Lake Nutrients P. 4-29 Biotic P. 5-15
Wasteload Allocation	Bacteria: *See Section 3.4.3.* Lake Nutrients: *See Section 4.7.2.1* Biotic Integrity: *See Section 5.3.1*	Bacteria P. 3-8 Lake Nutrients P. 4-30 Biotic P. 5-12
Load Allocation	Bacteria: *See Section 3.4.4* Lake Nutrients: *See Section 4.7.2* Biotic Integrity: *See Section 5.3.2*	Bacteria P. 3-8 Lake Nutrients Pp. 4-29,30 Biotic P. 5-12
Margin of Safety	Bacteria: An explicit 5% of loading capacity for each flow zone was used to represent the MOS. *See Section 3.4.2* Lake Nutrients: Explicit MOSs of 5% and 10% were used for Ann and Fish Lake, respectively. *See Section 4.7.3* Biotic Integrity: An explicit 10% of loading capacity from streambank sources was used for the MOS. *See Section 5.3.3*	Bacteria P. 3-7 Lake Nutrients P. 4-31 Biotic P. 5-15
Seasonal Variation	Bacteria: Load duration curve methodology accounts for seasonal variations. *See Section 3.4.1* Lake Nutrients: *See Section 4.7.6* Biotic Integrity: *See Section 5.3.5*	Bacteria P. 3-5 Lake Nutrients P. 4-35 Biotic P. 5-15
Reasonable Assurance	TMDL implementation will be carried out on an iterative basis so that implementation course corrections based on periodic monitoring and reevaluation can adjust the strategy to meet the standard. *See Section 7.0*	Section 7.0, P. 7-1
Monitoring	Progress of TMDL implementation will be measured through regular monitoring efforts of water quality and total BMPs completed. This will be accomplished through the efforts of	Section 8.0, P. 7-3,4

TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
	several cooperating agencies and groups. *See Section 8.0*	
Implementation	This report sets forth an implementation framework to achieve the TMDL. (A separate more detailed implementation plan will be developed within one year after of EPA's approval of this TMDL report.) *See Section 6.0*	Section 6.0, P. 6-1
Public Participation	*See Section 9.0* Public Comment Period: January 14th – February 13th, 2013	Section 9.0, P. 9-1

Acronyms

AUID	Assessment Unit ID
BMP	Best Management Practice
BWSR	Board of Water and Soil Resources
CADDIS	Causal Analysis/Diagnosis Decision Information System
CAFO	Confined Animal Feeding Operation
cfu	colony-forming unit
CHF	Central Hardwoods Forest
Chl-a	Chlorophyll-a
CLWP	Comprehensive Local Water Plan
CR	County Road
CWP	Clean Water Partnership
DNR	Department of Natural Resources
DO	Dissolved oxygen
DOQ	Digital Ortho Quadrangle
EQuIS	Environmental Quality Information System
F-IBI	Index of Biotic Integrity for Fish
FSA	Farm Service Agency
ft^3	cubic foot
ft/s^2	Foot per second squared
GIS	Geographical Information System
GSM	Growing Season Mean
HRU	Hydrologic Response Unit
IBI	Index of Biotic Integrity
IRG	intensive rotation grazing
kg/km^2-year	kilograms per square kilometer per year
kg/m^3	kilogram per cubic meter
LA	Load Allocation
lb/ft^2	pounds per square foot

m	meter
m^2/day	meters squared per day
m^2/mg	meters squared per milligram
m/s^2	meter per second squared
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day
M-IBI	Index of Biotic Integrity for Macroinvertebrates
ml	milliliter
mm	millimeter
mm/ft	millimeter per foot
mm/m	millimeter per meter
MN DNR	Minnesota Department of Natural Resources
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MR	Minnesota Rules
MS4	Municipal Separate Storm Sewer Systems
MSHA	Minnesota Stream Habitat Assessment
NASS	National Agricultural Statistics Service
NAWQA	National Water Quality Assessment Program
NCHF	North Central Hardwood Forest
NH_3-N	Total Ammonia-Nitrogen
NLF	Northern Lakes and Forests
NO_2/ NO_3-N	Nitrite/ Nitrate- Nitrogen
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	Natural Resource Conservation Service
NTU	Nephelometric Turbidity Units
NWI	National Wetland Inventory
ppb	parts per billion
RC&D	Resource Conservation and Development (Council)

SCS	Soil Conservation Service
SDS	State Disposal System
SONAR	Statement of Need and Reasonableness
SRWMB	Snake River Watershed Management Board
SSTS	Subsurface Sewage Treatment Systems
SSURGO	Soil Survey Geographic
SWCD	Soil and Water Conservation District
TDLC	Total Daily Loading Capacity
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSA	Technical Service Area
TSS	Total Suspended Solids
UAL	Unit-area Load
µg/L	microgram per liter
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WCA	Wetland Conservation Act
WMA	Wildlife Management Areas
WLA	Wasteload Allocation

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments in Ann Lake and Fish Lake, and fish and macroinvertebrate biotic integrity and *E. coli* impairments in the Ann River. The Ann River Watershed covers just over 86 square miles, and is located in Kanabec and Mille Lacs Counties in northern Minnesota. This watershed is part of the larger Snake River watershed, which is located in the St. Croix Basin. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients in Ann and Fish Lakes and *E. coli* and State Index of Biotic Integrity standards in the Ann River. This Ann River Watershed Bacteria, Nutrient, and Biota TMDL is established in accordance with Section 303(d) of the Clean Water Act and provides wasteload allocations (WLAs) and load allocations (LAs) for the Ann River Watershed.

Lakes. Ann and Fish Lake do not meet current Minnesota lake water quality standards for shallow lakes in the North Central Hardwood Forest ecoregion. While there is some variability in the monitoring data from year to year, observations over the past 10 years have been relatively stable, with no significant declines or improvements over this time period.

Phosphorus loading to Ann Lake is split almost evenly between watershed runoff and internal loading. A 39% reduction in overall phosphorus loading to Ann Lake is required to meet the State shallow lake growing season mean (GSM) standard of 60 µg/L. Reductions in internal loading to the lake are sufficient to meet the TMDL. However, as a margin of safety, the TMDL includes a 4% load reduction from the watershed. For Fish Lake, the majority of the phosphorus load is coming from upstream lakes, primarily Ann Lake, and watershed runoff from the land area between the Ann Lake outlet and Fish Lake. Fish Lake needs a 42% reduction in phosphorus loading to meet the TMDL with large reductions required from both the internal and watershed loads. It is also assumed that all subsurface sewage treatment systems (SSTSs) will be made compliant through future SSTS loans and grant funds. An important factor in meeting the TMDL in Fish Lake is the improvement of Ann Lake to meet the shallow lake standard of 60 µg/L GSM.

E. coli. Bacterial impairments in Ann River extend across all flow regimes and seasons. Under low flows, runoff processes are minimal as bacteria concentrations are primarily driven by failing SSTSs and animals in or near the receiving water. Conversely, at high flows, runoff from land with bacteria concentrations such as feedlots and pastures, urban areas and cropland often dominate. Exceedances appear to occur across all flow regimes in the bacteria-listed reach of Ann River. This suggests that, at times, all of the aforementioned flow-driven sources may contribute to high bacteria concentrations observed throughout this reach.

Potential bacterial sources were inventoried and their potential contribution to bacterial load were calculated. Livestock are by far the biggest producer of bacteria in the impaired reach watershed. The largest sources are those activities associated with pasture management. Limiting cattle access to Ann River and its tributaries and buffering runoff from pastures near streams and waterways will be necessary to reduce bacterial loads. BMPs for upland pasture land should also be implemented. Failing SSTSs also appear to be a relatively small source compared to livestock. However, depending on their location and level of failure, these systems have the potential to be significant bacteria contributors during low flow conditions and should be inspected and improved as necessary.

Biotic Integrity. The MPCA has developed an Index of Biotic Integrity (IBI) to evaluate the biological health of streams in the State. Currently, an IBI has been developed for two biological communities, fish and macroinvertebrates. Ann River is impaired based on both fish IBI (F-IBI) and the macroinvertebrate IBI (M-IBI). The fish impairment is not severe, with some sites scoring above the fish IBI standard and some less than but within the IBI confidence interval. Drought conditions during the macroinvertebrate sampling period 2006-2007 limits the usefulness of data collected at some of the monitoring sites. One site with acceptable data showed consistent impairment while others were less consistent.

A Stressor Identification Report was completed in spring 2009 using the USEPA's Causal Analysis/Diagnosis Decision Information System (CADDIS), which is a methodology for conducting a stepwise analysis of candidate causes of impairment using a "strength of evidence" approach to evaluate candidate causes affecting biotic integrity. Five candidate causes were identified in the Stressor ID – bedded sediment, riparian degradation, low dissolved oxygen, and loss of connectivity and altered flow due to dams on the river. The evidence is strongest that lack of benthic habitat due to sedimentation and impacts from riparian degradation are primary stressors to aquatic life in the Ann River. Low dissolved oxygen and the loss of connectivity due to dams are plausible stressors and are likely contributing to the impairment, however there is less direct or conflicting evidence of their role. Flow alteration was identified as a potential stressor but there is not enough evidence available to evaluate its strength.

Further assessment identified streambank erosion as a primary source of excess sediment. Stream morphology limits the ability of the stream to effectively transport excess sediment, which is causing aggradation and embeddedness that affects the quality of benthic habitat. Streambank instability is exacerbated by the type of vegetation maintained in the degraded riparian zone – primarily short pasture grasses. Animals generally enjoy unrestricted access to the stream, which has resulted in streambank failures and bare or sparsely vegetated banks and riparian area. Occasions of low dissolved oxygen concentrations are likely the result of excessive stream warming due to a lack of tree canopy, excessive sediment oxygen demand from overwide channels, and nutrient enrichment.

Restoration of eroded streambanks to reduce sediment contribution and channel narrowing to improve sediment flushing would have the greatest impact on improving benthic habitat. Planting wide native buffers and reestablishing a canopy cover should also be completed to reduce nutrient enrichment, decrease stream temperature, and increase dissolved oxygen. Improving water quality in Ann Lake will also reduce nutrient enrichment in flow discharged from the lake into the Ann River.

1.0 Introduction

1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments in Ann Lake and Fish Lake, and fish and macroinvertebrate biotic integrity and *E. coli* impairments in the Ann River. Ann Lake and Fish Lake are located in the Ann River subwatershed of the Snake River watershed, which is located in the St. Croix River major basin of Minnesota. The subwatershed is drained by the Ann River, which flows into the Snake River and eventually to the St. Croix River.

The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients in Ann and Fish Lakes and bacteria and State Index of Biotic Integrity standards in the Ann River. This Ann River Watershed Bacteria, Nutrient, and Biota TMDL is established in accordance with Section 303(d) of the Clean Water Act and provides wasteload allocations (WLAs) and load allocations (LAs) for the Ann River Watershed.

1.2 PROBLEM IDENTIFICATION

The Ann River (AUID 07030004-511) was first placed by the Minnesota Pollution Control Agency (MPCA) on the State of Minnesota's 303(d) list of impaired waters in 2002 for impaired biota (fish) based on bioassessments completed in 1996 and 1998. Subsequent monitoring confirmed the fish impairment. In 2010, the Ann River was placed on the 303(d) list for impaired biota (invertebrate) based on bioassessments completed in 1996 and confirmed by subsequent sampling. The Ann River was also listed in 2010 for excess *E. coli* concentrations. In 2004, Ann Lake (33-0040-00) and Fish Lake (33-0036-00) were both placed on the 303(d) list for nutrient (total phosphorus) impairment. Table 1.1 details those listings, which are shown on Figure 1.1.

Table 1.1. Waters in the Ann River watershed listed on the MPCA draft 2012 303(d) list of impaired waters.

Water Body	Yr Listed	Assessment Unit ID	Affected use	Pollutant or stressor	Target start// completion
Ann River – Ann Lake to confluence with Snake River	2002	07030004-511	Aquatic life	Fish Bioassessment	2008//2013
Ann River – Ann Lake to confluence with Snake River	2010	07030004-511	Aquatic life	Invertebrate Bioassessment	2008//2013
Ann River – Ann Lake to confluence with Snake River	2010	07030004-511	Aquatic recreation	*E. coli*	2008//2013
Ann Lake	2004	33-0040-00	Aquatic recreation	Excess Nutrients	2008//2013
Fish Lake	2004	33-0036-00	Aquatic recreation	Excess Nutrients	2008//2013

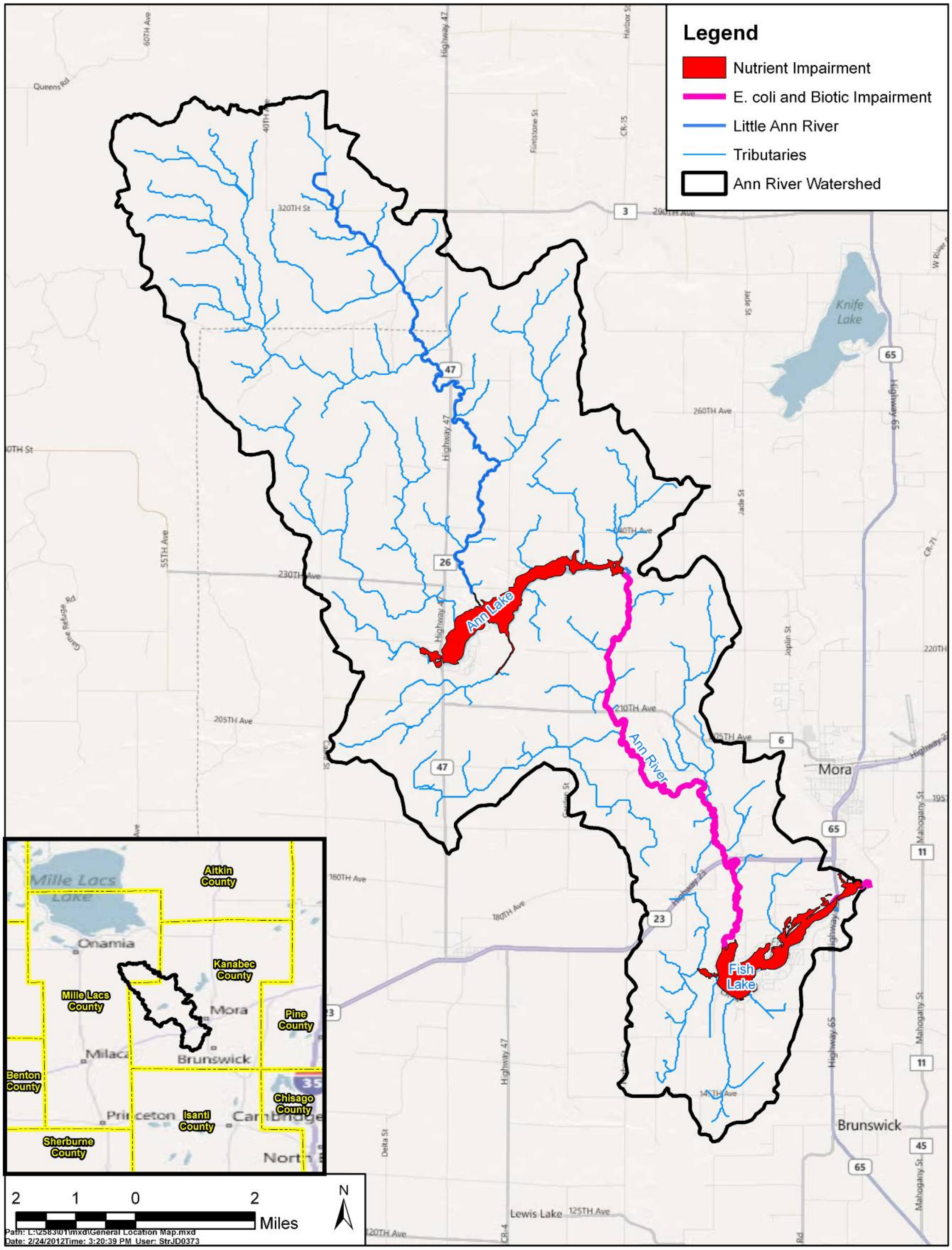

Figure 1.1 Impaired waters in the Ann River watershed.

1.3 IMPAIRED WATERS AND MINNESOTA WATER QUALITY STANDARDS

1.3.1 State of Minnesota Designated Uses

Ann River, Ann Lake, and Fish Lake are classified as class 2B waters for which aquatic life and recreation are the protected beneficial uses. The MPCA's projected schedule for TMDL completions on the 303(d) impaired waters list implicitly reflects Minnesota's priority ranking of this TMDL, which was scheduled to be initiated in 2008 and completed by 2013. 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.

1.3.2 State of Minnesota Standards and Criteria for Listing

Biotic Integrity. Minnesota's standard for biotic integrity is set forth in Minnesota Rules (MR) 7050.0150 (3) and (6). The standard uses an Index of Biotic Integrity (IBI), which evaluates and integrates multiple attributes of the aquatic community, or "metrics," to evaluate a complex biological system. Each metric is based upon a structural (e.g., species composition) or functional (e.g., feeding habits) aspect of the aquatic community that changes in a predictable way in response to human disturbance. Fish and macroinvertebrate IBIs are expressed as a score that ranges from 0-100, with 100 being the best score possible. The MPCA has evaluated fish and macroinvertebrate communities at numerous reference sites across Minnesota that have been minimally impacted by human activity, and has established IBI impairment thresholds based on stream drainage area, ecoregion, and major basin. A stream's biota is considered to be impaired when the IBI falls below the threshold established for that category of stream.

E. coli. The fecal coliform standard contained in MR. 7050.0222 (5) states that fecal coliform concentrations shall "not exceed 200 organisms per 100 milliliters as a geometric mean of not less than five samples in any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 2000 organisms per 100 milliliters. The standard applies only between April 1 and October 31." Impairment assessment is based on the procedures contained in the Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment (MPCA 2005).

With the revisions of Minnesota's water quality rules in 2008, the State changed to an *E. coli* standard because it is a superior potential illness indicator and costs for lab analysis are less (MPCA 2007). The revised standards now state:

"*E. coli* concentrations are not to exceed 126 colony forming units per 100 milliliters (cfu/100 ml) 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 cfu/100 ml. The standard applies only between April 1 and October 31."

The *E. coli* concentration standard of 126 cfu/100 ml was considered reasonably equivalent to the fecal coliform standard of 200 cfu/100 ml from a public health protection standpoint. The SONAR (Statement of Need and Reasonableness) section that supports this rationale uses a log plot to show the relationship between these two parameters. The relationship has an R^2 value of 0.69. The following regression equation was deemed reasonable to convert fecal coliform data to *E. coli* equivalents:

E coli concentration (equivalents) = 1.80 x (Fecal Coliform Concentration)$^{0.81}$

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

The numeric target used to list Ann Lake and Fish Lake in 2004 was the phosphorus threshold for Class 2B waters in the North Central Hardwood Forest (NCHF) ecoregion (Table 1.2). However, after Ann Lake was placed on the 2004 303(d) impaired waters list, the boundary between the NCHF and Northern Lakes and Forest (NLF) ecoregions was shifted, which put Ann Lake mostly in the NLF ecoregion. But despite this change, Ann Lake was considered to be in the NCHF for the purpose of this TMDL because it actually straddles the ecoregion boundary and shares key characteristics with Fish Lake: the two lakes are shallow, similar in water quality, and similar in origin (both are former wetlands flooded by constructed outlets). The Water Quality Standards Unit of the Water Assessment and Environmental Information Section of MPCA concurs that the NCHF ecoregion is appropriate for use in Ann Lake's TMDL.

Table 1.2. Trophic status thresholds for determination of use support for lakes.

305(b) Designation	**Full Support**			**Partial Support to Potential Non-Support**			
303(d) Designation	**Not Listed**			**Review**	**Listed**		
Ecoregion	**TP (ppb)**	**Chl-a (ppb)**	**Secchi (m)**	**TP Range (ppb)**	**TP (ppb)**	**Chl-a (ppb)**	**Secchi (m)**
North Central Hardwood Forests	< 40	< 14	> 1.4	40 - 45	> 45	> 18	< 1.1

Minnesota adopted lake water quality standards in 2008. Both lakes are shallow lakes as defined in Minnesota statute. The total phosphorus standard that applies to them, therefore, is the NCHF shallow lake standard of 60 µg/L (Table 1.3). Regression equations developed by the MPCA (2005) suggest that the two response variable, Secchi depth and chlorophyll-a, should also meet state standards when the necessary phosphorus reductions are made.

Table 1.3.Numeric standards for shallow lakes in the North Central Hardwood Forest ecoregion.

Parameters	**Standard**
Phosphorus Concentration (µg/L)	≤60
Chlorophyll-a Concentration (µg/L)	≤20
Secchi disk transparency (meters)	≥1.0

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

1.4 ANALYSIS OF IMPAIRMENT

The criteria used for determining impairments are outlined in the MPCA document Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment – 305(b) Report and 303(d) List, January 2010. The applicable water body classifications and water quality standards are specified in MR Chapter 7050. MR 7050.0407 lists water body classifications and MR 7050.2222 (5) lists applicable water quality standards.

Biotic Impairment. Table 1.4 shows the Index of Biotic Integrity scores used to evaluate the Ann River for biotic impairment.

Table 1.4. Index of Biotic Integrity standards and relevant Ann River data.

Year	Station ID	Location	Fish IBI		Invertebrate IBI	
			Standard	Score	Standard*	Score
2006	06SC122	Downstream of Hwy 23	69	71	39.5*	24
1998	98SC019	Upstream of CSAH 14	69	44	41.2	61
2006	06SC136	Upstream of CR 12	69	67	41.2	43
1996	96SC021	Downstream of CR 12	69	N/A	41.2	42

*The site downstream of Hwy 23 was evaluated against metrics for low-gradient streams; the other sites were evaluated based on metrics for high-gradient streams.

Nutrients. In 2004, Ann Lake and Fish Lake were both listed for nutrient impairments due to excess total phosphorus. The lakes also did not meet either chlorophyll-a or Secchi depth standards (Table 1.5).

Table 1.5. Lake nutrient standards and 2006 assessment data.

Water Body	Total Phosphorus (µg/L)		Chlorophyll-a (µg/L)		Secchi Depth (m)	
	Standard	2006 Data	Standard	2006 Data	Standard	2006 Data
Ann Lake	<60	90	<20	42	≥1.0	0.9
Fish Lake	<60	162	<20	64	≥1.0	0.8

E. coli. The Ann River was listed as impaired for bacteria in 2010. In 2007, as part of the Phase II biological assessment, MPCA staff collected *E. coli* samples from various sites throughout the Ann River watershed, which indicated exceedances of the bacteria standard. Additional samples taken in 2008 and 2009 that provided the necessary information to list the Ann River for *E. coli* and bacteria impairment.

If the geometric mean of the aggregated monthly *E. coli* concentrations for one or more months exceed 126 organisms per 100 ml, that reach is placed on the 303(d) impaired list. Also, a waterbody is considered impaired if more than 10% of the individual samples over the 10-year period (independent of month) exceed 1,260 organisms per 100 ml (cfu/100 ml).

1.5 DATA USED IN THE TMDL

This TMDL incorporates monitoring conducted for this report as well as previous studies and TMDLs prepared by the MPCA and the Mille Lacs and Kanabec SWCDs. This includes:

- A Stressor Identification (ID) report completed in 2009 for this study for Ann River fish and macroinvertebrates (Jasperson 2011).
- Chemical, physical, and biological monitoring conducted by the Kanabec SWCD, Citizen's Lake Monitoring Partnership, MPCA, Minnesota Department of Natural Resources (MN DNR), and USGS.

2.0 Watershed and Stream Characterization

2.1 ANN RIVER WATERSHED DESCRIPTION

The Ann River Watershed covers just over 86 square miles, and is located in Kanabec and Mille Lacs Counties (Figure 2.1). This watershed is part of the larger Snake River watershed, which is located in the St. Croix Basin. The watershed includes two major lakes, Ann Lake and Fish Lake. Ann Lake is the headwater of the Ann River, which starts at the outfall of the dam of Ann Lake and then flows southeast toward the City of Mora, where it enters Fish Lake. The outlet of Fish Lake is a short distance northeast of the confluence with the Ann River and flows into the Snake River. The upper watershed is drained by the Little Ann River, Camp Creek, Spring Brook and several smaller tributaries which drain to Ann Lake.

Ann Lake and Fish Lake are both reservoirs created by dams on Ann River. Both of these lakes are shallow, with maximum depths of 17 feet in Ann Lake and 10 feet in Fish Lake. Ann Lake has a surface area of 653 acres, while Fish Lake's is 407 acres.

2.2 LAND COVER

The communities nearest to the water bodies are the Cities of Mora and Ogilvie. In 2009, Mora had a population of approximately 3,600, while Ogilvie's population was about 460. The watershed is primarily rural and undeveloped. Forest and agriculture are the dominant land use types in the watershed, as shown in Table 2.1 and Figure 2.2.

Table 2.1. 2009 Land Cover of the Ann River Watershed.

Land Use	Area (acres)	Percent
Forest and Shrubland	33,709	61%
Hay and Pasture	13,206	24%
Wetlands and Open Water	5,404	10%
Urban/Roads	1,723	3%
Corn/Soybeans	1,088	2%
Grains and other Crops	300	<1%
TOTAL	55,430	100%

Source: 2009 NASS

The upper watershed includes part of the Mille Lacs Wildlife Management Area (WMA), which is managed by the Minnesota DNR for wildlife management, hunting, trapping, and hiking, and includes the Dewitt Pool and Marsh. On the south side of Ann Lake the Ann Lake WMA is managed for hunting and for wildlife viewing as is the Tosher Creek WMA on the west side of Fish Lake.

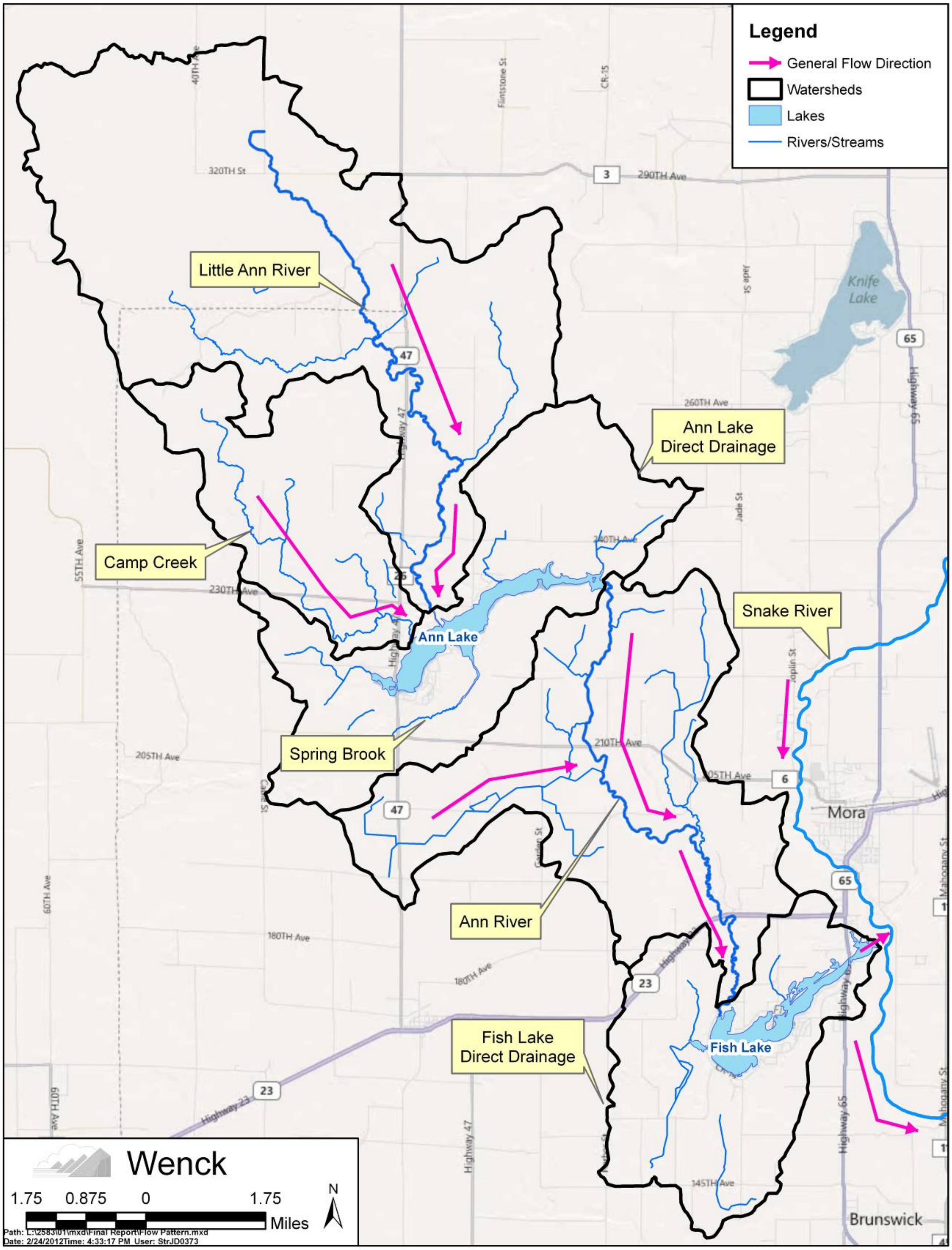

Figure 2.1. Ann River watershed flow patterns.

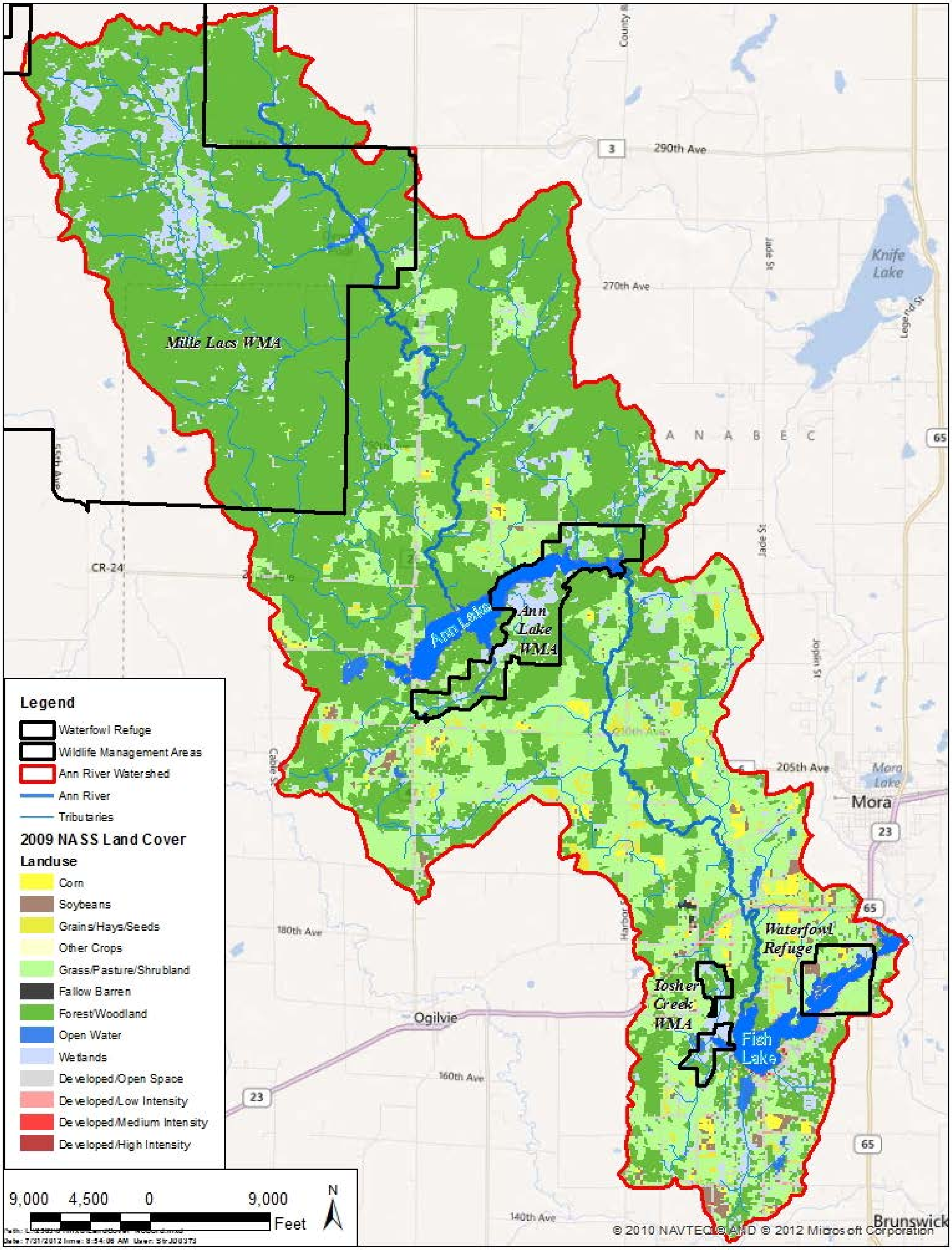

Figure 2.2. 2009 land cover in the Ann River watershed.

2.3 BIOTIC INTEGRITY IN ANN RIVER

The MPCA has developed an Index of Biotic Integrity (IBI) to evaluate the biological health of streams in the State. Currently, an IBI has been developed for two biological communities, fish and macroinvertebrates. Ann River is impaired based on both fish IBI (F-IBI) and the macroinvertebrate IBI (M-IBI).

The fish impairment was listed on the basis of monitoring conducted in 1996 and 1998 (see Figure 2.3 for monitoring locations.) Further fish and macroinvertebrate sampling was conducted in 2006-2008, which confirmed the fish impairment and strengthened the case for the macroinvertebrate listing. A new macroinvertebrate IBI was released in 2010, which was used to evaluate data and identify the macroinvertebrate impairment.

A Stressor Identification Report was completed in 2009 (Jasperson 2011) for both the fish and macroinvertebrate communities. This TMDL report summarizes the fish data and IBI results that were evaluated in more detail in that Stressor ID. The fish community was found to display both localized and systemic (watershed-wide) indicators of impairment. Localized indicators primarily relate to the availability and quality of benthic habitat at the different sampling sites influencing the numbers of and taxa richness of lithophilic species and benthic insectivores. More generally, the fish data indicate a comparative lack of common piscivorous, sensitive, and darter species that reflects degraded conditions in the stream. The fish impairment is not severe, with some sites scoring above the fish IBI standard and some less than but within the IBI confidence interval. The Stressor ID Study concluded that Sites 5, 6, and 8 did not meet the IBI standard (Figure 2.3).

Drought conditions during the macroinvertebrate sampling period 2006-2007 limits the usefulness of data collected at some of the monitoring sites. One site with acceptable data, Site 6, showed consistent impairment, indicated by an abundance of pollution-tolerant taxa and taxa that are often indicators of nutrient enrichment or low dissolved oxygen conditions. One site with acceptable data, Site 8, scored well above the IBI threshold. Sampling data from other sites did not meet MPCA data quality standards due to low water conditions.

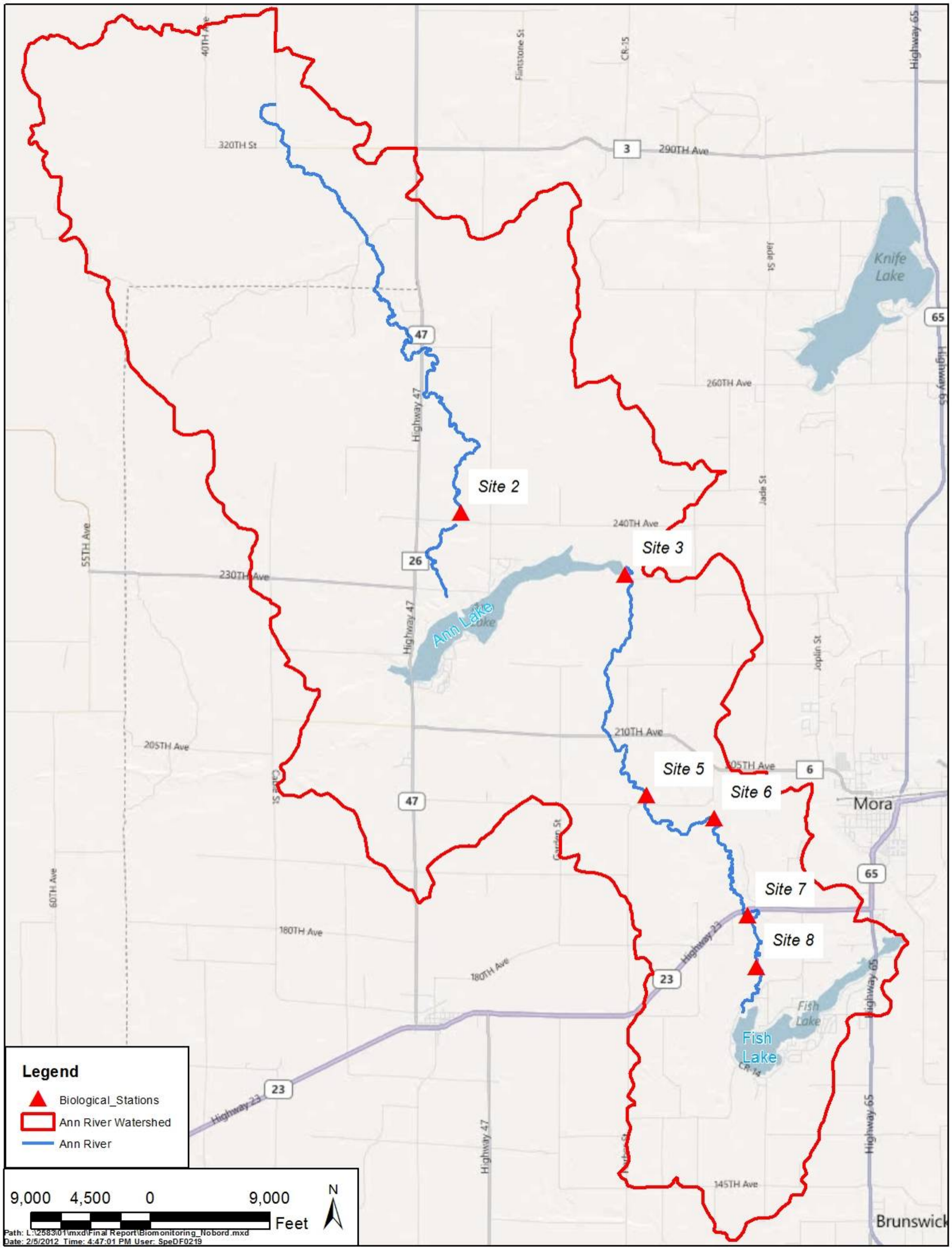

Figure 2.3. Biomonitoring locations from the Stressor Identification Study.

2.4 FACTORS INFLUENCING BIOTIC INTEGRITY IN THE ANN RIVER

The Stressor Identification analysis prepared for this TMDL used the United States Environmental Protection Agency's (US EPA) and MPCA's Stressor Identification guidance (Jasperson 2009) and the US EPA's Causal Analysis/Diagnosis Decision Information System (CADDIS). CADDIS (USEPA 2007), a methodology for conducting a stepwise analysis of candidate causes of impairment, characterizes the potential relationships between candidate causes and stressors, and identifies the probable stressors based on the strength of evidence from available data.

Potential candidate causes of the impairments that were ruled out based on a review of available data include: pH; turbidity/TSS; halogens/halides or salinity; pesticides and insecticides; toxic chemicals; interspecific competition; and heavy metals toxicity. Five stressors that are potential candidate causes were examined in more detail: loss of habitat due to substrate embeddedness; low dissolved oxygen concentrations; altered riparian corridor/channel morphology; loss of connectivity and habitat fragmentation; and altered flow regime. The Ann River Stressor Identification Report (Jasperson 2011) is incorporated into this report by reference; but can be found on the MPCA's website at: http://www.pca.state.mn.us/index.php/view-document.html?gid=16163 .

2.4.1 Loss of Habitat

Habitat describes the place where organisms feed, reproduce, shelter and escape predation. In streams, habitat for macroinvertebrates and fish includes the rocks and sediments of the stream bottom and banks; the plants growing in the stream or attached to rocks or debris in the stream; grasses and leaf litter and other organic material in the stream; and logs, sticks, twigs, and other woody debris. Habitat also includes elements of stream structure: streambed depressions that provide deeper pools of water; side channels, backwaters or other stream formations that are places outside the primary flow channel; and the vegetation on and adjacent to the streambank.

Each species has a specific set of habitat requirements, but can often tolerate conditions that are not ideal. Habitat complexity is necessary to provide an environment with a variety of attributes that can support a robust assemblage of organisms.

As described in the Stressor ID Report, loss of habitat due to excess bedded sediment appears to be most problematic in the lower reaches of the river, where the gradient is lower and is a natural depositional area for sediment from upstream sources. Agricultural land uses, primarily cattle grazing, are a significant source of sediment delivery in the watershed. Historical logging and use of the waterway for log driving is also suspected to play a role in present day sediment dynamics. Destabilization of stream banks has contributed to sediment loss and delivery downstream. Sediment deposition in the lower Ann River has reduced pool and riffle habitat quality, and has resulted in a lack of gamefish and fish species that depend on coarse substrates for feeding and reproduction.

2.4.2 Dissolved Oxygen

Living aquatic organisms such as fish and macroinvertebrates require oxygen to sustain life. Decreases in dissolved oxygen (DO) in the water column can cause changes in the types and numbers of fish and aquatic macroinvertebrates in surface waters, and shift the community composition to species that are tolerant of lower levels or wider diel swings in DO. Longitudinal and continuous (diurnal) measurements for dissolved oxygen were conducted at monitoring stations on the Ann River and Little Ann River during the summers of 2007, 2008 and 2009. The data indicates that dissolved oxygen concentrations in the mid-river reaches of the Ann River occasionally drop below the standard of 5 mg/L during mid to late summer months. There is some uncertainty regarding the processes driving this stressor, which may be related to lower summertime flows and high water temperatures, sediment oxygen demand, or possibly to nutrient enrichment from the nutrient impaired lake upstream.

2.4.3 Altered Riparian Corridor

The riparian zone of a stream is generally defined as the transition area between aquatic ecosystems and adjacent upland terrestrial ecosystem. High quality undisturbed riparian corridors provide shading from solar radiation, filtration of overland runoff, mitigation of bank erosion, and inputs of detritus and organic matter that are critical to supporting aquatic life.

A variety of land uses and land cover alterations have reduced the quality of the riparian corridor within the Ann River watershed. Cattle grazing and activity near the stream and removal of natural riparian vegetation have led to destabilized streambanks and increases in channel width to depth ratios. Logging and other activities have reduced the riparian canopy cover, decreasing woody inputs to the stream and increasing thermal loading. Channel widening, gully formation, and other erosional processes within the stream corridor appear to be contributing higher than normal sediment loads to the river.

2.4.4 Loss of Connectivity-Impoundments and Flow Alteration

The presence of impoundment structures on river systems are known to alter streamflow, water temperature regime, and sediment transport processes, which can negatively impact fish and macroinvertebrate habitat and thus their assemblages. Impoundments also can physically disconnect stream segments and reservoirs, limiting the ability of fish and macroinvertebrates to pass freely up and down stream.

There are three known dams in the Ann River watershed that may be altering streamflow and impeding fish passage. The outlets of the Dewitt Pool on the Little Ann River, Ann Lake, and Fish Lake are controlled by dams. These impoundments have been in place since the 1880's for the purpose of transporting logs downstream to the Snake and St. Croix Rivers. In 1965 a control structure was added to the Ann Lake outlet that increased the pool from about 350 acres to 1,100 acres to create waterfowl habitat and hunting opportunities. The lack of connectivity between the reservoirs and the Ann River may limit spawning of species that prefer both lotic and lentic habitats. The altered flow regime may prolong the duration of low flows, favoring fish and macroinvertebrate species that prefer lentic habitats.

2.5 BACTERIA IN THE ANN RIVER

E. coli bacteria are an indicator organism, meaning that not all the species of bacteria of this category are harmful but are usually associated with harmful organisms transmitted by fecal contamination. They are found in the intestines of warm-blooded animals, including humans. The presence of *E. coli* in water suggests the presence of fecal matter and associated bacteria, viruses, and protozoa (i.e. *Giardia* and *Cryptosporidium*) that are pathogenic to humans when ingested (USEPA 2001). The Ann River from the headwaters in Ann Lake to the confluence with the Snake River is listed as impaired for bacteria. The primary bacterium present in the Ann River is *E. coli*. Monitoring data were used to determine the extent to which factors are influencing bacteria levels in the watershed and to determine the potential sources of that bacterium.

2.6 FACTORS INFLUENCING BACTERIA IN ANN RIVER

The main factors influencing bacteria in the Ann River are potential for loading from point and non-point sources and streamflow. Understanding these factors and what contributes to their current conditions is important to addressing the bacteria TMDL.

2.6.1 Bacteria Loading

Bacteria loading can occur from both point and non-point sources, thus the potential sources of bacteria need to be identified as well as the linkages between those sources and the receiving water. Initial review of the Ann River watershed suggests that there are no current point sources (such as wastewater treatment plant discharges) in the watershed. This indicates that the bacteria exceedance is likely the result of loading from non-point sources. Available bacteria monitoring data was used to assess bacteria loading and develop the TMDL.

2.6.2 Streamflow

Streamflow data was examined to search for linkages between exceedances of the bacteria standard and to develop bacteria allocations for the TMDL. For example, exceedance during high flow events suggests that bacteria load may be related to washoff from the watershed. Exceedance during low flow suggests that septic system sources might be contributors. Flow regime, defined by selected flow levels ranging from dry to very high, when paired with bacteria data provides insights on potential sources.

2.7 NUTRIENTS IN ANN LAKE AND FISH LAKE

Understanding the sources of nutrients to a watershed or lake, such as Ann Lake or Fish Lake, is a key component in developing an excess nutrient TMDL. To that end, a phosphorus budget that sets forth the current phosphorus load contributions from each potential source was developed using the modeling and collected data described in Section 4.6.

2.8 FACTORS INFLUENCING NUTRIENTS IN ANN LAKE AND FISH LAKE

There are a number of factors that can influence the nutrient levels in a lake. In the case of Ann Lake and Fish Lake, both are considered a reservoir system with impoundments on the Ann River. The river is a direct connection between Ann Lake and Fish Lake, creating a situation where the water quality in Ann Lake can have a direct influence on the water quality in Fish Lake. Other factors influencing total phosphorus and other nutrient levels in these water bodies to consider are atmospheric nutrient loading, watershed nutrient loading, and internal phosphorus loading in each lake.

2.8.1 Atmospheric Nutrient Loading

The atmospheric load refers to the load applied directly to the surface of the lake through atmospheric deposition. Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report “Detailed Assessment of Phosphorus Sources to Minnesota Watersheds” (Barr Engineering 2004), and are based on annual precipitation. The values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km^2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre-year for dry, average, and wet years in English units, respectively.

2.8.2 Watershed Nutrient Loading

The watershed is larger than the area immediately adjacent to the Ann River, and Ann and Fish Lakes. The entire watershed is over 55,000 acres and includes a number of water bodies and tributaries. The upper portion of the watershed is primarily forested, while the lower portion that includes Ann Lake, Ann River, and Fish Lake includes a combination of agriculture, forest, grassland, and development around the lakes. All of these factors can contribute to watershed nutrient loading.

2.8.3 Internal Phosphorus Loading

Phosphorus release from sediment occurs as a result of changes in sediment chemistry under anoxic conditions and from bacterial decomposition of lake sediments. Under anoxic conditions, weak iron-phosphorus bonds break, releasing phosphorus in a highly available form for algal uptake. Shallow lakes typically demonstrate at least short periods of anoxia (dissolved oxygen <2 mg/L) where this release can occur. Release also occurs under oxygenated conditions (dissolved oxygen >2 mg/L) from bacterial decomposition of organic sediments. However, this rate is typically low and only a small part of a lakes nutrient budget. Internal loading is typically an important source of phosphorus to lakes and must be accounted for when developing a nutrient budget.

3.0 Bacteria Impairment

3.1 OVERVIEW OF *E. coli* IMPAIRED REACH WATERSHED

This TMDL applies to the *E. coli* bacteria impairment for the Ann River from the outlet of Ann Lake to the inlet of Fish Lake (Figure 3.1). Data from four main-stem monitoring stations and one tributary station in this watershed served as the basis of the impairment determination and were used to support development of the TMDL.

3.2 WATERSHED LANDUSE/LANDCOVER

Land use for the watershed draining directly to the Ann River *E. coli* impaired reach and the Ann River watershed upstream of Ann Lake was calculated using the 2009 National Agricultural Statistics Service (NASS) GIS land cover file (Table 3.1 and Figure 2.2). Land use in the *E. coli* impaired reach watershed is primarily a mixture of hay/pasture and forest/shrubland. Land cover in the Ann Lake watershed upstream of the impaired reach is dominated by forest land. The remaining land area in both watersheds is comprised of corn/soybean rotations, lakes and wetlands, developed land and non-corn/soybean crops.

Table 3.1. 2009 NASS land cover in the Ann River impaired reach watershed and Ann Lake watershed.

Land Cover	Percent of Total	
	[1]Impaired Reach Watershed	[2]Ann Lake Watershed
Hay and Pasture	53%	11%
Forest and Shrubland	33%	77%
Wetlands and Open Water	5%	10%
Urban/Roads	4%	2%
Corn/Soybeans	3%	<1%
Grains and other Crops	2%	<1%

[1] Only includes Ann River impaired reach watershed downstream of Ann Lake and upstream of Fish Lake (12,116 acres)

[2] Includes Ann Lake watershed upstream of Ann River impaired reach (47,941 acres)

3.3 DATA SOURCES

3.3.1 Water Quality Data

The *E. coli* data used for the development of this TMDL are grab samples collected by Mille Lacs and Kanabec County SWCDs and the MPCA between 2004 and 2009 (Table 3.2). Although data prior to this period exists, the more recent data better represent current conditions in the watershed. Samples were analyzed for fecal coliform prior to 2006 and more recently *E. coli*. All fecal coliform data was converted to *E. coli* “equivalents” using the equation discussed in Section 1.3.2. Figure 3.1 shows the location of the monitoring stations at which samples were collected to support this TMDL. All data were obtained through Minnesota Pollution Control Agency's EQuIS online database.

Table 3.2. Ann River *E. coli* monitoring sites.

EQuIS ID	Location	Parameter	Number of Samples	Years
S004-635	Tributary to Ann River at Co Rd 59	Fecal Coliform	None	--
		E. coli	31	2008-2009
S004-634	Tributary to Ann River at County State Aid Highway 12	Fecal Coliform	None	
		E. coli	23	2008-2009
S004-392	Main-stem Ann River at 210th Ave	Fecal Coliform	None	--
		E. coli	31	2008-2009
S003-530	Main-stem Ann River at Co Rd 12	Fecal Coliform	16	2004-2006
		E. coli	31	2008-2009
S004-066	Main-stem Ann River at Highway 23	Fecal Coliform	None	--
		E. coli	24	2006-2007
S003-782	Main-stem Ann River at Co Rd 14	Fecal Coliform	None	--
		E. coli	42	2007-2010

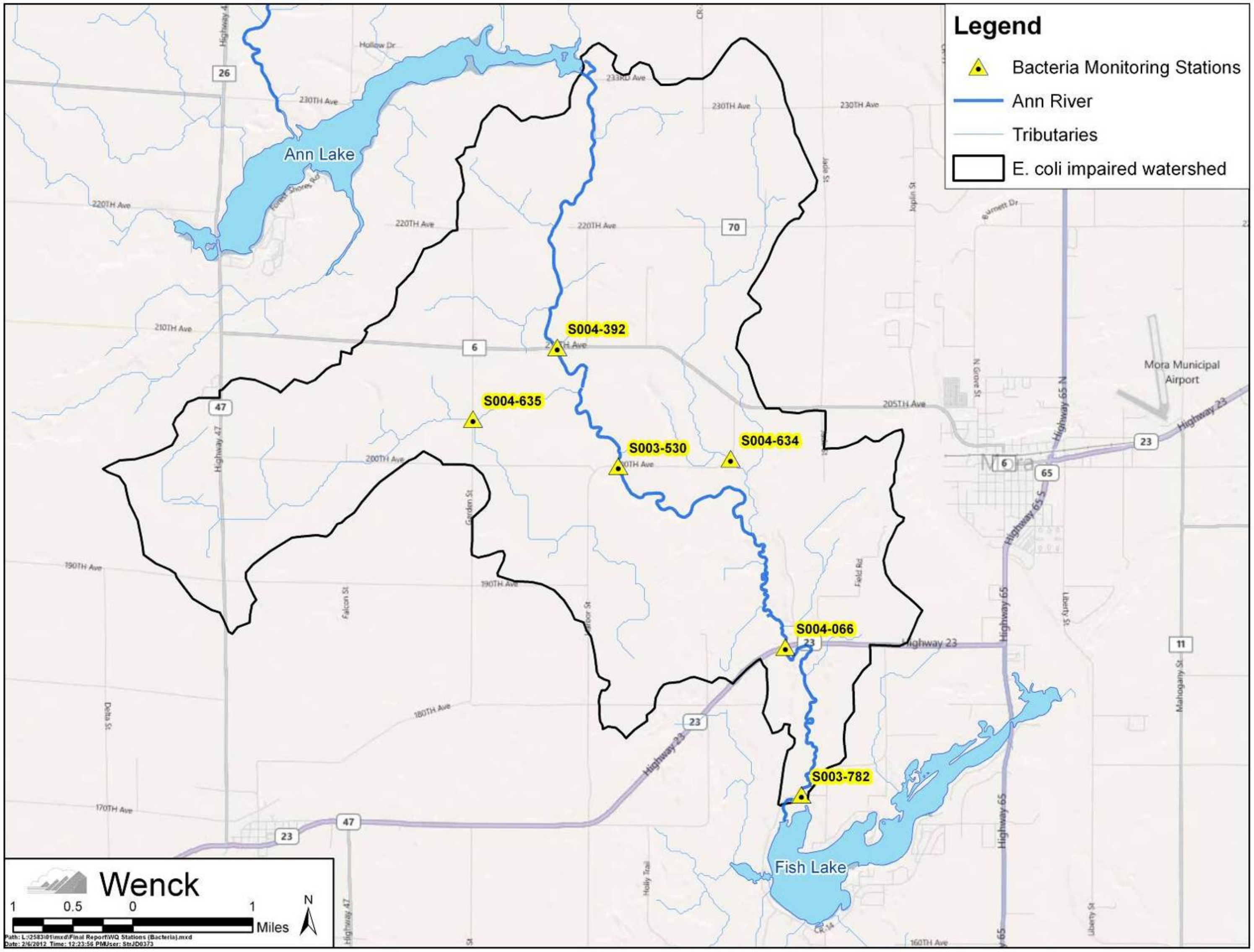

Figure 3.1. Bacteria monitoring stations in the Ann River E. coli impaired reach watershed.

3.3.2 Streamflow Data

Stream flow data was crucial to support development of the *E. coli* allocations for this TMDL. Streamflow data paired with *E. coli* measurements allow exceedances to be evaluated by flow regime which, in turn provides insight into potential sources.

There are two stations, S003-530 and S003-782, in the Ann River bacteria impaired reach with recent continuous flow data (Appendix A and Figure 3.1). These stations were operated during the 2008 and 2009 sampling season from April/March through the middle of November. There is also one long-term USGS flow monitoring station located downstream of Ann River watershed on the Snake River near Pine City. This station began operating in 1913 and has operated year around since the early 1990s. Regression relationships between the two Ann River stations and the Snake River USGS station show good correlation (R^2 of 0.75-0.79) and the regression equations were used to fill data gaps and predict all winter and non-monitored flows from 2000-2010.

3.3.3 Impairment Criteria for the Ann River

To determine *E. coli* impairment, the MPCA use data collected by the MPCA and other agencies that satisfy QA/QC requirements, meet EPA guidelines, are analyzed by an EPA approved method and entered into the MPCA's EQuIS/STORET online database. If multiple *E. coli* samples have been collected on the same assessment unit (reach), then the geometric mean of all measurements are used in the assessment analysis for that day. Then, data over the full 10-year period are aggregated by individual month (i.e. all April values for all 10 years). A minimum of five values for each month is ideal, but is not always necessary to make an impairment determination. If the geometric mean of the aggregated monthly *E. coli* concentrations for one or more months exceed 126 colony forming units per 100 ml (cfu/100 ml), that reach is placed on the 303(d) impaired list. Also, a waterbody is considered impaired if more than 10% of individual samples over the 10-year period (independent of month) exceed 1,260 cfu/100 ml.

E. coli and *E. coli* "equivalent" data from the four main-stem monitoring stations were combined into one dataset and analyzed according to the aforementioned MPCA assessment methodology to demonstrate the level of impairment in the impaired reach. Figure 3.2 shows the Ann River (all sites aggregated) monthly *E. coli* geometric means exceeded the 126 cfu/100 ml standard in 5 of 6 months during the bacteria index period (April-October). Also, approximately 9% of the individual values from all sites within the Ann River impaired reach exceed the 1,260 cfu/100 ml acute standard (Table 3.3).

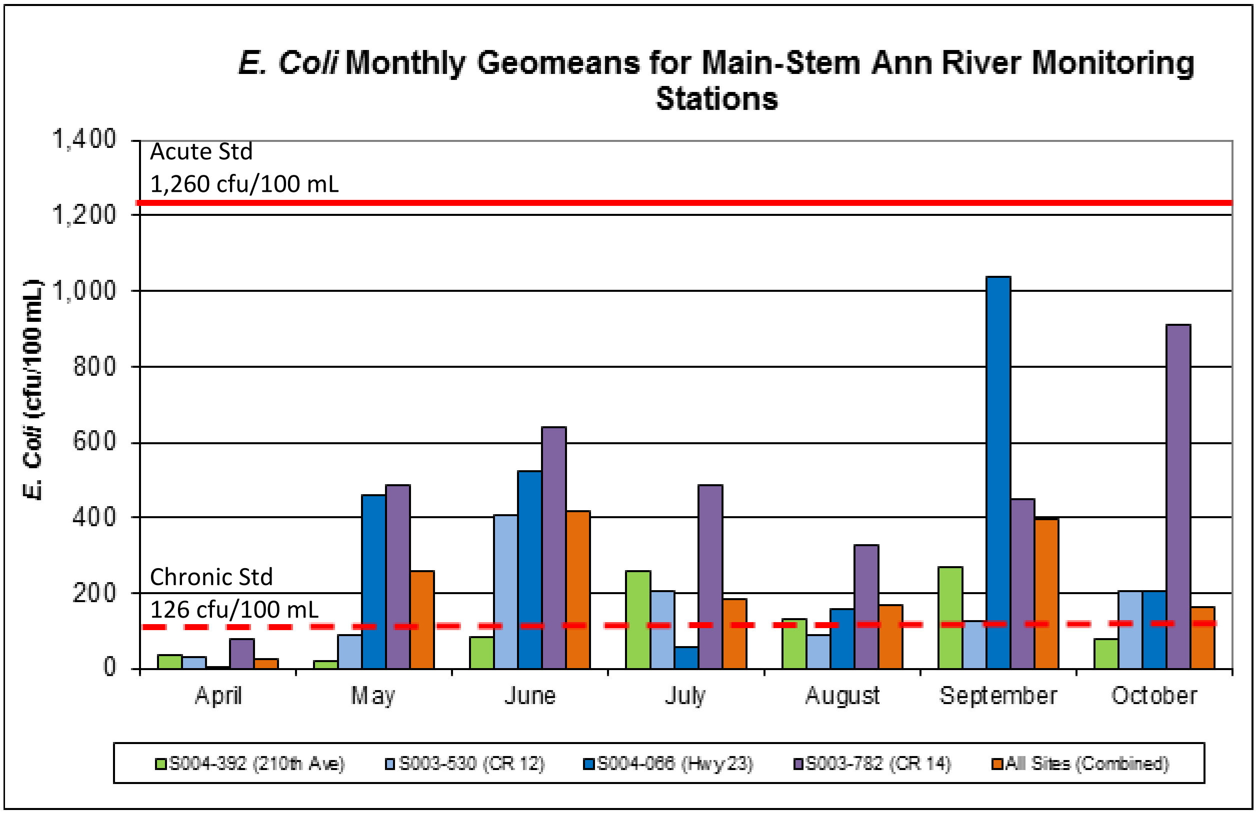

Figure 3.2. Monthly *E. coli* geometric means for each monitoring station in the Ann River impaired reach since 2004.

Note: The dotted and solid red lines indicate the *E. coli* chronic and acute state standards, respectively.

Table 3.3. Individual *E. coli* acute exceedances since 2004 for the main-stem Ann River impaired reach monitoring stations.

Site	Total Samples	Acute Exceedances	Percent	Months with Acute Exceedances
S003-530	46	2	4%	Apr (1); June (1)
S003-782	42	8	19%	Apr (1); May (2); June (1); July (1); Sep (1); Oct (2)
S004-066	24	1	4%	Sep (2)
S004-392	31	2	6%	Apr (1); July (1)
All Sites	143	13	9%	

3.4 ALLOCATION METHODOLOGY

3.4.1 Overview of Load Duration Curve Approach

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

A flow duration curve was developed using the 2008-2009 monitored average daily flow record and the 2000-2007 and 2010 simulated average daily flow record at the furthest downstream flow station in the impaired reach (S003-782). The curved line relates mean daily flow to the percent of time those values have been met or exceeded (Figure 3.3). For example, at the 50% exceedance value, the river was at 17 cubic feet per second or greater 50% of the time. The 50% exceedance is also the midpoint or median flow value. The curve is then divided into flow zones including very high (0-10%), high (10-40%), mid (40-60%), low (60-90%) and dry (90 to 100%) flow conditions. Subdividing all flow data over the past 10-years into these five categories ensures high-flow and low-flow critical conditions are accounted for in this TMDL study.

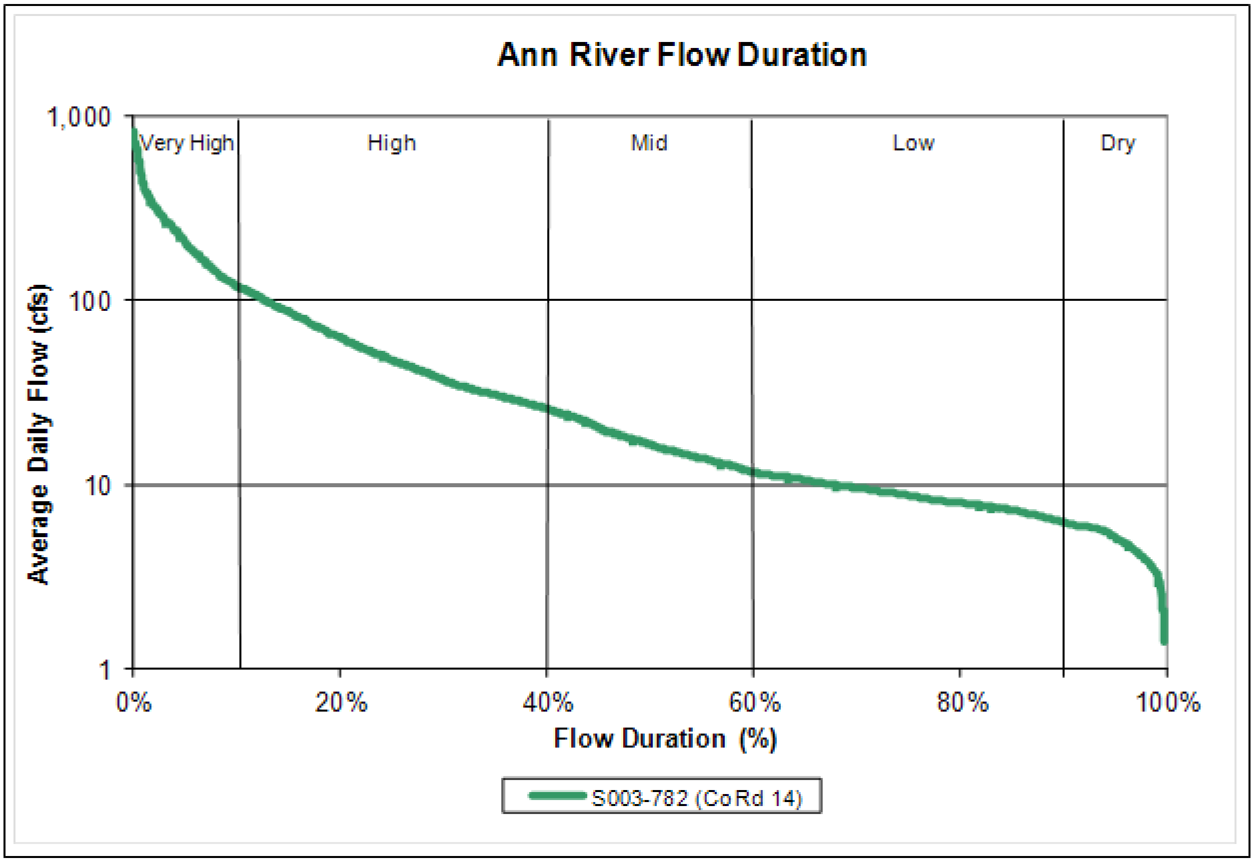

Figure 3.3. Flow duration curve for the Ann River impaired reach.

To develop a load duration curve, all average daily flow values were multiplied by the 126 cfu/100 ml standard and converted to a daily load to create a "continuous" load duration curve (Figure 3.4). Now the line represents the assimilative capacity of the stream for each daily flow. To develop the TMDL, the median load of each flow zone is used to represent the total daily loading capacity (TDLC) for that flow zone. The TDLC can also be compared to current conditions by plotting the measured load by exceedance for each water quality sampling event. Each value that is above the TDLC line represents an exceedance of the water quality standard while those below the line are below the water quality standard.

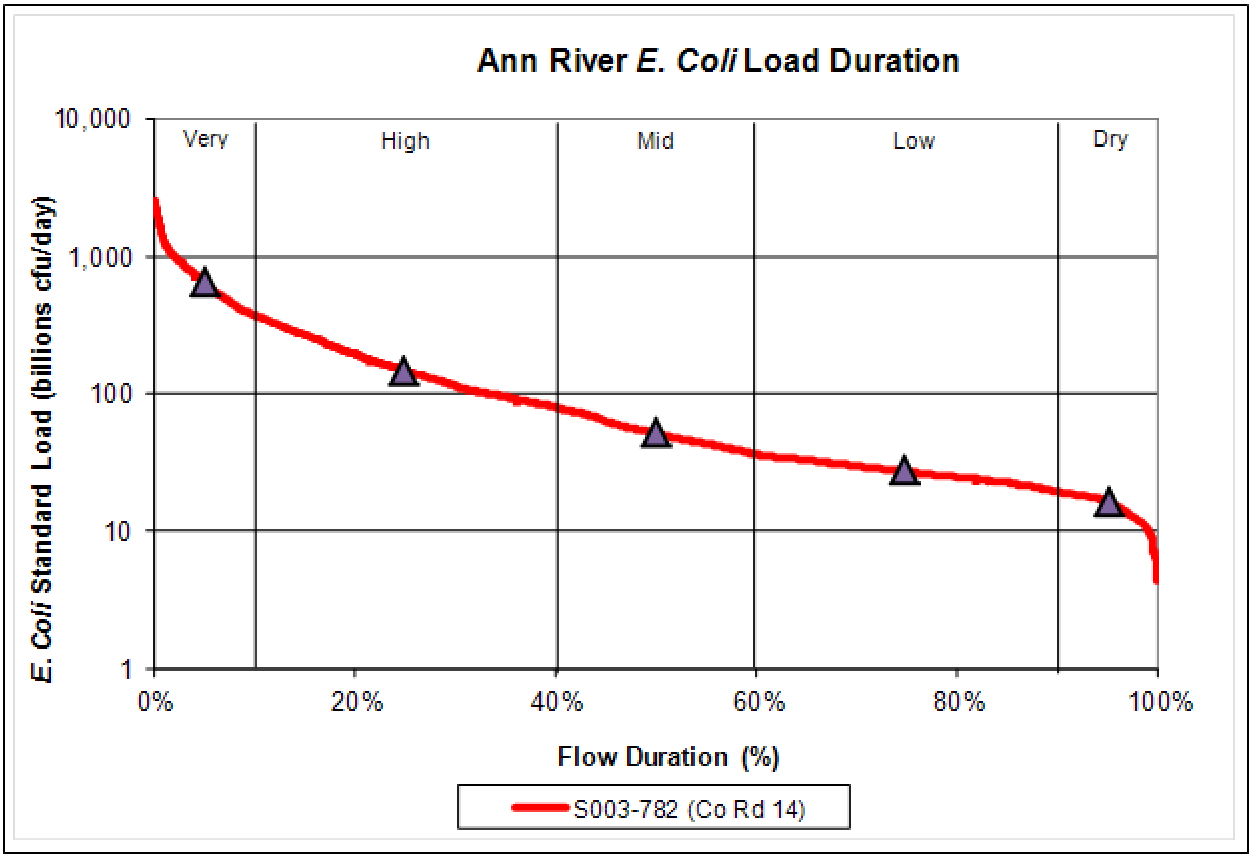

Figure 3.4. Ann River impaired reach *E. coli* load duration curve.

Note: This red line represents the maximum allowable daily *E. coli* load. The purple triangles represent the median standard *E. coli* load of each flow zone – these values are used to represent the total daily loading capacity for each flow zone.

3.4.2 Margin of Safety

The Margin of Safety (MOS) accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload, monitored flows and in-stream water quality. The purpose of the MOS is to account for uncertainty so the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 5 percent of the total load was applied whereby 5 percent of the loading capacity for each flow regime was subtracted before allocations were made among wasteload and non-point sources. Five percent was considered an appropriate MOS since the load duration curve approach minimizes a great deal of uncertainty associated with the development of TMDLs because the calculation of the loading capacity is simply a function of flow multiplied by the target value. Most of the uncertainty is therefore associated with the estimated flows in each assessed segment which were based on simulating a portion of the 10 year flow record at the most down-stream monitoring station. A similar MOS approach was applied in the Groundhouse River Bacteria TMDL (MPCA 2009).

3.4.3 Wasteload Allocations

Wasteload allocations for bacteria TMDLs are typically divided into three categories: permitted wastewater dischargers, Municipal Separate Storm Sewer Systems (MS4s), and construction and industrial stormwater. At the time of this study, the MPCA confirmed there were no active permitted NPDES surface wastewater dischargers or MS4s in the Ann River impaired reach watershed (Marco Graziani and Mike Trojan, personal communication). Thus, these wasteload categories were given a zero value in the Ann River *E. coli* allocation table (Table 3.4). Industrial facilities and construction sites with stormwater permits through the MPCA are not believed to discharge the pollutant of concern and were not given *E. coli* allocations for this TMDL.

3.4.4 Non-point Source Load Allocations

The non-point source load allocation is the remaining load after the MOS and wasteload allocations are subtracted from the total load capacity of each flow zone. Non-point sources include all non-permitted sources such as outflow from lakes and wetlands in the watershed and runoff from agricultural land, forested land, and non- regulated MS4 residential areas. For this TMDL, non-point sources were allocated to all of the available Ann River load capacity (minus the MOS) since there are no wasteload allocations in the impaired reach watershed.

3.5 TOTAL MAXIMUM DAILY LOADS

Table 3.4 presents the total loading capacity, margin of safety, wasteload allocations and the remaining non-point source load allocations for Ann River (07030004-511). The table also presents all load allocations in terms of the percent of total loading capacity in each flow category.

Table 3.4. Ann River *E. coli* impaired reach TMDL for each flow zone.

Ann River: 07030004-511		**Flow Zones**				
		Very High	**High**	**Mid-Range**	**Low**	**Dry**
		E. Coli Load (billions of organisms/day)				
Total Daily Loading Capacity		638.6	146.5	51.3	27.0	15.8
Margin of Safety (MOS)		31.9	7.3	2.6	1.4	0.8
Wasteload Allocations	Permitted Point Source Dischargers	0.0	0.0	0.0	0.0	0.0
	MS4 Communities	0.0	0.0	0.0	0.0	0.0
Load Allocation	Nonpoint source	606.7	139.2	48.7	25.6	15.0
Value expressed as percentage of total daily loading capacity						
Total Daily Loading Capacity		100%	100%	100%	100%	100%
Margin of Safety (MOS)		5%	5%	5%	5%	5%
Wasteload Allocation	Permitted Point Source Dischargers	0%	0%	0%	0%	0%
	MS4 Communities	0%	0%	0%	0%	0%
Load Allocation	Nonpoint source	95%	95%	95%	95%	95%

3.6 IMPACT OF GROWTH ON ALLOCATIONS

3.6.1 Wasteload Allocations

Currently there are no permitted wastewater dischargers in the Ann River watershed. If the watershed undergoes significant development and a future discharger were to be created, the additional load from the discharger will be offset by the increased flow associated with the facility adding to the overall capacity of the receiving water. Currently, wastewater discharges in the state of Minnesota are permitted and required to monitor for fecal coliform, not *E. coli*. As discussed in section 1.3.2, the current *E. coli* concentration standard of 126 cfu/100 ml was considered reasonably equivalent to the fecal coliform standard of 200 cfu/100 ml from a public health protection standpoint. Thus, as long as future wastewater discharger's fecal coliform permit limit does not exceed 200 cfu/100ml, it will not impact attainment of the water quality standards.

There are currently no MS4 communities in the Ann River watershed and there are no plans to develop MS4 communities in the watershed for the foreseeable future. However, future transfer of loads in this TMDL may be necessary if any of the following scenarios occur within the Ann River impaired reach watershed boundary:

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be given additional WLA to accommodate 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 an urban area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL was completed, but are now inside a newly expanded urban area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
5. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods consistent with those used in setting the allocations in other TMDLs. WLAs for new MS4s will be transferred from the LA and calculated by multiplying the municipalities' percent watershed area by the total watershed loading capacity after the MOS has been subtracted (MPCA, 2006). In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer. Ultimately, increases in urban stormwater also increase the loading capacity of the receiving water thereby supplying their own increases in receiving water assimilative capacity. Consequently, as long as stormwater discharges are held to the current 126 cfu/100 ml *E. coli* standard, increases in stormwater will not impact attainment of the water quality standards.

3.7 POLLUTANT SOURCE ASSESSMENT

This section is intended to present information that is helpful in identifying the potential sources of elevated bacteria concentrations in the Ann River impaired reach watershed. The first section is a discussion of background levels of bacteria in streams. The next section addresses seasonal influences and looks at the relationships between elevated bacteria concentrations and flow. The third section addresses the potential influence of tributary and the major upstream river inflows to this reach. The final section contains estimates of the potential sources of bacteria available for transport by source category for the Ann River *E. coli* impaired reach watershed.

3.7.1 *E. coli* Background Conditions

It has been suggested that *E. coli* bacteria has the capability to reproduce naturally in water and sediment and therefore should be taken into account when identifying bacteria sources. Two Minnesota studies describe the presence and growth of “naturalized” or “indigenous” strains of *E. coli* in watershed soils (Ishii et al. 2006), and ditch sediment and water (Sadowsky et al. 2010). The latter study, supported with Clean Water Land and Legacy funding, was conducted in the Seven Mile Creek watershed, an agricultural landscape in southwest Minnesota. DNA fingerprinting of *E. coli* from sediment and water samples collected in Seven Mile Creek from 2008-2010 resulted in the identification of 1568 isolates comprised of 452 different *E. coli* strains. Of these strains, 63.5% were represented by a single isolate, suggesting new or transient sources of *E. coli*. The remaining 36.5% of strains were represented by multiple isolates, suggesting persistence of specific *E. coli*. Discussions with the primary author of the Seven Mile Creek study suggest that while 36% might be used as a rough indicator of “background” levels of bacteria at this site during the study period, this percentage is not directly transferable to the concentration and count data of *E. coli* used in water quality standards and TMDLs. Additionally, because the study is not definitive as to the ultimate origins of this bacteria, it would not be appropriate to consider it as “natural” background. Finally, the author cautioned about extrapolating results from the Seven Mile Creek watershed to other watersheds without further studies.

3.7.2 Exceedances by Season and Flow Regime

Individual *E. coli* samples show exceedances during summer and fall and occasionally in the spring (Figure 3.5). April was the month with the lowest bacteria concentrations even though there is little crop canopy cover and there is often significant manure application during this time. This suggests seasonality of bacteria concentrations may be influenced by stream water temperature. Fecal bacteria are most productive at temperatures similar to their origination environment in animal digestive tracts. Thus, these organisms are expected to be at their highest concentrations during the warmer summer months when stream temperature are highest. High *E. coli* concentrations continue into the fall which may be attributed to cattle access to stream/tributaries and/or reapplication of manure.

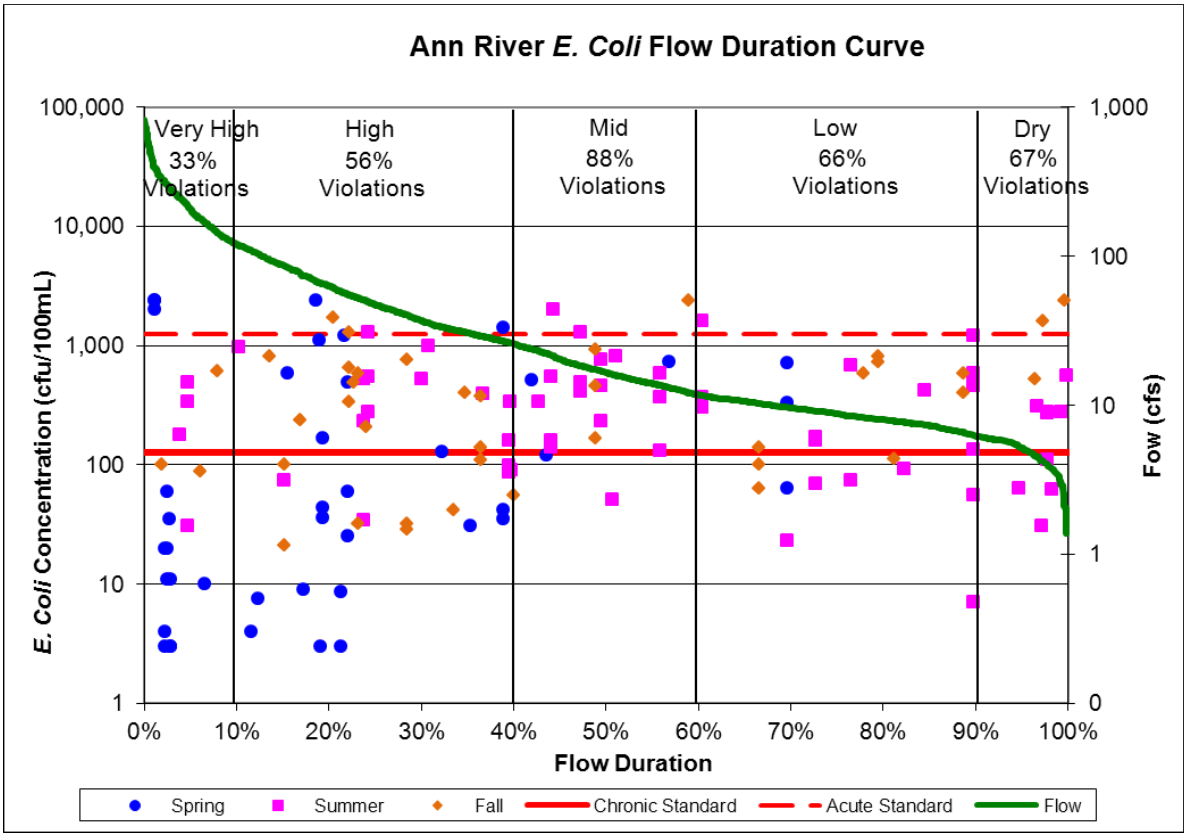

Figure 3.5. Individual *E. coli* measurements in the Ann River impaired reach plotted by season and flow regime.

Note: Flow frequencies were developed using the methods discussed in section 3.4.1 *E. coli* data from four main-stem monitoring stations within the impaired reach were combined and plotted as one dataset.

The relationship between flow and bacteria concentrations aid in identifying potential sources of elevated bacteria concentrations. Table 3.5 shows the conceptual relationship between flow and loading sources under various flow conditions. Under low flows, runoff processes are minimal as bacteria concentrations are primarily driven by wastewater treatment plants (if present), failing subsurface sewage treatment systems (SSTS) and animals in or near the receiving water. Conversely, at high flows, runoff from land with bacteria concentrations such as feedlots and pastures, urban areas and cropland often dominate. Exceedances appear to occur across all flow regimes in the bacteria-listed reach of Ann River. This suggests that, at times, all of the aforementioned flow-driven sources may contribute to high bacteria concentrations observed throughout this reach.

Table 3.5. Conceptual relationship between flow regime and potential pollutant sources.

Point Source Contributing Source Area	Flow Regime				
	Very High	**High**	**Mid**	**Low**	**Dry**
NPDES Permitted Treatment Facilities				M	H
Septic System w/ "Straight Pipe" connection				M	H
Livestock in receiving water				M	H
Sub-surface treatment systems			H	M	
Stormwater Runoff – Impervious Areas		H	H	H	
Combined Sewer Overflows	H	H	H		
Stormwater Runoff – Pervious Areas	H	H	M		
Bank Erosion	H	H	M		

Note: Potential relative importance of source areas to contribute loads under given hydrologic condition (H: High; M: Medium), based on USEPA Doc. 841-B-07-006.

3.7.3 Bacteria Levels in Ann Lake and Ann River Tributaries

The outlet of Ann Lake to the Ann River represents the upstream boundary of the *E. coli* impaired reach. There are currently no bacteria monitoring data available from the outlet of Ann Lake. Even if bacteria inputs to Ann Lake are high, the lake's volume should provide significant dilution. Thus, it is assumed a majority of the bacteria observed in the Ann River impaired reach is produced within the Ann River watershed.

There are two tributary monitoring stations, S004-634 and S004-635, in the Ann River impaired reach watershed with bacteria data (Figure 3.1). *E. coli* data from these stations indicate monthly geomeans are high and often exceed the 126 cfu/100 ml chronic standard, specifically between June and October (Figure 3.6). These concentrations match, and in some cases exceed the main-stem *E. coli* monthly geomeans which suggests these tributaries are major sources of bacteria to the Ann River impaired reach.

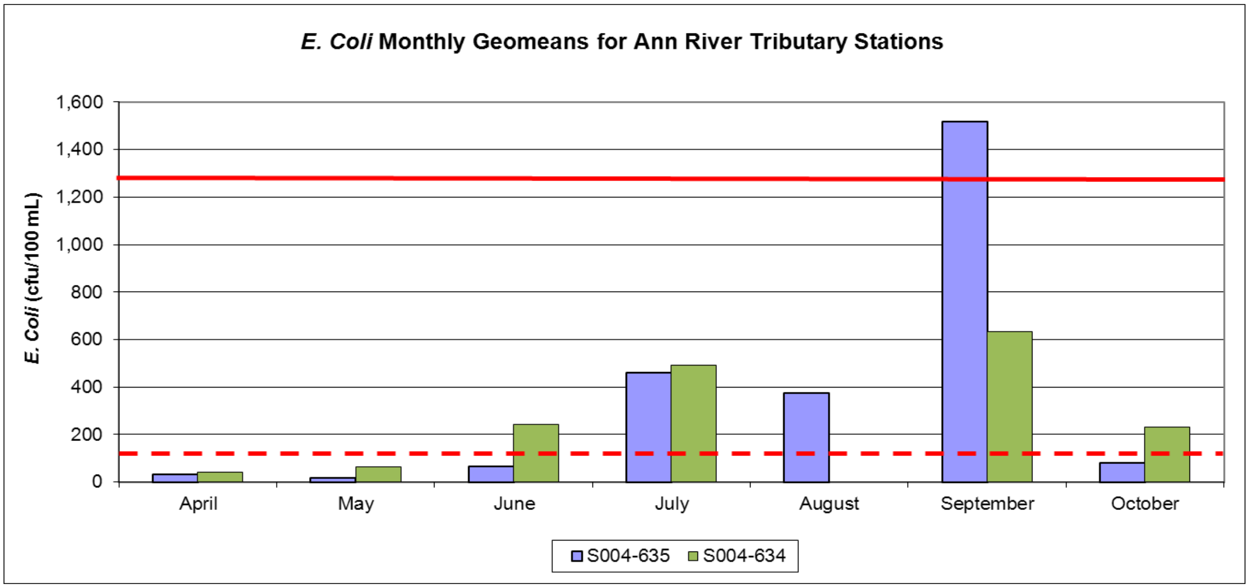

Figure 3.6. Monthly E. coli geomeans for the Ann River tributary monitoring stations.

3.7.4 Potential Bacteria Source Inventory

The purpose of the bacteria source assessment is to develop a comparison of the number of bacteria generated by the major known sources in the project area as an aid in focusing source identification activities. Only subwatersheds that drain directly to the Ann River *E. coli* impaired reach between Ann Lake and Fish Lake (reach 07030004-511) were included in the source inventory (Figure 3.1). The source assessment is not directly linked to the total maximum loading capacities and allocations, which are a function of the water quality standards and stream flow (i.e, dilution capacity). Further, the inventory itself uses fecal coliform concentrations as the metric, not *E coli*. This is because the inventory assessment is intended to evaluate the relative magnitude of bacteria loads being generated within the major source categories. The relative source comparisons are expected to be the same, regardless of whether fecal coliform or *E coli* units are used.

3.7.4.1 Livestock Sources

Animal units are the standardized measurement of livestock for various agricultural purposes. A livestock animal that consumes, on average, 26 pounds of dry matter forage per day is the standard metric for one animal unit. This number is based on the feeding requirements for a 1,000 pound beef cow. Owners of an animal feedlot or manure storage area with 50 or more animal units (10 animal units in shoreland areas) are required to register with the MPCA. Owners with fewer than 300 animal units are not required to have a permit for the construction of a new facility or expansion of an existing facility as long as construction is in accordance with the technical standards. For owners with 300 animal units or more, and less than 1,000 animal units, a streamlined short-form permit is required for construction/expansion activities. Feedlots greater than 1,000 animal units or a significant amount of confined animals are considered large confined animal feedlot operations (CAFOs) and are required to apply for a National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permit. These operations, by law, are not allowed to discharge to waters of the state (MR 7020.2003).

According to the 2010 MPCA database, there are 5 registered feedlots in the Ann River impaired reach watershed. Collectively, these feedlots house approximately 791 total animal units. The majority of the animal units are beef cattle (649 units) followed by dairy (137 units) and horses (5 units). A map showing the approximate location (as points) and size (total animal units) of each feedlot is shown in Figure 3.7. GIS data showing the exact location and feedlot boundary are not available.

There are a number of pathways by which fecal coliform produced by livestock can reach surface waters such as runoff from feedlots, overgrazed pastures, surface application of manure and incorporated manure. Following is a description of these sources

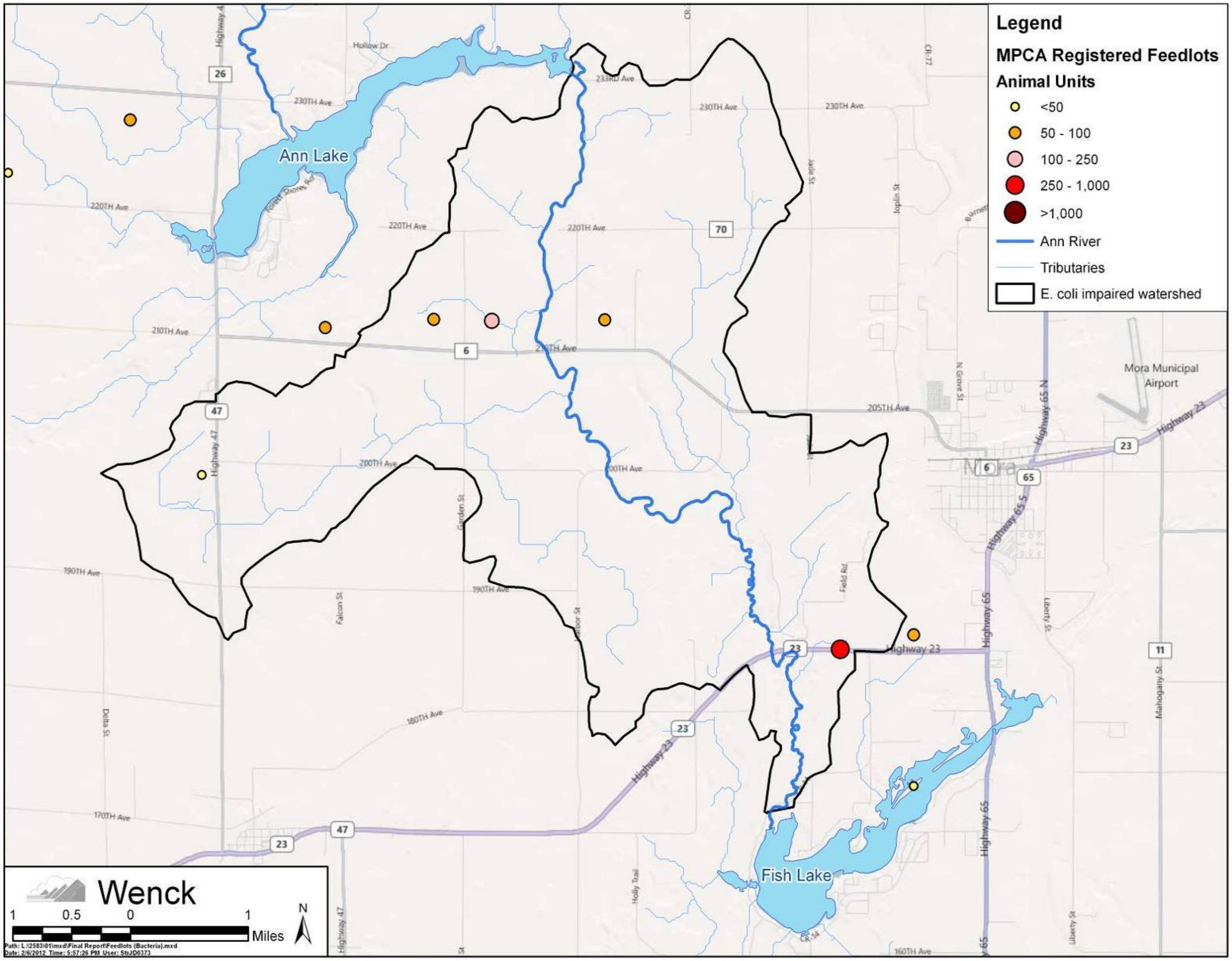

Figure 3.7. MPCA registered feedlots in the Ann River E. coli impaired reach watershed.

3.7.4.1.1 Manure Application

A significant proportion of the cropland throughout Minnesota and the upper Midwest receives some sort of manure application during different times of the year. Most beef manure is applied as a solid while dairy manure is applied as both liquid and solid manure. In most cases, the larger dairy operations have liquid manure pits, while the smaller dairies haul manure as a solid. Most liquid manure is injected into the soil or incorporated within 24 hours. Solid manure is spread on the soil surface where it is not immediately incorporated into the ground. A large portion of manure applications occur in the fall when animal waste pits are emptied out. However, some farmers (especially small dairy farmers) will spread this manure year round. In general, manure that is not incorporated has a higher potential for runoff.

Beef and dairy cattle and horses, all three of which are considered grazers, are the only agricultural animals in the Ann River watershed. For the purposes of this TMDL, it is assumed these animals spend about eight months of the year grazing in the 6,374 acres of pastureland throughout the impaired reach watershed. For the other four months, the animals are housed in barns or other confined spaces where their manure is stockpiled. Thus, approximately 33% of the animal manure produced in the watershed is available for spreading on cropland. However, since only five percent of the total land in the watershed is currently used to grow crops, it is assumed only half (16%) of the stockpiled manure is spread on cropland while the other half is spread on pastureland. This TMDL also assumes that all of the manure spreading in the watershed is surface applied.

3.7.4.1.2 Feedlots and Pastures Near Streams

GIS processing suggests that approximately 34% (2,172 acres) of the pastureland in the impaired reach watershed is located within 500 feet of Ann River and/or its major tributaries. As a result, this TMDL will assume that 34% of the fecal coliform produced by the agricultural animals in the watershed during grazing (eight months) is deposited within 500 feet of streams while the rest is deposited on upstream pastureland. As discussed in the previous section, this TMDL also assumes approximately 50% of the manure stockpile is spread on pastureland when stockpiles are emptied. Pastures, feedlots and open lot cattle and dairy facilities near streams or waterways have a higher likelihood of animal access to the stream and therefore higher likelihood of delivering bacteria to the receiving water.

3.7.4.2 Septic Systems

Failing or nonconforming subsurface sewage treatment systems (SSTS) can be an important source of bacteria especially during dry periods when runoff driven sources are not active. To date, there have been no field surveys to inventory SSTSs throughout the Ann River watershed and determine which systems are in compliance or may be failing. For this TMDL study, Kanabec County Environmental Services and the Kanabec and Mille Lacs SWCDs compiled all available SSTS records in order to estimate the total number of SSTSs in the watershed. They also used available information such as SSTS type and year constructed to predict which systems are likely not in compliance and potentially failing. Results suggest there are approximately 126 SSTSs in the Ann River impaired reach watershed. It was assumed that about 50% (63 systems) of the systems throughout the watershed are currently not in compliance (Kanabec SWCD staff, personal communication). Wastewater from failing septic systems may include many types of contaminants such as nitrates, harmful bacteria and viruses, and other toxic substances, which can be hazardous to both groundwater and surface water.

3.7.4.3 Wildlife

Wildlife in the Ann River impaired reach watershed encompasses a broad group of animals. For this assessment, deer and waterfowl were assumed to be the main contributors while all other wildlife was grouped into one separate category.

The Minnesota DNR estimated there are approximately 10-12 deer per square mile in the Ann River watershed and surrounding areas (Doug Welinski, MN DNR Cambridge Office Wildlife technician, personal communication). This report assumes an average deer density of 11 deer per square mile for the entire watershed.

There are currently no waterfowl surveys or data available for Ann River or the surrounding area. A 2011 Waterfowl Breeding Population Survey by the MN DNR and U.S. Fish & Wildlife Service estimated that there are approximately 10 waterfowl (includes both geese and ducks) per square mile throughout the state (Minnesota DNR 2011). Applying this average to Ann River suggests there are, on average 189 waterfowl in the impaired reach watershed at any given time.

3.7.4.4 Urban Stormwater Runoff

Untreated urban stormwater has demonstrated bacteria concentrations as high as or higher than grazed pasture runoff, cropland runoff, and feedlot runoff (USEPA 2001, Bannerman et al. 1993, 1996). There is very little urban/roadway area in the Ann River impaired reach watershed. This TMDL source assessment assumes urban bacteria contributions come exclusively from improperly managed waste from dogs and cats (Table 3.6). Deer and waterfowl densities in urban areas were assumed to be the same as those discussed in the previous section. Consistent with the methodology outlined in the Southeast Minnesota Regional Bacteria TMDL (MPCA 2002), it was assumed that there were 0.58 dogs/household and 0.73 cats/household in the urban areas. It was assumed there are currently 35 households in the Ann River impaired reach watershed based on the Kanabec County SSTS inventory.

3.7.5 Ann River Bacteria Available for Transport

Each bacteria source was assigned a percentage that attempts to predict the likelihood of that animal's bacteria reaching the Ann River and its tributaries (Table 3.7). It is important to note that this process assumes that all bacteria produced in the watershed remain in the watershed. For example, all beef cow manure is potentially available for runoff and is distributed as follows: 17% is assumed to be from surface applied manure in the watershed, 55% from upland pastures and 28% from pastures near streams and waterways. Similarly, it was assumed that only 10% of the bacteria load associated with cat and dog waste in urban areas was improperly managed and potentially available for transport. These assumptions are approximations that were first developed as part of the Southeast Regional TMDL (MPCA, 2002), then altered to reflect GIS calculations and current (based on predictions/estimates) conditions within the watershed.

Table 3.6. Inventory of fecal coliform bacteria producers in the Ann River impaired reach watershed.

Category	Sub-Category		Animal Units or Individuals
Livestock	The Basin contains an estimated 5 registered livestock facilities ranging in size from less than 50 animal units to several hundred	Dairy	137 animal units
		Beef	649 animal units
		Swine	5 animal units
		Poultry	0 animal units
		Other (Horses)	0 animal units
Human[1]	Population with Inadequate Wastewater Treatment[2]		170 people
	Population with Adequate Wastewater Treatment		170 people
	Municipal Wastewater Treatment Facilities		0 people
Wildlife[3]	Deer (average 11 per square mile)		208 deer
	Waterfowl (average 10 per square mile)		189 geese/ducks
	Other		Other wildlife was assumed to be the equivalent of deer and waterfowl combined in the watershed.
Pets	Dogs and Cats in Urban Areas[3]		48 dogs and cats

[1] Based on Kanabec County SSTS inventory

[2] Assumes 2.7 people per household (USEPA 2002) and a 50% failure rate based on Kanabec County SSTS inventory

[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2002).

Table 3.7. Assumptions used to estimate the amount of daily fecal coliform production available for runoff in the Ann River impaired reach watershed.

Category	Source	Assumption
Livestock	Pastures near streams or waterways	28% of beef, dairy and horse manure
	Upland pastures	55% of beef, dairy and horse manure
	Cropland surface applied manure	17% of beef, dairy and horse manure
Human	Failing septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

Next, potential fecal coliform runoff loads were estimated for the Ann River impaired reach watershed (Table 3.8 and Figure 3.8). Daily fecal coliform production estimates for each animal unit or individual were derived from the Southeast Regional TMDL and the USEPA Onsite Wastewater Treatment Systems Manual (MPCA 2002; USEPA 2002).

Table 3.8. Summary of estimated daily fecal coliform potentially available for delivery to Ann River from the impaired reach watershed.

Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9) (% of total watershed bacteria production)
Livestock	Pastures near streams or waterways	Dairy Animal Units	2,264	18,766 (28%)
		Beef Animal Units	16,419	
		Horse Animal Units	83	
	Upland pastures	Dairy Animal Units	4,381	36,311 (54%)
		Beef Animal Units	31,770	
		Horse Animal Units	160	
	Cropland surface applied manure	Dairy Animal Units	1,329	11,016 (16%)
		Beef Animal Units	9,638	
		Horse Animal Units	49	
Human	Failing septic systems and unsewered communities	People	340	340 (<1%)
	Municipal wastewater treatment facilities	People	0	
Wildlife	Deer	Deer	104	359 (<1%)
	Waterfowl	Geese and ducks	76	
	Other wildlife	Equivalent of deer plus waterfowl	179	
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	Dogs and cats	7	7 (<1%)
Total				**66,799**

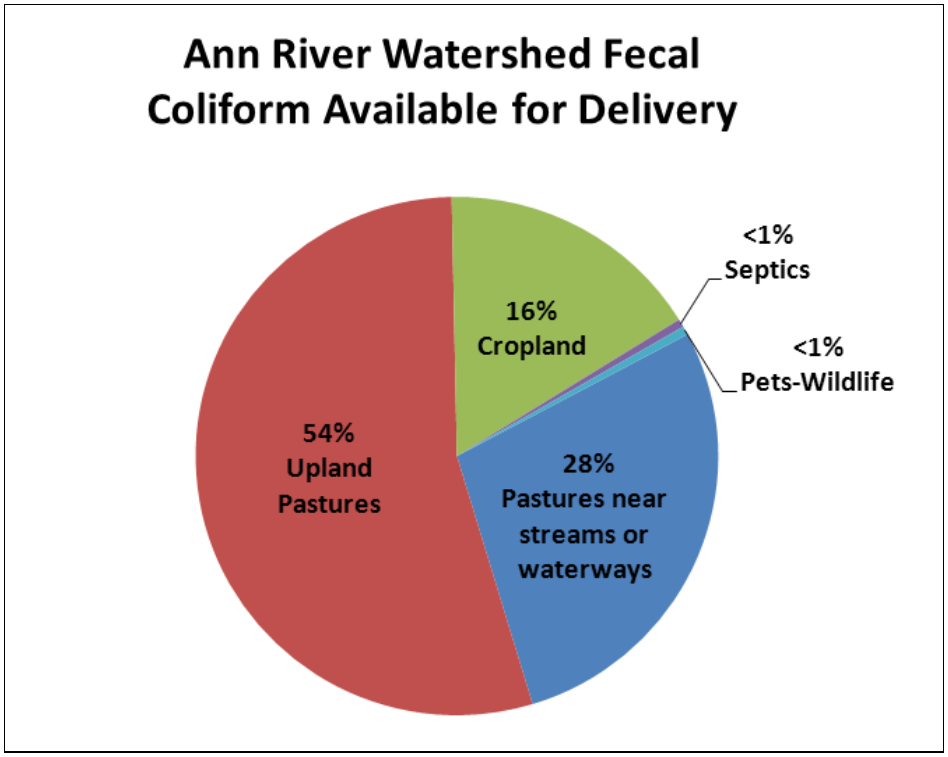

Figure 3.8. Fecal coliform available (by source) for delivery in the Ann River impaired reach watershed.

3.7.6 Pollutant Source Assessment Summary

Based on the outcome of the bacteria pollutant source inventory, the results suggest that:

- Livestock are by far the biggest producer of bacteria in the impaired reach watershed.
- The largest potential sources are those activities associated with pasture management. Implementation activities should focus on limiting cattle access to Ann River and its tributaries, and buffering runoff from pastures near streams and waterways. Secondarily, BMPs for upland pasture land should also be implemented.
- Cropland manure application does not appear to be a top source of bacteria to Ann River since cropland represents only 5 percent of the landuse throughout the watershed. That said, cropland with high runoff potential and fields located near streams/waterways should be targeted for BMPs.
- Collectively, failing SSTSs appear to be a relatively small source compared to livestock. However, depending on their location and level of failure, these systems have the potential to be significant bacteria contributors during low flow conditions.

4.0 Lake Nutrient Impairments

4.1 WATERSHED AND LAKE CHARACTERIZATION

Ann Lake (DNR Lake # 33-0040) and Fish Lake (DNR Lake # 33-0036) are located in east-central Minnesota in in Kanabec County (Figure 4.1). Ann Lake is located upstream of Fish Lake and both lakes are impoundments on the Ann River. The outlet of Fish Lake discharges to the Snake River; which eventually discharges to the St. Croix River east of Pine City, Minnesota.

Ann Lake is a moderately large (653 acre) impoundment at the headwaters of the Ann River north of Ogilvie, Minnesota. Outflow from Ann Lake eventually flows to Fish Lake via the Ann River. The water level on Ann Lake is maintained by a Division of Fish and Wildlife sheet piling dam on the southeast end of the lake. Ann Lake is a shallow (max depth of 17 feet) lake with a short residence time (55 days) meaning that the lake flushes about once every two months (Table 4.1). Approximately 92% of Ann Lake can be expected to support submerged aquatic vegetation growth.

Ann Lake has a moderately large drainage area (35,826 acres). The Little Ann River watershed which enters the lake on the north end is approximately 20,000 acres and accounts for a large portion (56%) of the lake's total watershed. The remainder of the Ann Lake watershed is made up of direct drainage to the lake (27%) and the Camp Creek watershed (17%).

Similar to Ann Lake, Fish Lake is a long, narrow, shallow (max depth of 8 feet) 407 acre impoundment of the Ann River (Table 4.1). Fish Lake is located approximately 1 mile southwest of Mora, Minnesota. Fish Lake discharges to the Snake River and the lake's outflow is controlled by a 50 foot long dam in the northeast corner of the lake. Fish Lake has an extremely short residence time (approximately 14 days). Due to its shallow nature, Fish Lake should be expected to have 100% coverage of submerged aquatic vegetation.

Fish Lake is located at the downstream end of the Ann River watershed and has a relatively large drainage area (55,431 acres). Fish Lake hydrology is largely controlled by the Ann River which enters the lake on the north end of the lake's eastern basin. The Ann River watershed above Fish Lake is made up of the aforementioned Ann Lake watershed (35,826 acres) as well as the 12,109 Ann River watershed between Ann and Fish Lake (Figure 4.1). Direct drainage to Fish Lake accounts for approximately 14% (7,496 acres) of the lake's total watershed and is made up of various small tributaries that drain directly to the lake.

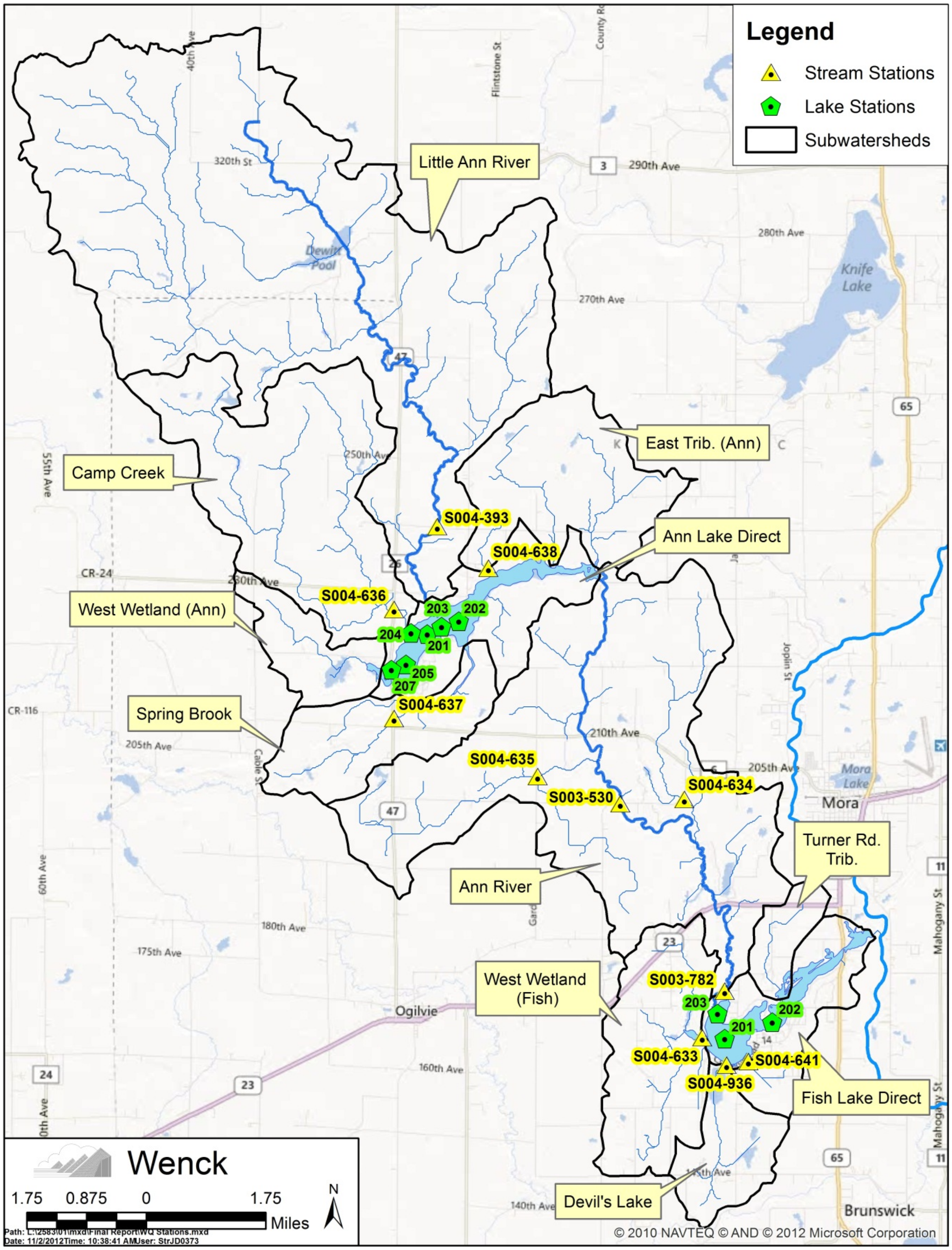

Figure 4.1. Lake and stream water quality monitoring stations and major subwatersheds in the Ann and Fish Lake watershed.

Table 4.1. Ann and Fish Lake morphometry and watershed characteristics.

Parameter	Ann Lake	Fish Lake
Surface Area (acres)	773	418
Average Depth (ft)	6.5	4.8
Maximum Depth (ft)	17	10
Volume (ac-ft)	5,029	2,009
Residence Time (years)	0.15	0.04
Littoral Area (acres)	710	418
Littoral Area (%)	92%	100%
Watershed[1] (acres)	35,826	19,605

[1] Totals do not include the area of major upstream lakes.

4.2 LAKE WATER QUALITY

4.2.1 Introduction

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

Lake water quality samples have been collected at various locations on Ann and Fish Lake under a variety of efforts (Appendix B). Station 33-0036-00-201 is the primary sampling location for Ann Lake while station 33-0040-00-203 is the main sampling site for Fish Lake (Figure 4.1). Both stations are centrally located near the deep hole of each lake's largest basin. Since 2000, however some samples (particularly Secchi depth) have been collected from the other stations shown in Figure 4.1.

Sampling in 2008 and 2009 was specifically intended to support this TMDL study as the data from these years represent the most complete and robust dataset for both lakes since 2000. 2008 and 2009 Ann and Fish Lake monitoring was conducted bi-weekly from May through September for the following lake water quality parameters: Secchi depth, total phosphorus (TP), chlorophyll-a, ortho-phosphorus, nitrate + nitrite, total Kjeldahl nitrogen (TKN), total suspended solids (TSS), and temperature and dissolved oxygen measurements. Collection efforts were coordinated and carried out by citizens onAnn Lake, Fish Lake, the Kanabec County SWCD, and the Minnesota Pollution Control Agency (MPCA).

4.2.2 Temperature and Dissolved Oxygen

Dissolved oxygen profiles for Ann and Fish Lakes were collected monthly in 2008 and 2009. These profiles show slight stratification and temperature gradients between the surface and bottom waters during the mid-summer months (Appendix C). Dissolved oxygen (DO) profiles demonstrate anoxia (DO ≤ 2 mg/L) occasionally occurs in the bottom 1-2 meters of the water column during the warm summer months (July to early September) which suggests the potential for some internal loading of phosphorus. However, it should be noted that Ann and Fish Lakes are shallow systems with relatively high surface area to depth ratios causing the lakes to be more susceptible to wind-driven mixing events. Thus the lakes do not sustain strong thermoclines and large anoxic areas for the entire summer period.

4.2.3 Total Phosphorus

Summer average total phosphorus (TP) concentrations for Ann and Fish Lake consistently exceeded the 60 µg/L standard for shallow lakes in the North Central Hardwood Forest (NCHF) Ecoregion (Figures 4.2 and 4.3). The highest summer average TP concentration for Ann Lake was 94 µg/L in 2008. Fish Lake's highest average summer TP concentration was also measured in 2008 and was 112 µg/L.

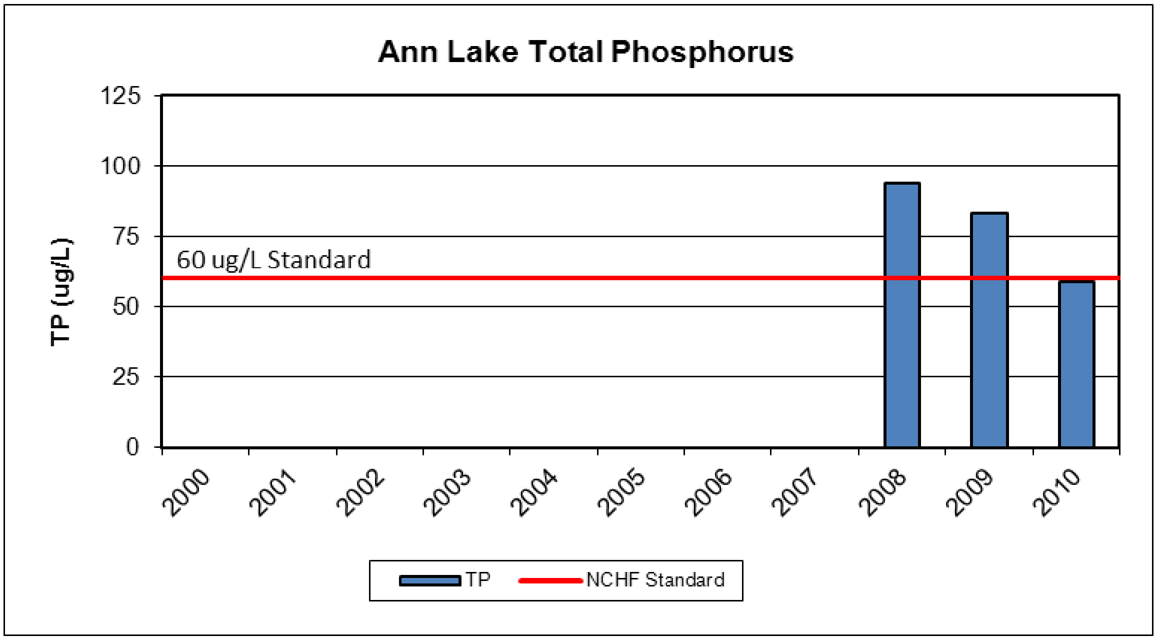

Figure 4.2. Summer mean TP for Ann Lake since 2000.

Notes for all figures: Results display the average from all sampling sites during the summer index period (June 1 through September 30). The solid red line represents the shallow lake state standards for the NCHF ecoregion. Only sampling seasons with four or more measurements/observations are displayed.

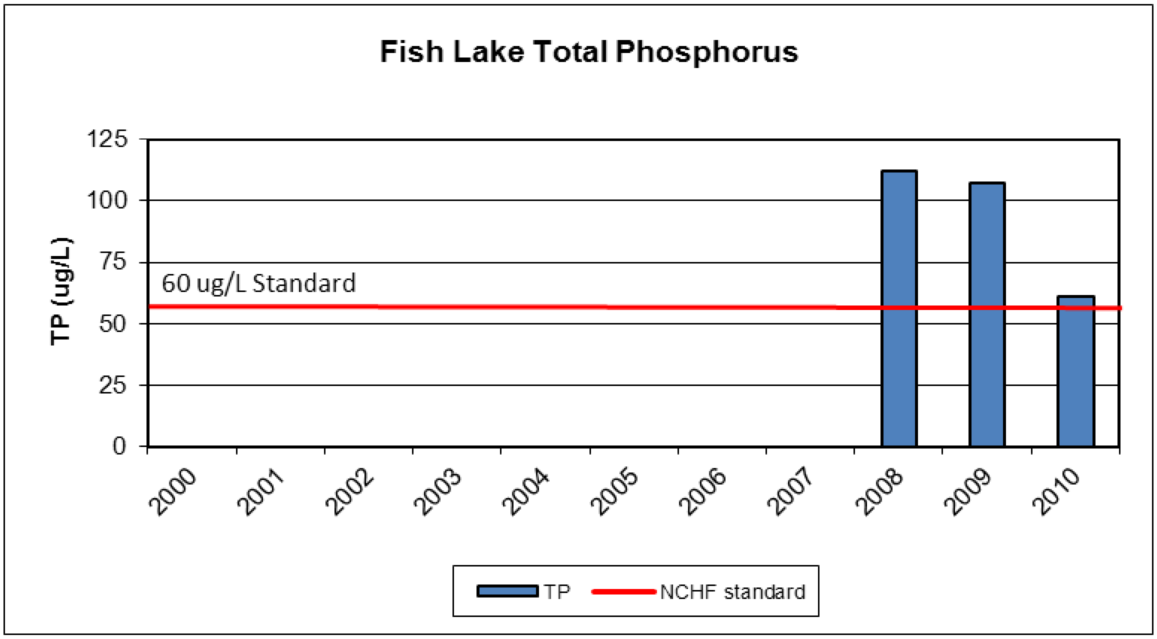

Figure 4.3. Summer mean TP for Fish Lake since 2000.

4.2.4 Chlorophyll-a

Since 2000, average chlorophyll-a concentrations in Ann Lake have ranged from 25 µg/L to as high as 39 µg/L in years with four samples or more during the summer season. Fish Lake average summer chlorophyll-a concentrations have ranged from 37 µg/L to 54 µg/L (Figures 4.4 and 4.5). Chlorophyll-a concentrations over 20 µg/L are exceed the state water quality standards for shallow lakes in the NCHF ecoregion and indicate a high incidence of nuisance algae blooms. Mean summer chlorophyll-a concentrations for both lakes have exceeded the state standard in all three sampling seasons with adequate monitoring data.

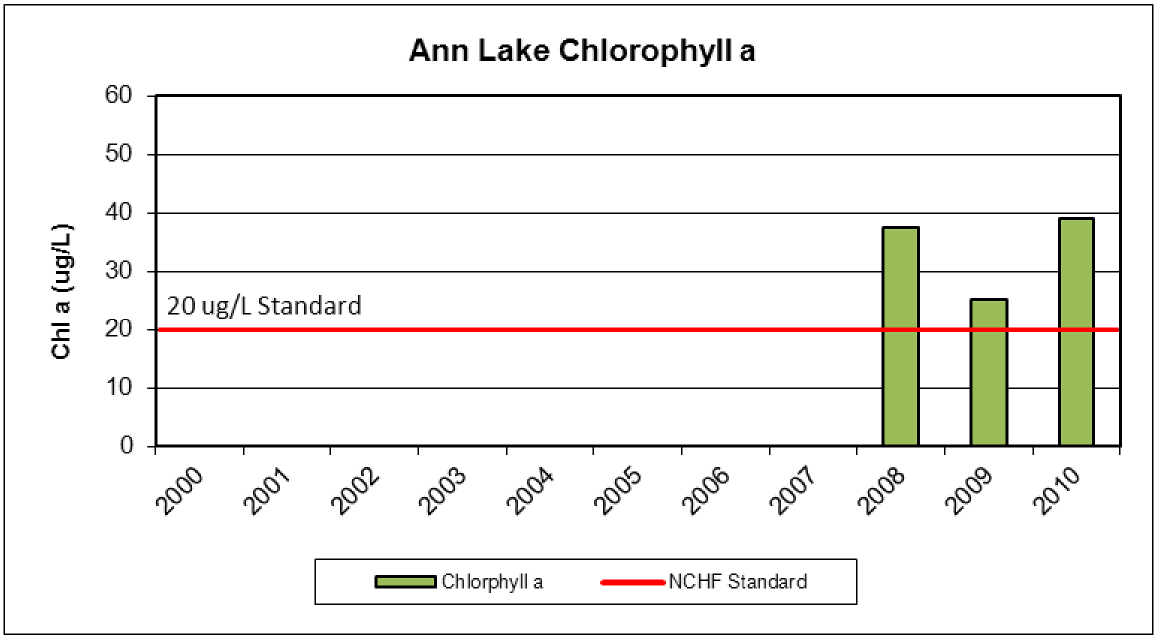

Figure 4.4. Summer mean chlorophyll-a for Ann Lake since 2000.

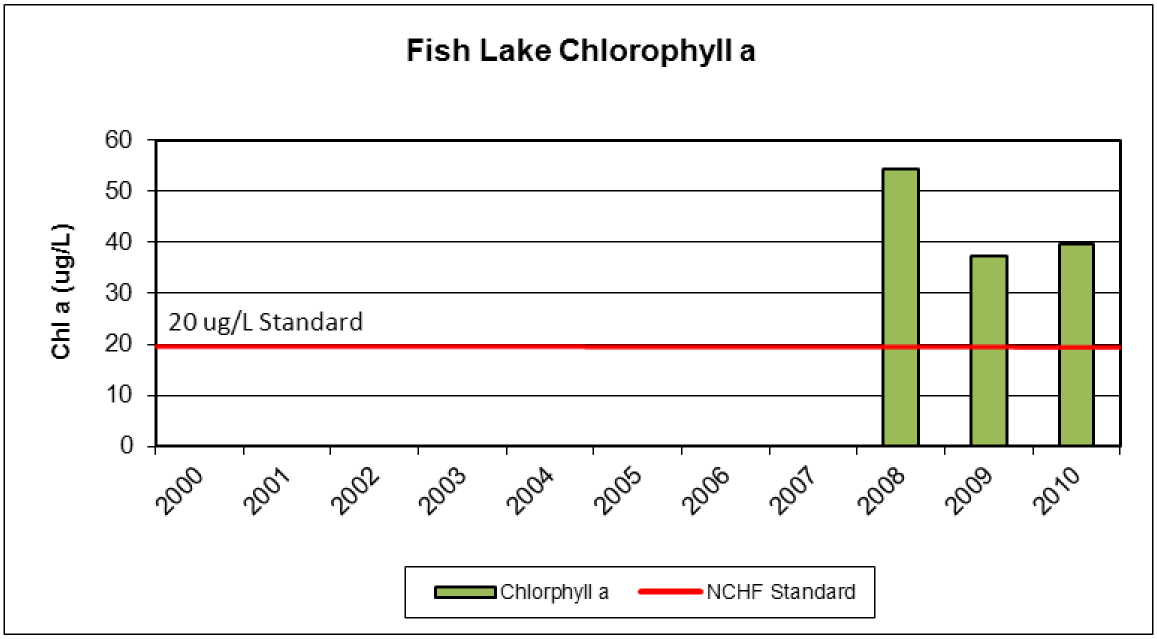

Figure 4.5. Summer mean chlorophyll-a for Fish Lake since 2000.

4.2.5 Secchi Depth

Water clarity (Secchi depth) in general follows the same trend as TP and chlorophyll-a. Since 2000, mean summer Secchi depth in Ann Lake has met or been better than the 1.0 meters (3.3 ft) NCHF shallow lake standard for 4 of the 8 years with adequate monitoring data (Figure 4.6). Fish Lake has met the shallow lake Secchi depth standard in only 2 of the 7 monitored years since 2000 (Figure 4.7).

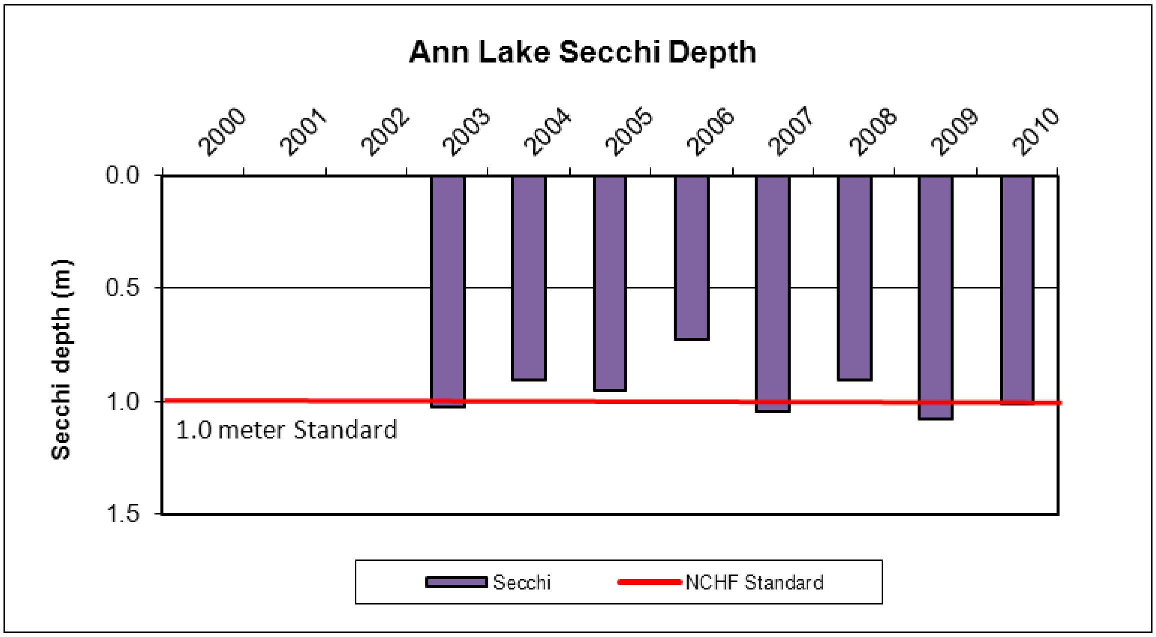

Figure 4.6. Summer mean Secchi depth for Ann Lake since 2000.

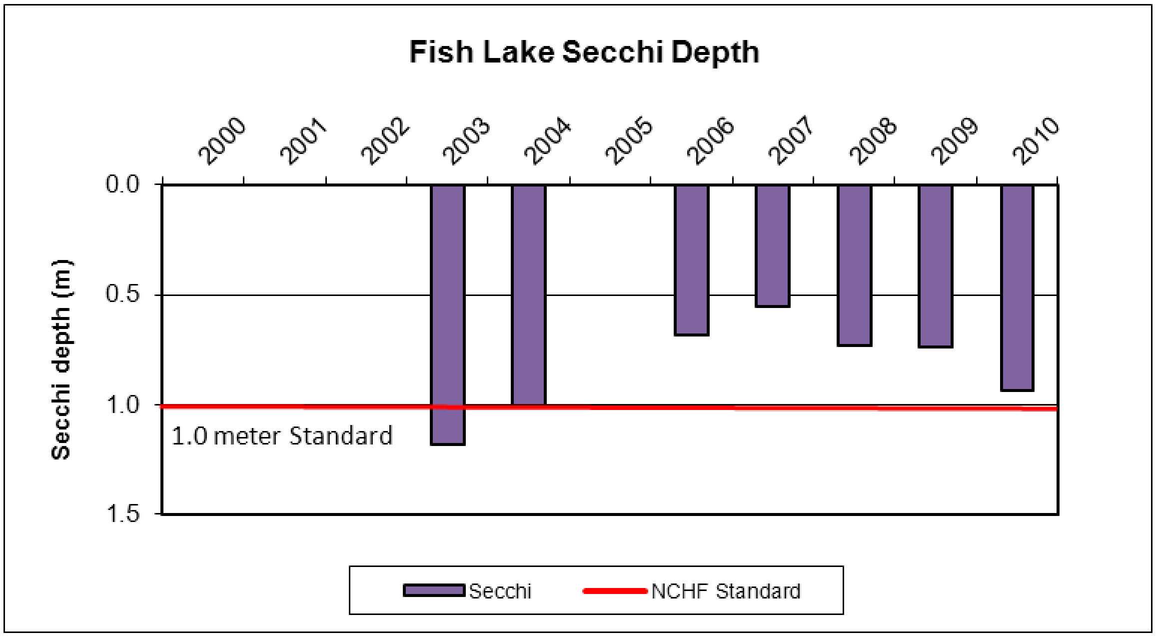

Figure 4.7. Summer mean Secchi depth for Fish Lake since 2000.

4.2.6 Lake Water Quality Conclusions

Overall, Ann and Fish Lake do not meet current Minnesota lake water quality standards for shallow lakes in the NCHF ecoregion. While there is some variability in the monitoring data from year to year, trends over the past 10 years show that water quality in these lakes is relatively stable in its current state. There has not appeared to be a significant decline or improvement in the water quality of either lake over this time period. However, it is important to note that these observations are based on limited data and a rigorous trend analysis has not been conducted on the data set.

4.3 LAKE ECOLOGY

4.3.1 Fish Populations and Fish Health

Fish survey reports for Ann and Fish Lake were provided by the DNR Area Fisheries Office in Hinckley, Minnesota. The first DNR fish surveys for Ann and Fish Lake were conducted in 1980 and 1979, respectively. Standard survey methods used by the DNR include gill net and trap nets. These sampling methods do have some sampling bias, including focusing on game management species (i.e., northern pike and walleye), under representing small minnow and darter species presence/abundance, and under representing certain management species such as largemouth bass. The current methods also likely under represent carp populations in the lakes. However, in our experience, when carp are present in the lakes, the sampling methods do capture some of the population. So, although carp density is likely under represented, the methods do provide a reasonable year to year comparison.

There have been 24 species collected during the Ann and Fish Lake DNR surveys:

- black bullhead
- black crappie
- bluegill
- bowfin
- brown bullhead
- common carp
- channel catfish
- freshwater drum
- golden redhorse
- golden shiner
- greater redhorse
- hybrid sunfish (Ann Lake only)
- largemouth bass
- northern pike
- pumpkinseed
- rock bass
- shorthead redhorse
- silver redhorse
- walleye
- white bass (Fish Lake only)
- white crappie
- white sucker
- yellow bullhead
- yellow perch

Ann Lake supports a diverse fish community and receives high fishing pressure at times especially when the panfish bite is on. Although natural walleye reproduction likely occurs, the DNR typically stocks 300 pounds of walleye fingerlings every fall. Walleye and northern pike abundance have been slightly down in recent years likely due to a slight decrease in yellow perch populations. In Ann Lake, perch function mostly as a forage base for walleye, northern and other top predators.

The fish community in Fish Lake is diverse and supports relatively good fishing opportunities. Primary gamefishes include walleye, northern pike, largemouth bass, bluegill, and black crappie. The walleye population is maintained through biannual fry/fingerling stocking, although natural reproduction does occur. Similar to Ann Lake, yellow perch are an important forage fish and numbers may be declining due to predation from other gamefish populations.

Common carp have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. Carp and other rough fish are present in both Ann Lake and Fish Lake, but their size and composition is currently unclear. At least one common carp was captured in 7 of the 10 Ann Lake surveys and in all 7 Fish Lake surveys. Each Ann Lake survey from 1980-2000 netted at least one common carp; however no carp were captured the past two surveys in 2005 and 2010. Common carp are more common in Fish Lake in terms of both abundance and biomass. The 37 carp sampled during the 2007 Fish Lake survey is the highest catch for common carp in Fish Lake since the 1979 survey.

Fish community data for each lake was summarized by trophic groups (Figures 4.8 through 4.11). Species within a trophic group serve the same ecological process in the lake (i.e., panfish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community then analyzing individual species trends. The following conclusions can be drawn from the fish data:

- Both Ann and Fish Lake are impoundments of the Ann River and the river system undoubtedly has an impact on each lake’s fish populations. Golden, greater, shorthead and silver redhorse are all a common river species that were captured and documented in numerous Ann and Fish Lake surveys. Other species, such as white suckers and channel catfish can live and survive in both lake and stream environments. Ann River may also aid in the migration and movement of carp and other rough fish in and out of each lake.
- Top predators have comprised the largest percentage of the total biomass catch during 6 of the 10 Ann Lake DNR surveys. For Ann Lake, northern pike, walleye and bowfin make up a majority of the predator biomass. While top predator biomass in Ann Lake is high, overall abundance is relatively low suggesting a few large individuals.
- Total biomass in Fish Lake has appeared to shift year to year between forage species, pan fish and top predators. However, the increase in common carp and other rough fish (particularly black, brown and yellow bullhead) biomass in recent surveys could be impacting lake water quality and other trophic groups.

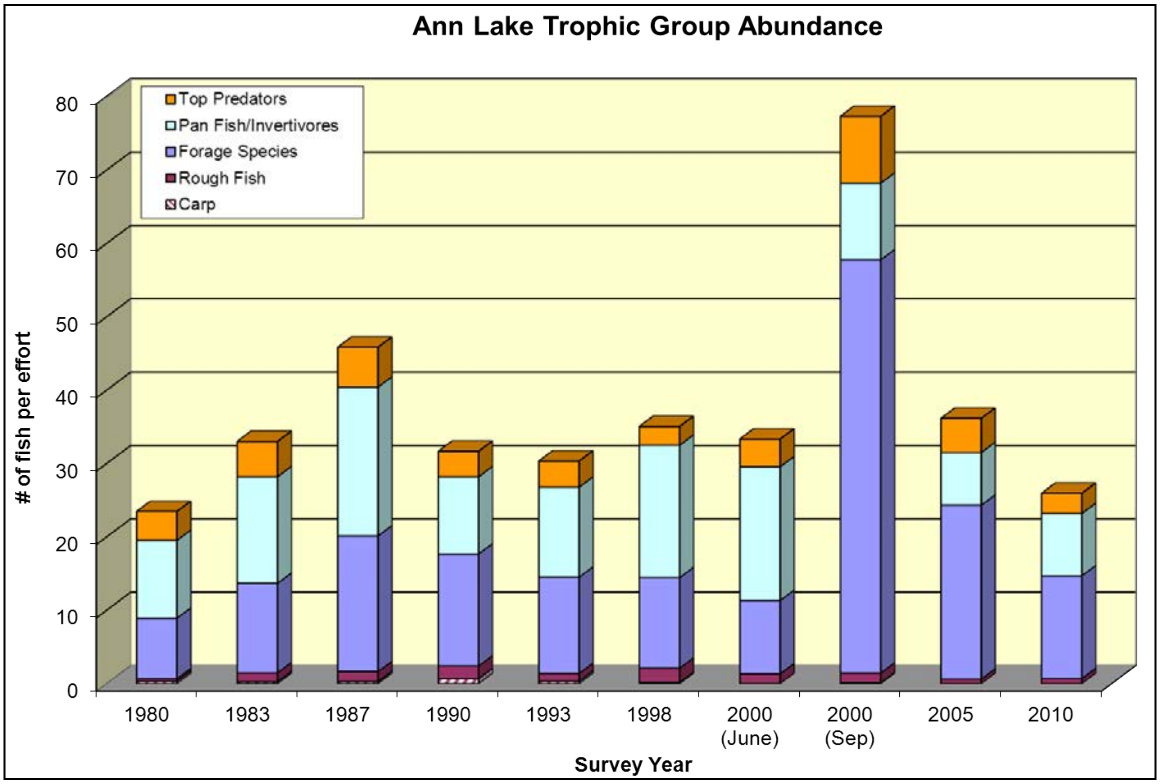

Figure 4.8. Trophic group abundance in Ann Lake based on historic MN-DNR fish survey results.

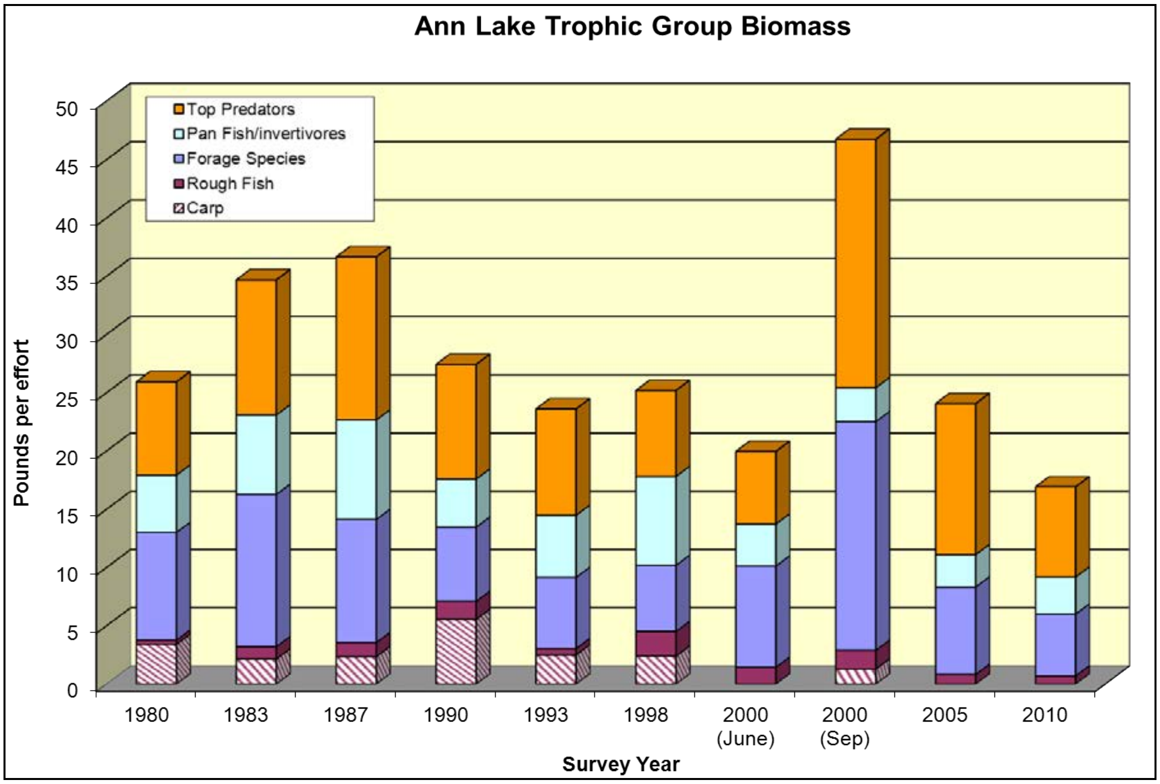

Figure 4.9. Trophic group biomass in Ann Lake based on historic MN-DNR fish survey results.

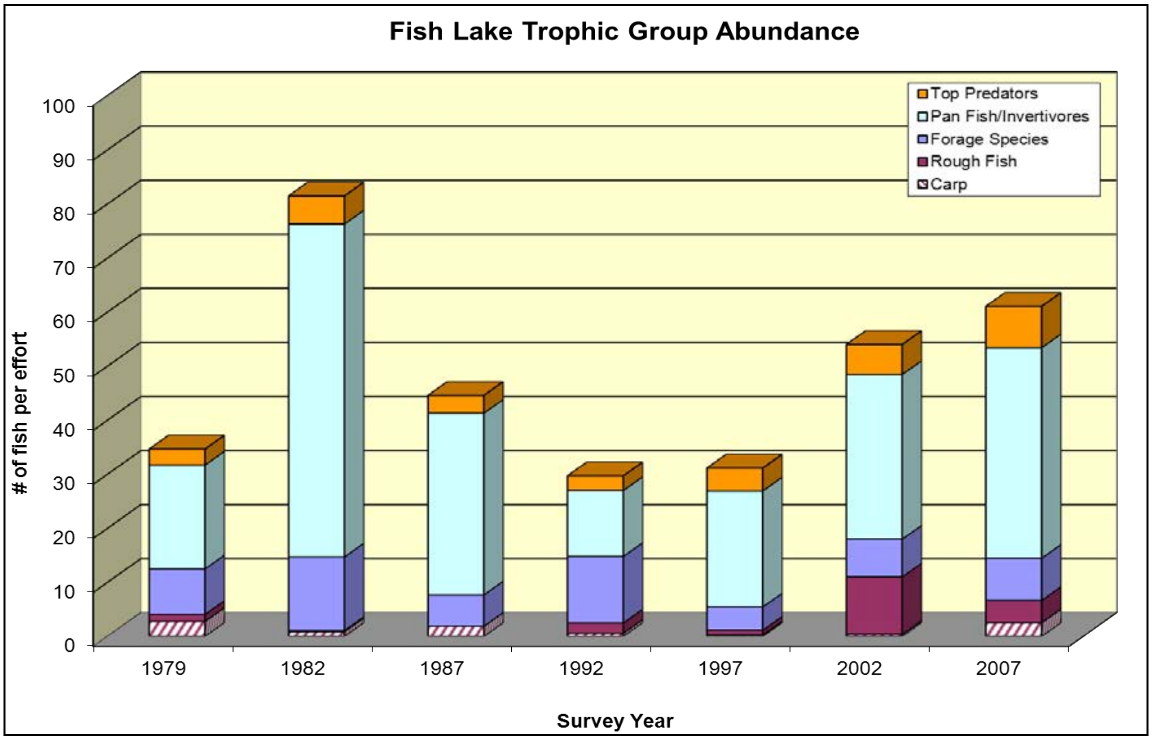

Figure 4.10. Trophic group abundance in Fish Lake based on historic MN-DNR fish surveys.

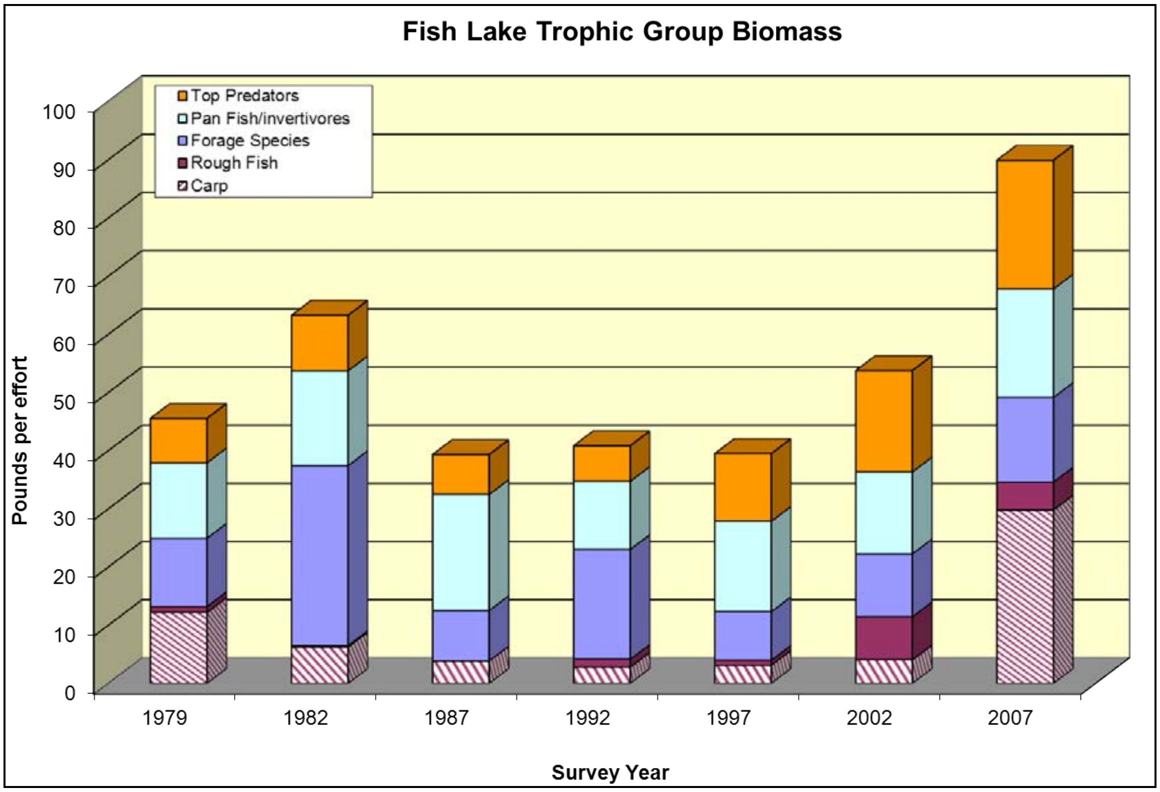

Figure 4.11. Trophic group biomass in Fish Lake based on historic MN-DNR surveys.

4.3.2 Aquatic Plants

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

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

The DNR conducted qualitative plant surveys during the June fish surveys in 1980, 1990 and 1998. In May 2010 the DNR conducted a quantitative point-intercept plant survey to assess the spring plant community of Ann Lake (Sewell 2010). Ann Lake possesses a moderately diverse aquatic plant community with 42 different species observed across the various surveys. The surveys included a mix of emergent, floating leaf and submerged plant species. There were 19 different submerged species observed during the four aquatic plant surveys from 1980 through 2010 (Figure 4.12). There was a relatively high abundance of desirable native submerged species such as clasping-leaf pondweed, flat-stem pondweed and floating-leaf pondweed. Also present were species such as Canada waterweed, coontail and curly-leaf pondweed which, when in high abundance, have the potential to out-compete other vegetation resulting in less species diversity. Neither Ann nor Fish Lake are on the 2011 Minnesota Department of Natural Resources Designated Infested Waters list for Eurasian water milfoil or the other nuisance species included in this list.

Ann Lake Vegetation Surveys - Submerged Species Mean Abundance

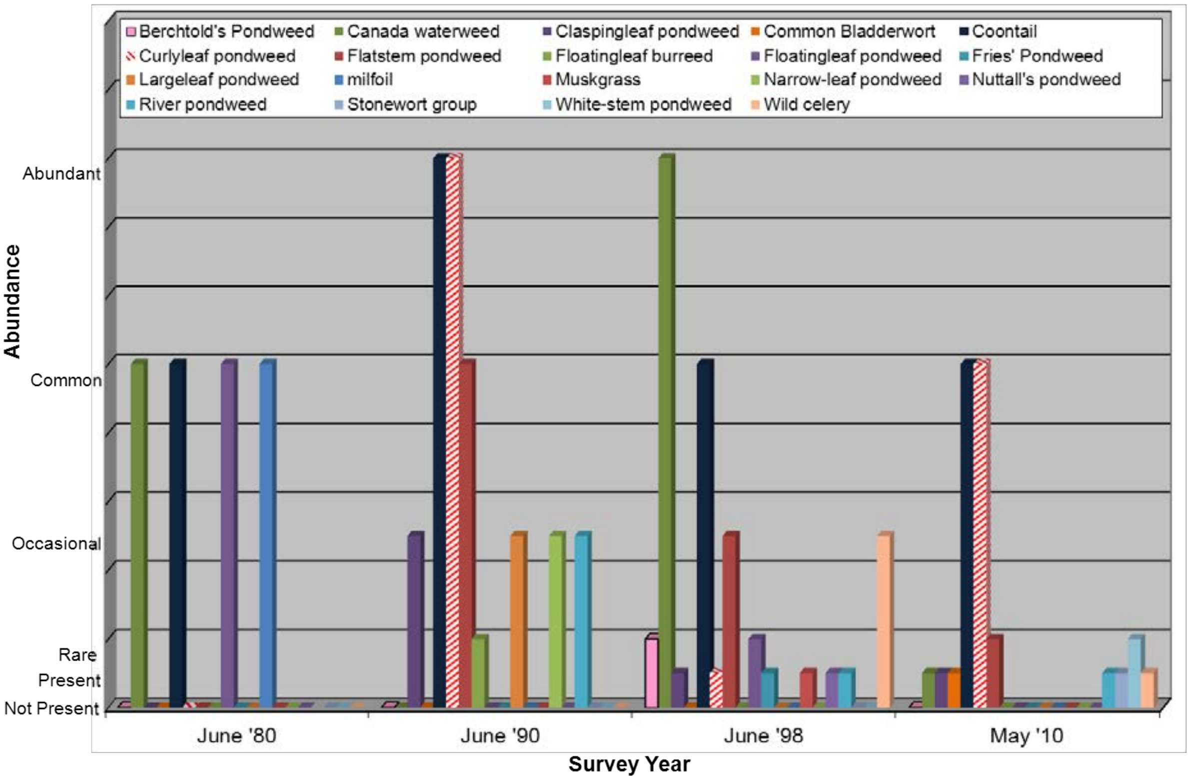

Figure 4.12. Submerged aquatic plant species in Ann Lake.

Vegetation surveys for Fish Lake were performed by the DNR in conjunction with the August 1982, July 1992 and July 2002 fish surveys. The DNR also conducted a point-intercept plant survey for Fish Lake in June 2010 to assess curly-leaf pondweed and the rest of the spring/early summer plant community (Sewell 2010). Results indicate 14 different submerged species have been observed in Fish Lake across the four surveys (Figure 4.13). The two most common submerged plant species observed during the 2010 survey were coontail and curly-leaf pondweed. Both of these are considered less desirable species in supporting plant diversity and water quality. In general, the aquatic vegetation community in Fish Lake is slightly more degraded than Ann Lake in terms of vegetation coverage (abundance) throughout the lake and species diversity.

Fish Lake Vegetation Surveys - Submerged Species Mean Abundance

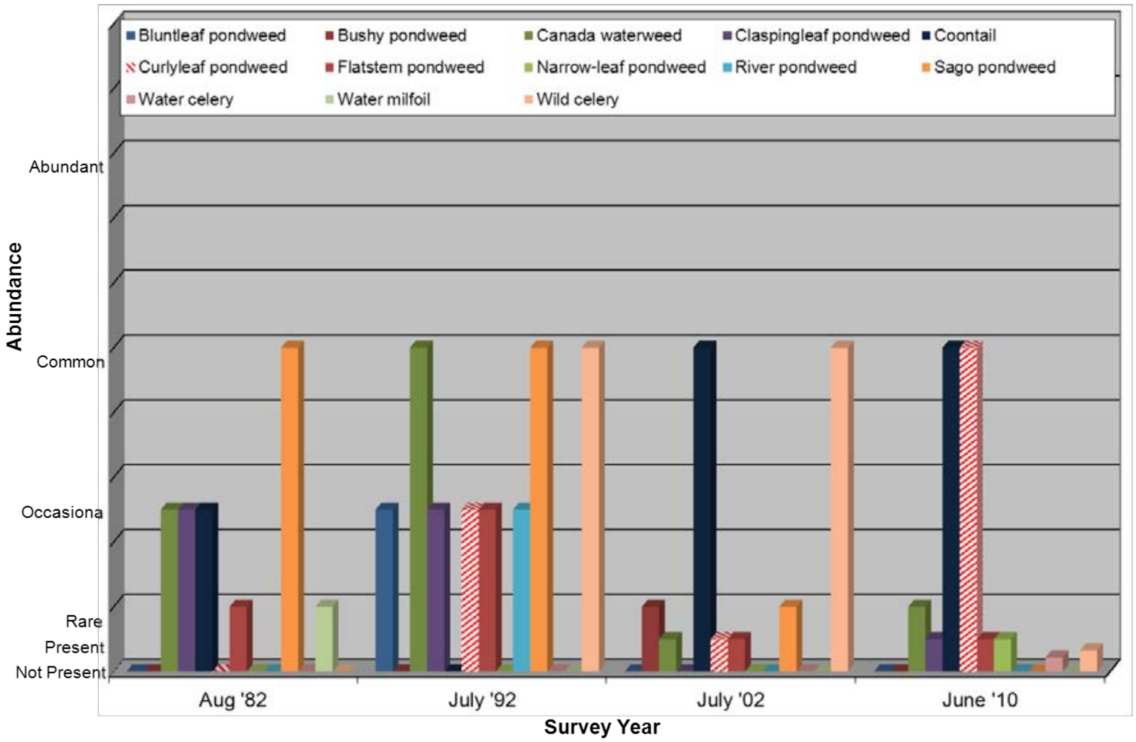

Figure 4.13. Submerged aquatic plant species in Fish Lake.

One of the submerged species noted in both Ann and Fish Lake, curly-leaf pond weed, is invasive and has been one of the more dominant species in Ann Lake dating back to 1990 and in Fish Lake since 1992. Curly-leaf pondweed, like Eurasian watermilfoil, can easily take over a lake's aquatic macrophyte community. Curly-leaf pondweed presents a unique problem in that it is believed to significantly affect the in-lake availability of phosphorus, contributing to the eutrophication problem. Curly-leaf pondweed begins growing in late-fall, continues growing under the ice, and dies back relatively early in summer, releasing nutrients into the water column as it decomposes, possibly contributing to algal blooms. Curly-leaf pondweed can also out-compete more desirable native plant species.

One important emergent species, wild rice, is relatively abundant in both Ann and Fish Lake. Wild rice is a persistent annual grass that reproduces each year from seed stock deposited in previous fall seasons. The plant typically grows in shallow to moderate water depths (1-3 feet) and is affected by water flow, turbidity, water quality and water level fluctuations. Wild rice is sensitive to varying water levels, and production in individual stands from year-to-year is highly variable depending on local water conditions. Wild rice has important cultural value to Native American tribes and local communities and is also very attractive to migrating waterfowl.

It is unusual for wild rice and curly-leaf pondweed to be present in the same water body, and this presents some implications for the potential management of curly-leaf pondweed. Any treatment that would have the potential to negatively affect wild rice, or any other native species, would not be permitted under Minnesota's aquatic plant management rules.

4.4 STREAM MONITORING

Kanabec and Mille Lacs SWCDs and MPCA staff collected total phosphorus grab samples at 11 main-stem river and tributary monitoring stations throughout the Ann and Fish Lake watershed during the 2008-2009 sampling season. Continuous flow was also measured by the MPCA at four monitoring stations in 2008 and 2009 (Table 4.2 and Figure 4.14). Total phosphorus data shows concentrations from certain sites, particularly certain tributaries, are relatively high and occasionally exceed the proposed state stream TP standard of 100 µg/L (Figures 4.14 and 4.15).

Table 4.2. Continuous flow and total phosphorus stream monitoring stations in the Ann and Fish Lake watershed.

Station ID	Location	Continuous Flow Monitoring	TP Samples (2008)	TP Samples (2009)
S004-393	Little Ann River at CSAH 26	Yes	24	16
S004-636	Camp Creek at Hwy 47	Yes	23	23
S004-637	Spring Brook at Hwy 47	No	15	16
S004-638	Trib to Ann Lake at Crest View Dr	No	15	16
S004-635	Trib to Ann River at Co Rd 59	No	16	16
S004-634	Trib to Ann River at CSAH 12	No	12	10
S004-633	Tosher Creek at CSAH 14	No	15	14
S004-936	Devils Lake outlet at CSAH 14	No	5	none
S004-641	Trib to Fish Lake at CSAH 14	No	14	16
S003-530	Main-stem Ann River at Co Rd 12	Yes	23	21
S003-782	Main-stem Ann River at Co Rd 14	Yes	23	14

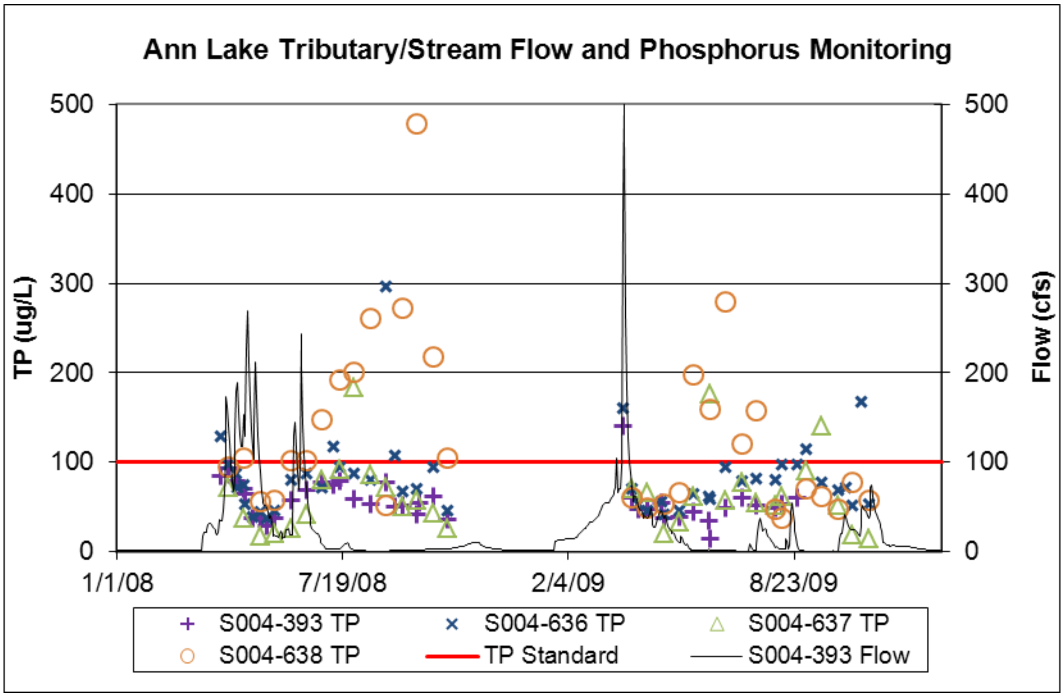

Figure 4.14. 2008 and 2009 TP and stream flow monitoring in the Ann Lake watershed. The red line indicates the proposed TP standard for rivers/streams.

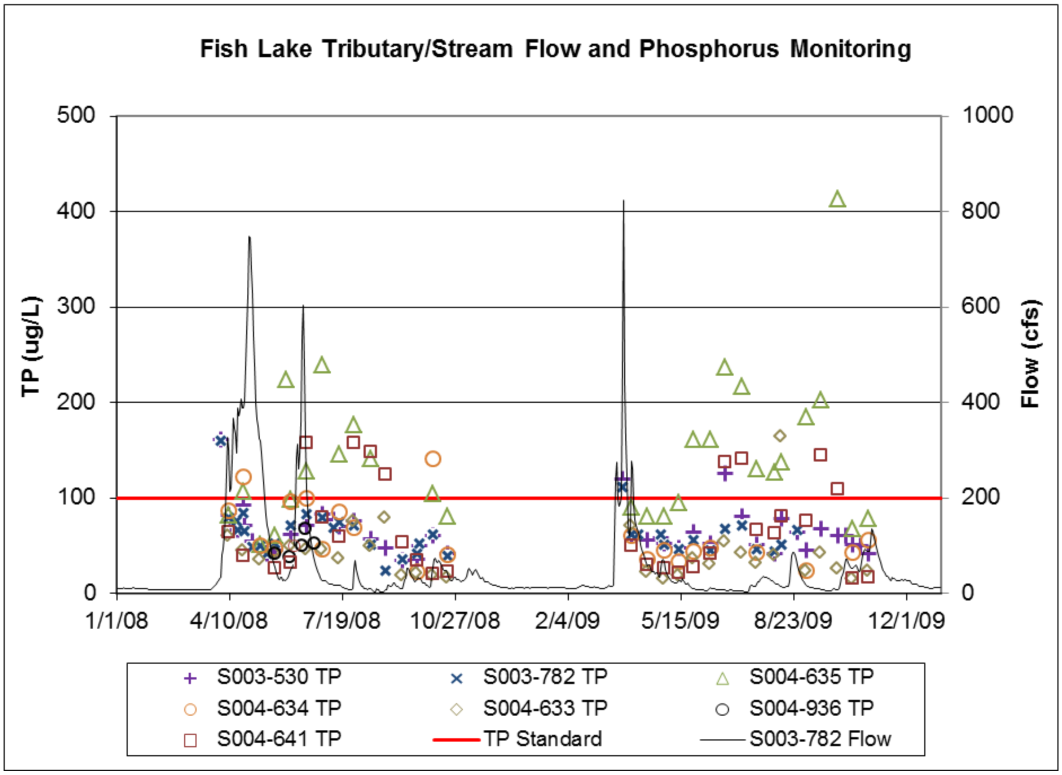

Figure 4.15. 2008 and 2009 TP and stream flow monitoring in the Fish Lake watershed. The red line indicates the proposed TP standard for rivers/streams.

4.5 NUTRIENT SOURCES AND LAKE RESPONSE

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

4.5.1 Modeling Approach

Several models were used to develop the nutrient budget necessary to establish load and wasteload allocations.

4.5.2 Watershed Models

The National Resource Conservation Service's (NRCS) Curve Number method was used to model watershed runoff to Ann and Fish Lake. This approach uses hydrologic soil group, impervious fraction and plant/land use cover type to develop various curve numbers throughout each watershed. Surface runoff is then calculated by applying daily temperature and precipitation data to the SCS runoff equation (USDA 1986). Ann and Fish Lake watershed hydrologic soil groups were obtained from the U.S. Department of Agriculture NRCS's soil Survey Geographic (SSURGO) database. Watershed plant and land cover was defined using the 2009 National Agricultural Statistics Services Land Cover (NASS) GIS shapefile. The US Fish and Wildlife Service National Wetland Inventory (NWI) GIS file was burned into the 2009 NASS layer to more accurately define all wetland boundaries. Daily temperature and precipitation for the Mora, Minnesota weather station was downloaded from the Minnesota State Climatology website (http://climate.umn.edu/). Slight calibration adjustments to curve numbers were needed to match model predicted runoff to observed measurements. Overall, the model performed well in predicting 2008 and 2009 annual runoff at the Little Ann River (S004-393), Camp Creek (S004-636) and main-stem Ann River (S003-530 and S003-782) flow monitoring stations (Appendix D).

Total phosphorus was measured at seven subwatershed monitoring stations in 2008 and 2009 (Table 4.2). Phosphorus loading from these subwatersheds was calculated by multiplying the monitored flow weighted mean TP concentration for each year by the model predicted runoff volume. A unit-area load (UAL) approach was also used to estimate phosphorus loading from all non-monitored subwatersheds. This approach divides each subwatershed into Hydrologic Response Units (HRUs) which are unique combinations of land cover, soils and slope. Ann and Fish Lake watershed HRUs were developed in GIS by overlaying the watershed's soil attributes (SSURGO database), slope (10 meter Digital Elevation Model) and land use (2009 NASS). A range of loading rates were selected to represent phosphorus loading from each of the HRUs (Appendix E). Data were selected based on literature review for land uses in Minnesota (Reckhow et al. 1980). Phosphorus outflow from Ann Lake to main-stem Ann River was built into the UAL model by multiplying Ann Lake's annual flow-weighted mean phosphorus concentrations (for all months) by model predicted outflow volumes. HRU loading rates were adjusted slightly to match model predicted phosphorus loads to annual observed loads at the four monitoring sites. Final UAL calibration results are presented in Appendix F. Appendix G provides a complete summary of total annual watershed runoff and phosphorus loading by subwatershed.

4.5.3 Internal Loading

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

To estimate internal loading, an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, is estimated from dissolved oxygen profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor was then used along with a sediment release rate to estimate the total phosphorus load from the sediments. Oxic and anoxic phosphorus release rates were estimated individually for Ann and Fish Lake by collecting sediment cores from each basin and incubating them in the lab under oxic and anoxic conditions (ACOE-ERD 2011; Appendices H-I).

4.5.4 Atmospheric Load

The atmospheric load refers to the load applied directly to the surface of the lake through atmospheric deposition. Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report “Detailed Assessment of Phosphorus Sources to Minnesota Watersheds” (Barr Engineering 2004), and are based on annual precipitation. The values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km^2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre-year for dry, average, and wet years in English units, respectively.

4.5.5 BATHTUB Model (Lake Response)

Once the nutrient budget for a lake has been developed, the response of the lake to those nutrient loads must be established. The focus of the lake response modeling is on total phosphorus, chlorophyll-a and Secchi depth. For this TMDL, the BATHTUB model 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). BATHTUB has been used successfully in many lake studies in Minnesota and throughout the United States. BATHTUB is a steady-state annual or seasonal model that predicts a lake’s summer (June – September) mean surface water quality. BATHTUB’s time-scales are appropriate because watershed Phosphorus (P) loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions.

The heart of BATHTUB is a mass-balance P model that accounts for water and P inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and P sedimentation and retention in the lake sediments. BATHTUB allows choice among several different mass-balance P models. For deep lakes in Minnesota, the option of the Canfield-Bachmann lake formulation has proven to be appropriate in most cases. For shallow Minnesota lakes, other options such as a second order decay model have often been more useful. BATHTUB’s in-lake water quality predictions include two response variables, chlorophyll-a concentration and Secchi depth, in addition to total phosphorus concentration. Empirical relationships between in-lake total phosphorus, chlorophyll-a, and Secchi depth form the basis for predicting the two response variables. Among the key empirical model parameters is the ratio of the inverse of Secchi depth (the inverse being proportional to the light extinction coefficient) to the chlorophyll-a concentration. The ratio's default value in the model is 0.025 meters squared per milligram (m^2/mg); however, the experience of Minnesota Pollution Control Agency staff supports a lower value, as low as 0.015 m^2/mg, as typical of Minnesota lakes in general.

A BATHTUB lake response model was constructed using the nutrient budget developed using the methods previously described in this section. As many years as possible out of the last 10 years were modeled to validate the assumptions of the model. Several models (subroutines) are available for use within the BATHTUB model. The selection of the subroutines is based on past experience in modeling lakes in Minnesota and is focused on subroutines that were developed based on data from natural lakes. The Canfield-Bachmann natural lake model was chosen for the phosphorus model. For more information on these model equations, see the BATHTUB model documentation (Walker 1999) or the MPCA report (MPCA 2005). Model coefficients are also available in the model for calibration or adjustment based on known cycling characteristics. Any applied calibration coefficients are discussed in Section 4.6.3.

4.6 ESTIMATION OF SOURCE LOADS

4.6.1 Atmospheric Load

The atmospheric loads (pounds/year) for the lakes were calculated by multiplying the lake area (acres) by the atmospheric deposition rate (pounds/acre-year). For example, in an average precipitation year the atmospheric load to Ann and Fish Lake would be 0.24 pounds/acre-year times the lake surface areas (773 acres for Ann; 418 for Fish), which equals approximately 186 and 100 pounds/year, respectively.

4.6.2 Watershed Phosphorus Loading

4.6.2.1 Upstream Lakes

The small wetland on the western edge of Ann Lake near MN Highway 47 was treated as an upstream lake for this study. Load from this wetland was estimated by multiplying modeled runoff from the West Wetland subwatershed by the average TP concentration measured at station 33-0040-00-207 in 2008. There are two major lakes upstream of Fish Lake including Ann Lake and Devils Lake. Ann Lake currently represents approximately 67% of the water load to Fish Lake. Phosphorus outflow from Ann Lake was calculated by multiplying Ann Lake's annual flow weighted mean TP concentration by the lake's modeled outflow volume (Table 4.3). Devils Lake represents approximately 2% of the water budget for Fish Lake. While no TP samples have been collected on Devils Lake since 1981, the lake association has collected Secchi depth measurements multiple times each year the past 10 years. This data suggests Devils Lake currently meets state water quality standards for deep lakes in the NCHF ecoregion.

Table 4.3. 2008 and 2009 outflow and phosphorus load from Ann Lake.

Year	Annual Outflow (acre-ft)	Annual Outflow Flow-Weighted mean TP Concentration (µg/L)	Annual TP outflow (lbs/year)
2008	35,358	53	5,098
2009	31,928	59	5,125
Average	33,643	56	5,112

4.6.2.2 Loading by Land Use

Figure 4.16 shows average annual phosphorus loading throughout the Ann and Fish Lake watersheds based on the UAL approach. Table 4.4 summarizes UAL model predicted phosphorus loading for the Ann and Fish Lake watershed by land use type. Values are presented in terms of percent of the total watershed runoff phosphorus load for each watershed. These results indicate forested land represents a majority of the watershed load in the Ann Lake watershed. Phosphorus loading from forested land is typically low, so management initiatives in the Ann Lake watershed should focus on sustainable forestry practices and BMPs for sensitive agricultural areas. For the Fish Lake watershed, agricultural land practices, primarily pasture/hay, and corn/soybean rotations, are the biggest contributors of watershed phosphorus loading. In both watersheds, urban areas and roads/highways represent a very small portion of the total watershed load.

Table 4.4. Model predicted watershed phosphorus load for Ann and Fish Lake by loading source.

Loading Source	Ann Lake Watershed Phosphorus Load (pounds/year)	Ann Lake Watershed Percent of Total	[1]Fish Lake Watershed Phosphorus Load (pounds/year)	Fish Lake Watershed Percent of Total
Pasture Land	1,235	19%	2,116	44%
Corn/Soybean	515	8%	1,539	32%
Other Agriculture	74	1%	288	6%
Urban/Roads	84	1%	96	2%
Forested	4,703	71%	769	16%

[1] Fish Lake loading includes only watershed area downstream of Ann Lake

4.6.2.3 Animal Agriculture

To assess the role of manure management on surface water nutrient concentrations and loads, an inventory of all the animals in the watershed was conducted. The MPCA maintains a statewide database of Confined Animal Feeding Operations (CAFO; greater than 1,000 animals) and registered feedlots (greater than 300 animals). These data are linked in GIS to evaluate the spatial distribution of animals in the watershed (Figure 4.16).

Owners with fewer than 300 animal units are not required to have a permit for the construction of a new facility or expansion of an existing facility as long as construction is in accordance with the technical standards. For owners with 300 animal units or more, and less than 1,000 animal units, a streamlined short-form permit is required for construction/expansion activities. Feedlots greater than 1,000 animal units or a significant amount of confined animals are considered large confined animal feedlot operations (CAFOs) and are required to apply for a National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permit. These operations, by law, are not allowed to discharge to waters of the state (MR 7020.2003). There are currently no permitted CAFOs in the Ann or Fish Lake watershed.

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

There are 13 MPCA registered animal operations that contain more than 1,227 animal units throughout the watershed, a majority of which are located in the Fish Lake watershed (Table 4.5). Dairy and beef cattle operations together account for nearly all of the animals in each watershed. Owners of an animal feedlot or manure storage area with 50 or more animal units (10 animal units in shoreland areas) are required to register with the MPCA.

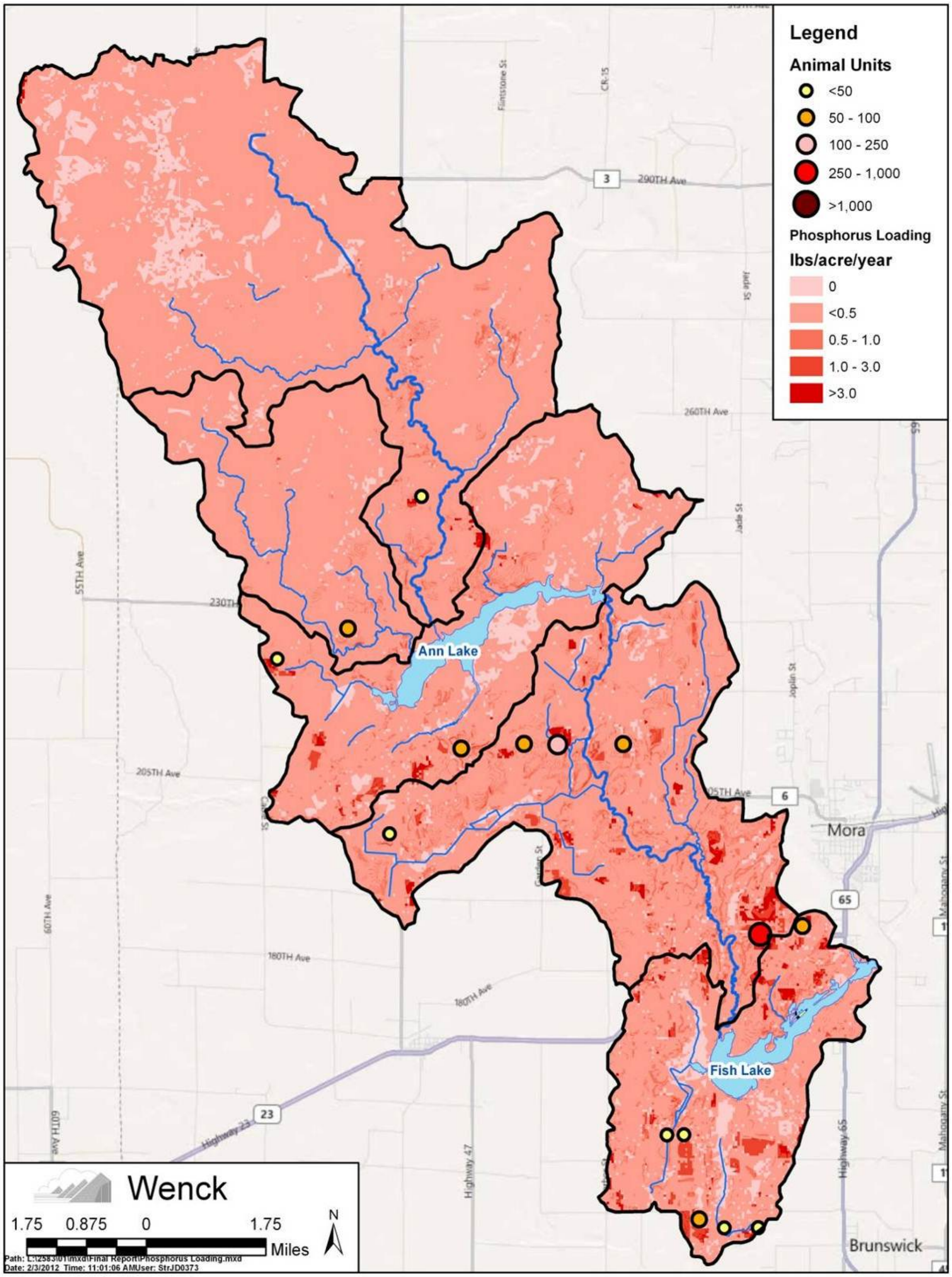

Figure 4.16. Average annual phosphorus loading and MPCA registered feedlots in the Ann and Fish Lake watershed

Table 4.5. Total animal units by animal type throughout the Ann and Fish Lake watersheds. Animal numbers are based on the MPCA's 2010 registered feedlot database.

Subwatershed	Acres	Dairy Cows	Beef Cows	Swine	Poultry	Horses	Other	Total
Little Ann River	20,016	0	16	0	0	0	0	16
Camp Creek	6,145	0	52	0	0	0	0	52
West Wetland (Ann)	1,330	0	48	0	0	0	0	48
Spring Brook	2,343	0	84	0	0	2	0	86
East Trib. (Ann)	3,492	0	0	0	0	0	0	0
Ann Lake Direct	2,499	0	0	0	0	0	0	0
Ann Lake Totals	**35,825**	**0**	**200**	**0**	**0**	**2**	**0**	**202**
Ann River	12,116	137	649	0	0	5	0	791
West Wetland (Fish)	3,139	0	0	0	0	0	0	0
Devil's Lake	1,431	77	36	0	0	1	0	114
Turner Rd. Trib.	714	0	100	0	0	0	0	100
Fish Lake Direct	1,758	0	10	0	0	10	0	20
Fish Lake Totals	**19,158**	**214**	**795**	**0**	**0**	**16**	**0**	**1,025**

The total mass of phosphorus produced by each animal unit category can be estimated using literature values (Evans, et al. 2008). Based on these estimates, over 73,000 pounds of phosphorus are potentially applied or deposited on the land in the form of manure throughout the Ann and Fish Lake watershed (Table 4.6). To put this in perspective, total loading to Fish Lake is typically around 12,709 pounds or approximately 17% of the phosphorus applied to the land throughout both watersheds. Only a small proportion of this phosphorus makes its way into each lake to cause serious eutrophication issues. The Ann and Fish Lake watershed UAL model does not explicitly model phosphorus contributions from manure spreading. The model does, however, implicitly account for animal contributions by calibrating to monitored data from four different sites throughout the watershed.

Table 4.6. Agricultural animal phosphorus production in the Ann and Fish Lake watershed.

Watershed	Acres	Total P (lbs/day)	Total P (lbs/year)	Total P (lbs/year/acre)
Little Ann River	20,016	3	1,190	0.1
Camp Creek	6,145	10	3,796	0.6
West Wetland (Ann)	1,330	10	3,468	2.6
Spring Brook	2,343	17	6,242	2.7
East Trib. (Ann)	3,492	0	0	0
Ann Lake Direct	2,499	0	0	0
Ann Lake Totals	**35,825**	**40**	**14,696**	**0.4**
Ann River	12,116	130	47,614	3.9
West Wetland (Fish)	3,139	0	0	0
Devil's Lake	1,431	8	2,742	1.9
Turner Rd. Trib.	714	20	7,300	10.2
Fish Lake Direct	1,758	3	1,205	0.7
Fish Lake Totals	**19,158**	**161**	**58,861**	**3.1**

4.6.2.4 Septic Systems

Failing or nonconforming subsurface sewage treatment systems (SSTS) can be an important source of phosphorus to surface waters. To date, there have been no field surveys to inventory SSTSs throughout the Ann and Fish Lake watershed to determine which systems are in compliance or may be failing. For this TMDL study, Kanabec County Environmental Services and the Kanabec SWCD compiled all available SSTS records throughout each watershed in order to estimate the total number of SSTSs. They also used available information such as SSTS type and year constructed to predict which systems are likely not in compliance and potentially failing. Results suggest there are approximately 158 SSTSs in the Ann Lake watershed and 341 systems in the Fish Lake watershed (Table 4.7). Kanabec County SWCD estimates about 50% of the systems throughout the Ann and Fish Lake watersheds are currently not in compliance (Osterdyk, Kanabec County SWCD, personal communication). Total phosphorus loads to Ann and Fish Lake from SSTSs not in compliance was calculated assuming 2.7 people per household and an average phosphorus production of 2.7 grams/person/day (USEPA 2002). It is assumed that all systems not in compliance are completely failing and contribute phosphorus to each lake through ground or surface water discharge.

Table 4.7. Septic estimates in the Ann and Fish Lake watersheds.

Subwatershed	Total SSTS	Failing SSTS	TP Load (lbs/day)	TP Load (lbs/year)
Little Ann River	39	19	0.31	114
Camp Creek	11	6	0.09	32
West Wetland (Ann)	6	3	0.05	18
Spring Brook	11	5	0.09	32
East Trib. (Ann)	19	10	0.15	56
Ann Lake Direct	72	36	0.58	211
Ann Lake Total	**158**	**79**	**1.27**	**463**
Ann River	126	63	1.01	370
West Wetland (Fish)	14	7	0.11	41
Devil's Lake	33	17	0.27	97
Turner Rd. Trib.	0	0	0	0
Fish Lake Direct	168	84	1.35	493
Fish Lake Total	**341**	**171**	**2.74**	**1,001**

4.6.2.5 Internal Phosphorus Loading

For Ann and Fish Lake, dissolved oxygen data were collected monthly in 2008 and 2009. However, very little anoxia was measured during these events. It is important to note that shallow lakes can often demonstrate short periods of anoxia due to instability of stratification which is often missed by monthly measurements. So, for Ann and Fish Lakes, an equation was used (Nürnberg 2005) to estimate the anoxic factor. Once the anoxic factor is estimated, the next step is to identify the rate at which sediments release phosphorus under both anoxic and oxic conditions. The measured rate of phosphorus release from anoxic sediments is 15.0 mg/m^2/day for Ann Lake, and 5.4 mg/m^2/day Fish Lake, respectively. Under oxic conditions, Ann and Fish Lakes were measured to release phosphorus at a rate of 0.2 mg/m^2/day and 0.3 mg/m^2/day, respectively. These rates were then multiplied by the total area of each lake to estimate gross internal loading in each system (Nürnburg 2004). The estimated loads for Ann and Fish are presented in Table 4.8 and were used in the lake response models to estimate the role of internal loading on current lake water quality.

Table 4.8. Oxic and anoxic release rates and annual loading estimates in Ann and Fish Lake.

Lake	Year	Oxic Release (mg/m^2/day)	Anoxic Release (mg/m^2/day)	[1]Anoxic Factor (days)	Oxic Release (lbs/year)	Anoxic Release (lbs/year)	Total Internal Load (lbs/year)
Ann	2008	0.2	15.0	53	168	5,483	5,651
	2009	0.2	15.0	50	168	5,173	5,341
	Ave	*0.2*	*15.0*	*52*	*168*	*5,328*	*5,496*
Fish	2008	0.3	5.4	64	136	1,289	1,425
	2009	0.3	5.4	64	136	1,289	1,425
	Ave	*0.3*	*5.4*	*64*	*136*	*1,289*	*1,425*

[1] Anoxic factors for Ann and Fish Lake were estimated according to methods developed by Nürnberg (2005) for shallow lakes

4.6.3 Fit of the Lake Response Model

Two years were modeled for Ann Lake with predicted values within 5-10% of monitored values (Figure 4.17). Modeled years were selected based on available water quality data over the past 10 years. A calibration factor was not applied to the settling rate for the Ann Lake model.

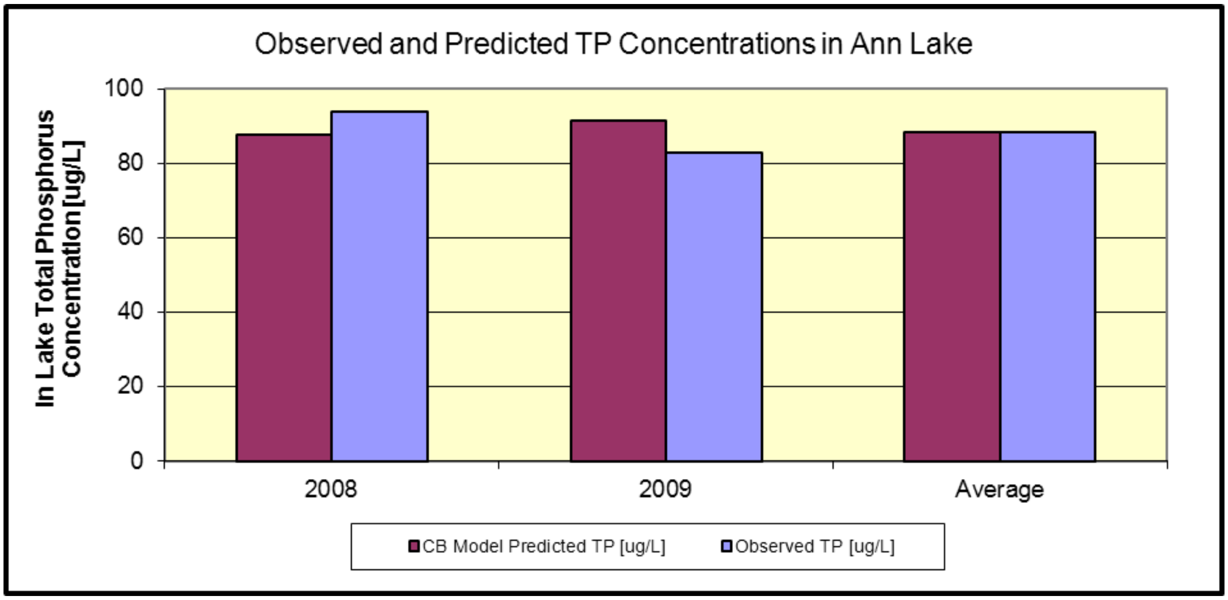

Figure 4.17. Observed versus BATHTUB model-predicted total phosphorus for Ann Lake.

Two years were modeled for Fish Lake with modeled values within 5-20% of observed values (Figure 4.18). Modeled years were selected based on available water quality data over the past 10 years. Fish Lake is a challenging lake to model because of its very short residence time (~15 days). For the model to predict close to the monitored values, the settling rate had to be set to 0 meaning that the lake is simply a mass balance of all the inputs. This approach appears to be reasonable because of the short residence time allowing for little algal settling in the lake. However, it is important to note, even after all of the measured phosphorus inputs are included, the model under-predicts measured in-lake concentrations.

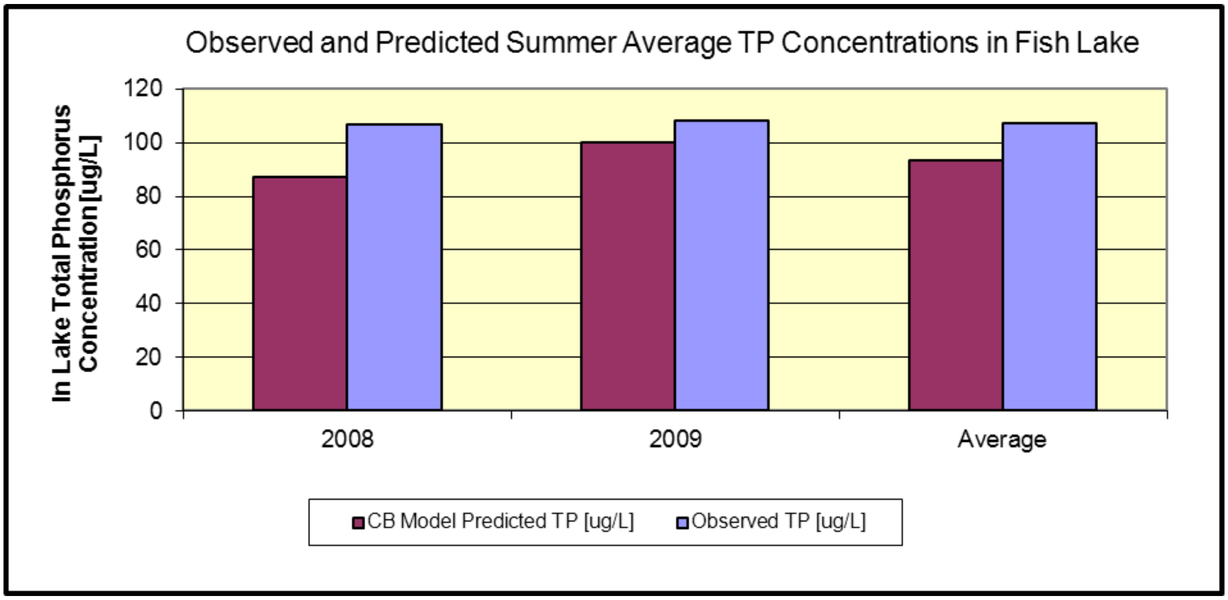

Figure 4.18. Observed versus BATHTUB model predicted total phosphorus for Fish Lake.

4.6.4 Linking Water Quality Targets and Sources

The final step in understanding lake response to nutrient loads is to link the previously described nutrient budgets to lake water quality. This step is accomplished through the use of lake response models previously described in Section 4.5.5. The lake response model was applied using the water and nutrient budgets previously described in this section. Physical lake attributes such as volume, average depth, and surface area were derived from GIS and Minnesota DNR contour maps. All model inputs are detailed in Appendix J.

Phosphorus loading to Ann Lake is almost split evenly between watershed runoff (47%) and internal loading (46%). Only about 4% of the phosphorus load comes from potentially failing SSTSs. West Ann Lake and atmospheric deposition account for only 2% and 1% of the total phosphorus load to Ann Lake, respectively (Figure 4.19).

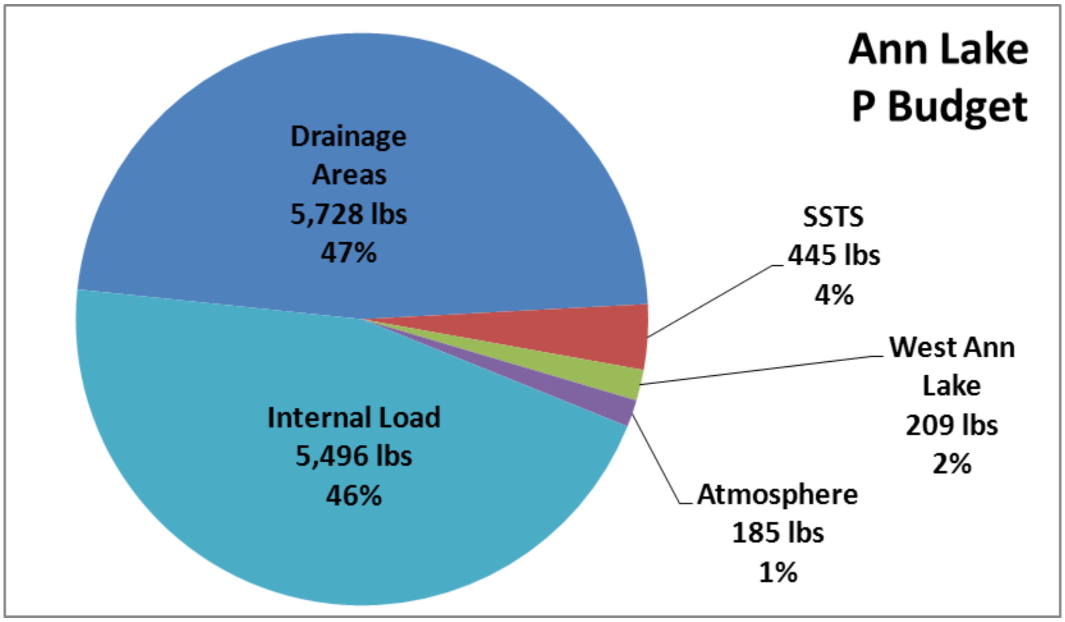

Figure 4.19. Total phosphorus loading to Ann Lake by source.

For Fish Lake, the majority of the phosphorus load is coming from upstream lakes (41%), primarily Ann Lake, and watershed runoff (40%) which includes the land area between the Ann Lake outlet and Fish Lake as well as the direct drainage area. Internal sediment release and failing SSTSs represent approximately 11% and 7% of the lake's phosphorus budget. Atmospheric deposition accounts for only 1% of the phosphorous loading to Fish Lake (Figure 4.20).

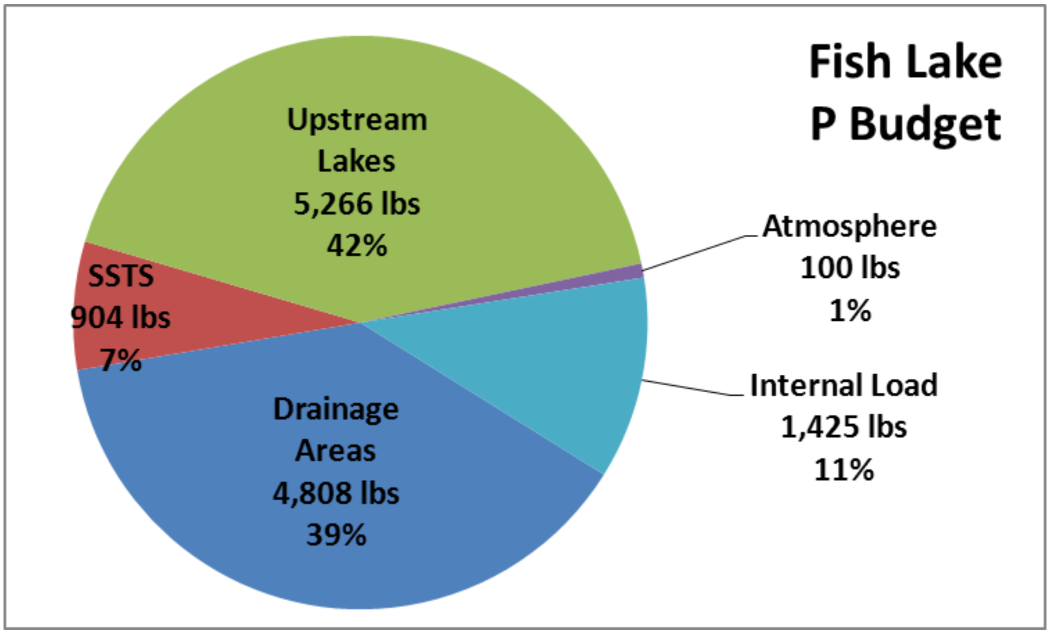

Figure 4.20. Total phosphorus loading to Fish Lake by source.

4.7 TMDL ALLOCATIONS

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

4.7.1 Total Loading Capacity

The first step in developing an excess nutrient TMDL for lakes is to determine the total nutrient loading capacity for the lake. To determine the total loading capacity, the current nutrient budget and the lake response modeling (average of 2008 and 2009) presented in Section 3 were used as the starting point. The nutrient inputs were then systematically reduced until the model predicted that the lakes met the current total phosphorus standard of 60 µg/L as a growing season mean. The reductions were applied first to the internal load and then the watershed sources. The TMDL loading capacities for Ann Lake and Fish Lake were calculated to be 7,689 and 8,047 pounds, respectively. Further details of how these numbers were calculated are included in the following sections.

4.7.2 Load Allocations

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

One of the first steps in determining the allowable phosphorus loads to the lakes is setting the appropriate internal load release rate. Measured release rates in Ann and Fish (anoxic release of 15.0 and 5.4 mg/m^2-day respectively) were compared to expected release rates for mesotrophic lakes (Figure 4.21; Nürnberg 1997). Mesotrophic lakes demonstrate internal phosphorus release rates ranging from 0 to 12 mg/m^2-day with a median release rate around 4 mg/m^2-day. Although the median is 4 mg/m^2-day, there is a broad range of internal loads in mesotrophic lakes which makes selecting an appropriate number difficult. Furthermore, the majority of lakes in this database are deep lakes whereas Ann and Fish Lake are shallow lakes. By comparison, anoxic release rates in Oneka Lake, a shallow, submerged aquatic vegetation dominated lake located in Anoka County, were below detection (Oneka Lake is the only healthy shallow lake with release measurements near the Ann and Fish Lake watershed). Therefore, release rates in healthy shallow lakes could arguably be zero. Given Ann Lake's high internal loading rate, a significant load reduction would be achieved by reducing the lake's internal load from around 15 mg/m^2-day to 4 mg/m^2-day For Fish Lake, the internal release rate was lowered to 1.4 mg/m^2-day so that the ultimate release rate after the MOS is approximately 1 mg/m^2-day.

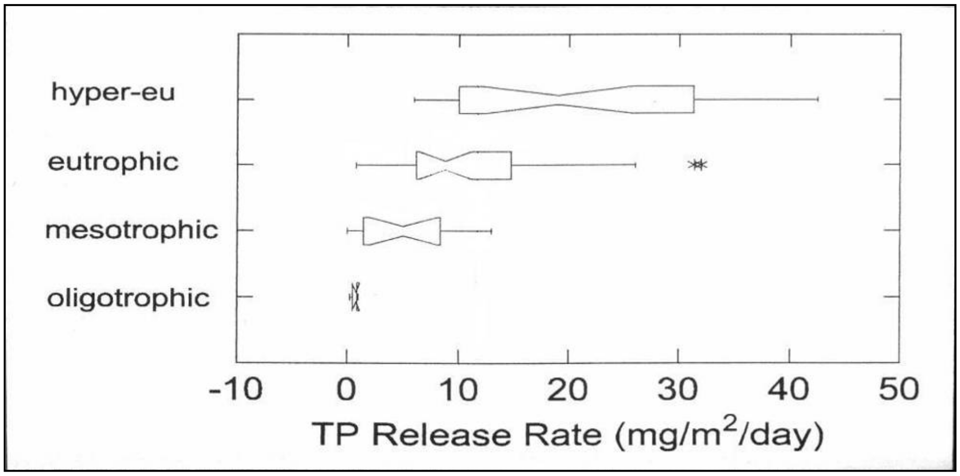

Figure 4.21. Sediment phosphorus release rates by eutrophic condition. (Nürnberg 1997).

Oxic release of phosphorus was also measured in both lakes with Ann Lake and Fish Lake demonstrating oxic internal release rates of 0.3 and 0.2 mg/m^2-day. These rates were not adjusted assuming that the release is a result of the natural breakdown of sediment in the lakes. The remaining load reductions come from watershed source reductions.

It is also important to note that the selected Canfield-Bachmann lake response model implicitly accounts for some internal loading because the response is predicted from external loads from a database that includes lakes with internal loading. Therefore, the assigned internal load in these models is included above and beyond the implicitly included internal load. Therefore, the lake can likely demonstrate an internal load greater than what is explicitly identified in the TMDL and still meet state water quality standards.

To determine the allowable watershed phosphorus load, the lake response model was updated with the selected allowable internal load as determined in the previous section. Next, current estimated watershed loading in the lake response models was reduced until the models predicted an in-lake phosphorus concentration of 60 µg/L. In addition to failing SSTS upgrades (zero load contribution), a 4% reduction in watershed nutrient loads to Ann Lake will be required to meet State standards. A 46% reduction in watershed nutrient loads to Fish Lake was required to meet State standards.

4.7.2.1 Wasteload Allocations

At the time of this study, the MPCA confirmed there were no active permitted NPDES surface wastewater dischargers or MS4s in the Ann Lake and Fish Lake watersheds (Marco Graziani and Mike Trojan, personal communication). There were also no active National Pollutant Discharge Elimination System (NPDES) construction permits in the Ann or Fish Lake watersheds. To account for future growth (reserve capacity), construction stormwater allocations in the TMDL are set to one percent. Also at the time of this study, there were two active industrial stormwater permits in the Fish Lake watershed and no industrial permits in the Ann Lake watershed. To account for these permits and future growth (reserve capacity), allocations for industrial stormwater in the TMDL are set at a half percent.

4.7.2.2 Confined Animal Feeding Operations (CAFOs)

CAFOs are not permitted to discharge from the lots by rule, and therefore are considered to not be currently discharging any phosphorus. Furthermore, CAFOs are assigned an allocation of zero based on the state rules. There are 13 active MPCA registered feedlots located in the Ann and Fish Lake watershed. However, none of these operations are currently large enough to require a CAFO permit.

4.7.3 Margin of Safety

The MOS is intended to ensure achievement of the water quality goals in the face of inevitable scientific uncertainties. This TMDL has a robust dataset that includes lake water quality monitoring over multiple years, extensive tributary flow and load monitoring and lab measured internal phosphorus release rates. An explicit margin of safety of 5% of the load has been set aside for Ann Lake. The 5% MOS was considered reasonable given Ann Lake's robust dataset and lake response model performance. A 10% MOS was used for Fish Lake due to the greater uncertainty in the model since the model slightly under-predicts monitored lake concentrations.

4.7.4 Summary of TMDL Allocations

A 39% reduction in overall phosphorus loading to Ann Lake is required to meet the State shallow lake standard of 60 µg/L GSM (Table 4.9). Reductions in internal loading to the lake are sufficient to meet the TMDL. Five percent of the load (384 pounds) was set aside for the MOS, half of which comes from the watershed load and the other half from the internal load. Ultimately, a 4% and 75% reduction in watershed and internal loading are required to meet the TMDL for Ann Lake. It was also assumed that all of SSTSs will be made compliant, eliminating phosphorus loading from SSTSs.

Table 4.9. Ann Lake Total Maximum Daily Load allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations (WLA & LA)		Load Reduction[3]	
		(lbs/year)	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)	%
Wasteload Allocation	Construction & Industrial Stormwater	115	0.3	115	0.3	0	0%
Load Allocation	Drainage Areas	5,613	15.4	5,402	14.8	211	4%
	SSTS	445	1.2	0	0.0	445	100%
	West Ann Lake	209	0.6	203	0.6	6	3%
	Atmosphere	185	0.5	185	0.5	0	0%
	Internal Load	5,496	15.0	1,400	3.8	4,096	75%
MOS		--	--	384	1.1	--	--
TOTAL		**12,063**	**33**	**7,689**	**21.1**	**4,758**	**39%**

[1] Existing load is the average for the years 2008 and 2009.

[2] Annual loads converted to daily by dividing by 365.25 days per year accounting for leap years

[3] Net reduction from current load to TMDL is 4,374 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 4,374 + 384 = 4,758 lbs/yr.

For Fish Lake, a 42% reduction in phosphorus loading is required to meet the TMDL with large reductions required from both the internal and watershed loads (Table 4.10). However, 10% of the load was set aside (805 pounds) for the MOS, 75% of which comes from the watershed load and the other 25% from the internal load. It was also assumed that all of the SSTSs will be made compliant, eliminating phosphorus loading from SSTSs. Since Devils Lake is believed to meet state water quality standards, Ann Lake is the only upstream Lake in the Fish Lake watershed that will require load reductions in this TMDL. Load allocations for Ann Lake were calculated assuming in-lake TP concentrations during the growing season will be lowered to meet the shallow lake standard of 60 µg/L.

Table 4.10. Fish Lake Total Maximum Daily Load allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations (WLA & LA)		Load Reduction[3]	
		(lbs/year)	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)	%
Wasteload Allocation	Construction & Industrial Stormwater	121	0.3	121	0.3	0	0%
Load Allocation	Drainage Areas	4,688	12.8	2,177	6.0	2,511	54%
	SSTS	904	2.5	0	0.0	904	100%
	Upstream Lakes	5,266	14.4	4,586	12.6	680	13%
	Atmosphere	100	0.3	100	0.3	0	0%
	Internal Load	1,425	3.9	258	0.7	1,167	82%
MOS				805	2.2	--	--
TOTAL		**12,504**	**34.2**	**8,047**	**22.1**	**5,262**	**42%**

[1] Existing load is the average for the years 2008 and 2009.

[2] Annual loads converted to daily by dividing by 365.25 days per year accounting for leap years

[3] Net reduction from current load to TMDL is 4,457 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 4,457 + 805 = 5,262 lbs/yr.

4.7.5 Lake Response Variables

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

Input phosphorus loads were reduced in the BATHTUB TMDL model run by 5% increments to predict each lake’s response to changes in phosphorus loading (Figure 4.22).

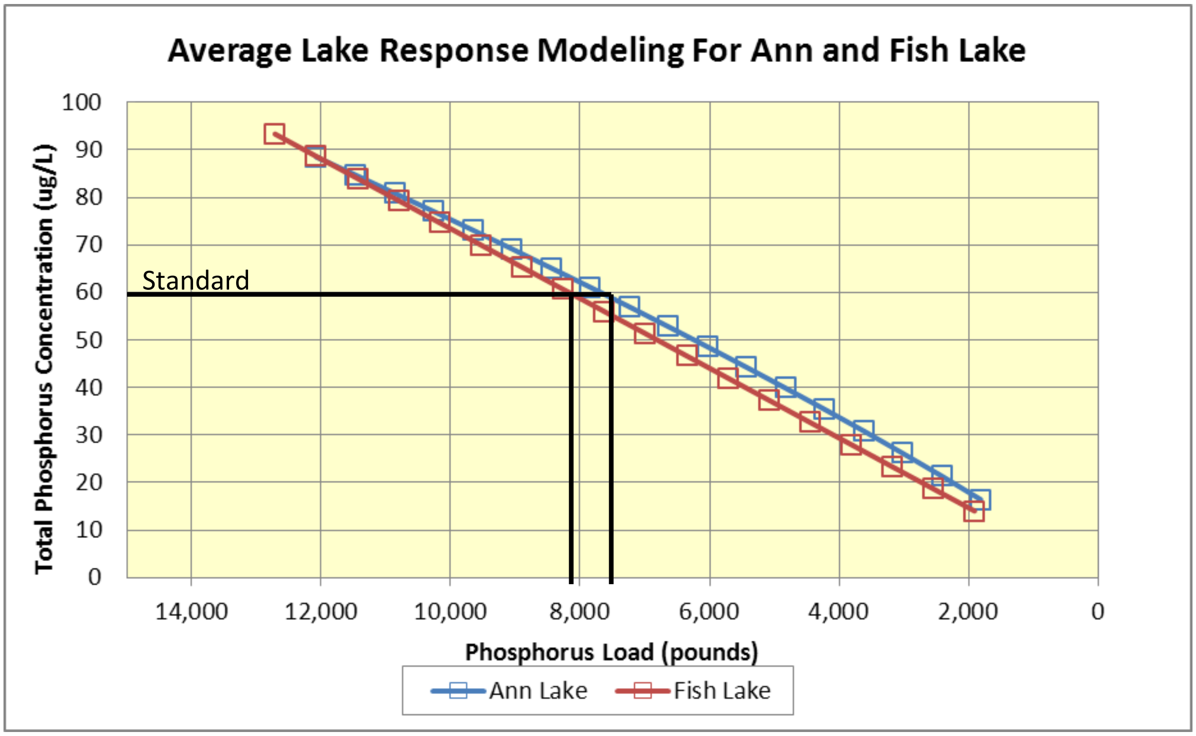

Figure 4.22. In-lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources.

Note: The horizontal black line indicates the state TP standard for shallow lakes (60 µg/L) in the NCHF ecoregion. The vertical black lines indicate the TMDL loading capacity for each lake set forth in this TMDL.

Using the predicted total phosphorus concentrations, chlorophyll-a concentrations were estimated using regression equations in the MPCA (2005) used to develop shallow lake standards (Figure 4.23). Using these equations, both Ann and Fish Lakes are predicted to meet the 20 µg/L chlorophyll-a standard for shallow lakes in the North Central Hardwood Forest ecoregion.

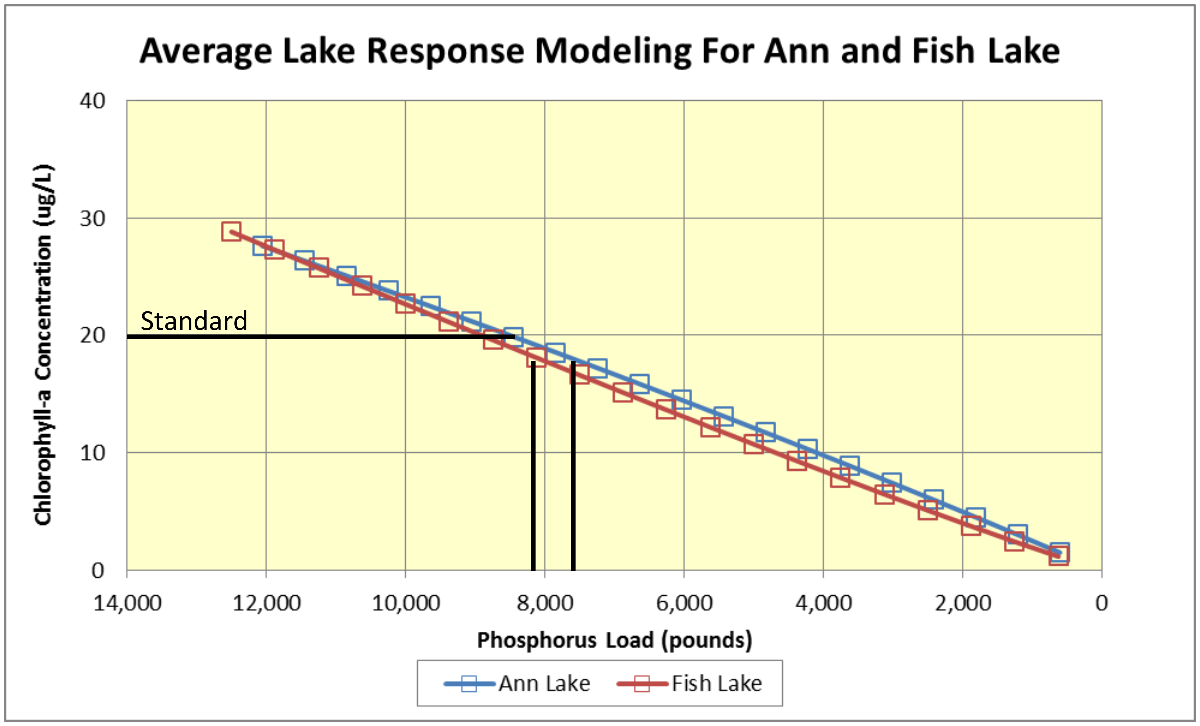

Figure 4.23. . In-lake total chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources.

Note: The horizontal black line indicates the state chlorophyll-a standard for shallow lakes (20 µg/L) in the NCHF ecoregion. The vertical black lines indicate the TMDL loading capacity for each lake set forth in this TMDL.

Both Ann and Fish Lakes are already close to meeting the Secchi depth standard of greater than 1 meter for shallow lakes in the North Central Hardwood Forest ecoregion. Both lakes will easily attain the 1 meter standard at the TMDL allocations (Figure 4.24).

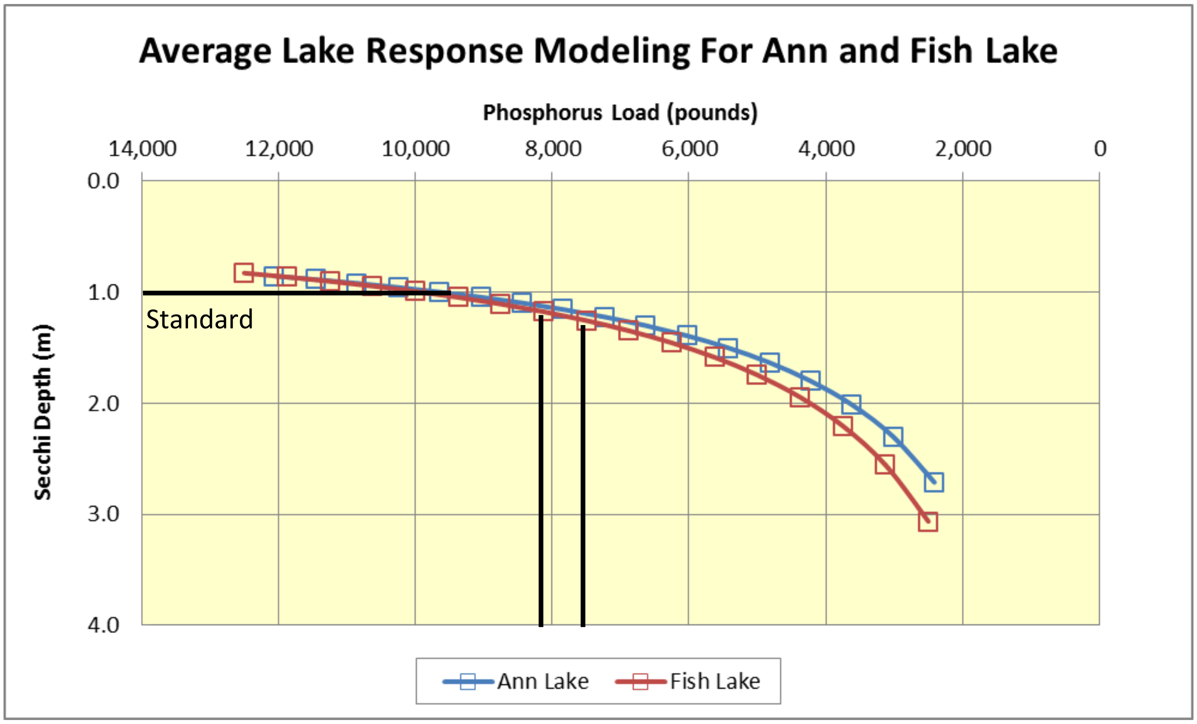

Figure 4.24. In-lake Secchi depth predicted for total phosphorus load reductions applied to all sources.
Note: The horizontal black line indicates the state Secchi standard for shallow lakes (1 meter) in the NCHF ecoregion. The vertical black lines indicate the TMDL loading capacity for each lake set forth in this TMDL.

4.7.6 Seasonal and Annual Variation

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

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

4.7.7 Reserve Capacity

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

5.0 Biotic Impairment

5.1 EVALUATING BIOTIC INTEGRITY

The CADDIS Stressor Identification analysis uses a “strength of evidence” approach to evaluate candidate causes affecting biotic integrity. The five candidate causes identified in the Stressor ID – low dissolved oxygen, lack of habitat, altered hydrology, loss of connectedness, and ionic strength – were evaluated and the results summarized in Table 5.1.

Data are analyzed in terms of associations that might support, weaken or refute the case for a candidate cause. This strength of evidence analysis is a systematic approach that sorts through the available data to determine the most probable cause or causes based on weight of evidence. Each of the types of evidence is scored based on the degree to which it supports or weakens the case using pluses (++) or minuses (--). The number of pluses or minuses depends on the likelihood that an association might be observed by chance rather than because of the true cause. A score of 0 indicates that the evidence neither supports nor weakens the case for the cause, a D is diagnostic of the cause and an R refutes the case for the cause.

The evidence for the stressors lack of benthic habitat due to sedimentation and impacts from riparian degradation is strongest. Low dissolved oxygen and the loss of connectivity due to dams are plausible stressors and are likely contributing to the impairment, however there is less direct or conflicting evidence of their role. Flow alteration was identified as a potential stressor but there is not enough evidence available to evaluate its strength.

Table 5.1. Stressor identification strength of evidence table.

Types of Evidence	Sediment Score	Low DO Score	Riparian Degradation Score	Connectivity Score	Flow Alteration Score
Evidence using data from Ann River					
Spatial/temporal co-occurrence	+	+	+	0	NE
Evidence of exposure, biological mechanism	+	+	+	0	NE
Causal pathway	++	+	++	+	NE
Field evidence of stressor-response	0	0	+	0	NE
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE
Temporal sequence	0	NE	NE	NE	NE
Verified or tested predictions	NE	NE	NE	NE	NE
Symptoms	+	0	0	0	NE

Table 5.1, cont. Stressor identification strength of evidence table.

Types of Evidence	Sediment Score	Low DO Score	Riparian Degradation Score	Connectivity Score	Flow Alteration Score
Evidence using data from other systems					
Mechanistically plausible cause	+	+	+	+	+
Stressor-response in other field studies	+	+	+	+	+
Stressor-response in other lab studies	+	+	NE	NE	NE
Stressor-response in ecological models	+	NE	+	NE	+
Manipulation experiments at other sites	NE	NE	+	+	+
Analogous stressors	++	NE	++	+	+
Multiple lines of evidence					
Consistency of evidence	+	0	+	0	NE
Explanatory power of evidence	++	0	++	0	NE

Note: "+" symbols indicate support for that cause, and "–" symbols indicate evidence weakens the cause, with the number of symbols indicating strength of evidence. A "0" indicates evidence neither supports nor weakens the cause. "NE" indicates there is no evidence available for analysis.

5.2 SEDIMENT SOURCES

Excess sedimentation and embeddedness was identified as being a primary stressor on aquatic life in the Ann River. The primary sources of sediment in streams are sediment conveyed from the landscape and soil particles detached from the streambank. The amount of sediment conveyed from the landscape will vary based on general soil erodibility, land cover, slope, and conveyances to the stream. Streambank erosion is a natural process that can be accelerated significantly as a result of change in the watershed or to the stream itself. Field data was collected to better understand the source of excess sedimentation so that the most effective mitigation actions could be identified.

5.2.1 Sediment Conveyed from the Landscape

Alterations to the landscape that might result in excessive sediment delivery to streams include row crop agriculture, deforestation, high-density pasturage, and removal or lack of vegetative buffers adjacent to ditches, channels and streams. Figure 2.2 above shows that a relatively small percentage of land in the Ann River is cultivated row crops, and that it is concentrated in the lower watershed. While the upper watershed is forested, the lower watershed contains patches of remnant forest, which was logged in the past and has revegetated as grasslands and shrublands, both fallow and used for pasturage. There are a number of animal operations of various sizes, mostly small, but two significant feedlots are located almost immediately adjacent to the Ann River.

These changes in landcover from forest to grass and shrublands can increase sediment delivery if the watershed is ditched or tiled, or if there is a lack of intervening buffer vegetation to filter sediment from overland flow. While neither the Stressor ID nor this TMDL modeled sediment from the watershed, the Stressor ID Study evaluated Total Suspended Sediment data for Ann River and found that suspended sediment concentrations in Ann River were well below the State of Minnesota turbidity standard and within the lower percentiles of North Central Hardwood Forest ecoregion reference streams.

The Universal Soil Loss Equation (USLE) was used to estimate the potential amount of sediment delivered to Ann River from watershed sources. USLE is a widely-used model developed by the Natural Resources Conservation Service (NRCS), and uses factors such as soil erodability, topography, and cropping practices to estimate potential soil loss. Since not all soil loss will be delivered downstream, the potential soil loss is corrected by applying a Sediment Delivery Ratio (SDR) (Vanoni 1975) to estimate how much soil loss from a drainage area will be delivered downstream.

$SDR = 0.451(b)^{-0.298}$
Where b = watershed size in square kilometers

USLE predicts that the annual potential soil loss in the 12,116 acres watershed is 5,452 tons. The sediment delivery ratio is 0.14, and the annual estimated mass of sediment delivered from the watershed to the river is (5,452 tons/year * 0.14) or 763 tons/year.

5.2.2 Sediment Contributed from Streambank Erosion

Streambank erosion may be a source of excess bedded sediment. Landcover changes in the riparian zone may weaken streambanks by reducing or eliminating long-rooted native vegetation that strengthens and stabilizes the banks. Changes in flow regime may also destabilize streambanks that are exposed to prolonged periods of wetting or wet-dry cycles. By observation, many areas along the Ann River the riparian area are not maintained in native vegetation, and there are bank failures and evidence of mass wasting and sediment accumulation, including channel braiding.

To evaluate whether soil loss from streambank erosion may be contributing significantly to sediment load, stream reaches at the biomonitoring sites on Ann River were evaluated for stability and amount of observed soil loss by severity. The annual soil loss by mile by stream order was estimated, and the results extrapolated to the whole stream.

The annual soil loss was estimated using field collected data and a method developed by the Natural Resources Conservation Service referred to as the “NRCS Direct Volume Method,” or the “Wisconsin method,” (Wisconsin NRCS 2003). Soil loss is calculated by:

1. measuring the amount of exposed streambank in a known length of stream;
2. multiplying that by a rate of loss per year;
3. multiplying that volume by soil density to obtain the annual mass for that stream length; and then
4. converting that mass into a mass per stream mile.

The Direct Volume Method is summarized in the following equation:

$$\frac{\text{(eroding area) (lateral recession rate) (density)}}{\text{2,000 lbs/ton}} = \text{erosion in tons/year}$$

5.2.2.1 Streambank Conditions

The following sections describe how each of the parameters in the Direct Volume equation was estimated for the Ann River.

Eroding Area. The eroding area is defined as that part of the streambank that is bare, rilled, or gullied, and showing signs of active erosion such as sloughed soil at the base. The length and width of the eroding face of the streambank is multiplied to get an eroded area. As each of the evaluated reaches was walked, each area of significant erosion on either side of the streambank was measured and recorded on a field sheet. Professional judgment was used to determine which areas were significant.

Lateral Recession Rate. The lateral recession rate is the thickness of soil eroded from a streambank face in a given year. Soil loss may occur at an even rate every year, but more often occurs unevenly as a result of large storm events, or significant land cover change in the upstream watershed. Historic aerial or other photographs, maps, construction records, or other information sources may be available to estimate the total recession over a known period of time, which can be converted into an average rate per year. However, these records are often not available, so the recession rate is estimated based on streambank characteristics that evaluate risk potential. Table 5.2 presents the categories of bank condition that are evaluated and the varying levels of condition and associated risk severity score.

Table 5.2 Bank condition severity rating.

Category	Observed Condition	Score
Bank Stability	Do not appear to be eroding	0
	Erosion evident	1
	Erosion and cracking present	2
	Slumps and clumps sloughing off	3
Bank Condition	Some bare bank, few rills, no vegetative overhang	0
	Predominantly bare, some rills, moderate vegetative overhang	1
	Bare, rills, severe vegetative overhang, exposed roots	2
	Bare, rills and gullies, severe vegetative overhang, falling trees	3
Vegetation / Cover on Banks	Predominantly perennials or rock	0
	Annuals / perennials mixed or about 40% bare	1
	Annuals or about 70% bare	2
	Predominantly bare	3
Bank / Channel Slope	V-shaped channel, sloped banks	0
	Steep V- shaped channel, near vertical banks	1
	Vertical Banks, U-shaped channel	2
	U-shaped channel, undercut banks, meandering channel	3
Channel Bottom	Channel in bedrock / non-eroding	0
	Soil bottom, gravels or cobbles, minor erosion	1
	Silt bottom, evidence of active down cutting	2
Deposition	No evidence of recent deposition	1
	Evidence of recent deposits, silt bars	0

A Cumulative Rating score of 0-4 indicates a streambank at slight risk of erosion. A score of 5-8 indicates a moderate risk, and 9 or greater a severe risk. The Wisconsin NRCS used its field data from streams in Wisconsin to assign a lateral recession rate for each category (Table 5.3). Professional judgment is necessary to select a reasonable rate within the category.

Table 5.3 Estimated annual lateral recession rates per severity risk category.

Lateral Recession Rate (ft/yr)	Category	Description
0.01 - 0.05 feet per year	Slight	Some bare bank but active erosion not readily apparent. Some rills but no vegetative overhang. No exposed tree roots.
0.06 - 0.15 feet per year	Moderate	Bank is predominantly bare with some rills and vegetative overhang. Some exposed tree roots but no slumps or slips.
0.16 - 0.3 feet per year	Severe	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignment of roads or trails. Channel cross section becomes U-shaped as opposed to V-shaped.
0.5+ feet per year	Very Severe	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains and culverts eroding out and changes in cultural features as above. Massive slips or washouts common. Channel cross section is U-shaped and stream course may be meandering.

At each of the measured erosion areas, evaluators performed the above severity assessment, recorded on the field sheet the score for each of the condition categories above and the total score, and selected an appropriate recession rate.

Density. Soil texture was field evaluated at each location and noted on the field sheet.

5.2.2.2 Annual Streambank Soil Loss

Data were compiled into a spreadsheet database that summarized stream length, total eroding area, Bank Condition Severity Rating, and soil texture. The estimated recession rate was multiplied by the total eroding area to obtain the estimated total annual volume of soil loss (Table 5.4). To convert this soil loss to mass, soil texture was used to establish a volume weight for the soil. The total estimated volume of soil was multiplied by the assumed volume weight and converted into annual tons.

Figure 5.1 shows the biomonitoring sites where the field stream conditions were assessed. The most severe bank erosion is detailed in Table 5.4.

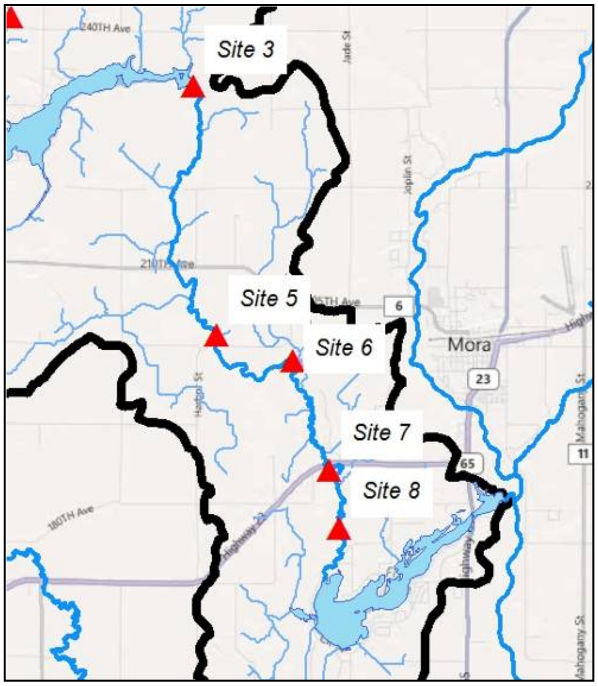

Figure 5.1. Biomonitoring sites on the Ann River.

Table 5.4. Estimated annual streambank soil loss in surveyed locations.

Description	Bio Site	Eroding Bank Length (Ft)	Eroding Bank Height (Ft)	Area of Eroding Streambank (Ft^2)	Condition Rating	Lateral Recession Rate (Estimated) (Ft / Year)	Estimated Volume (Ft^3) Eroded Annually	Soil Texture	Approximate Pounds of Soil per Ft^3	Estimated Soil Loss (Tons/Year)
Below Dam	3	90	5	450	4	0.05	22.5	Sandy Loam	100	1.1
Below Dam	3	60	3.5	210	7	0.1	21.0	Sandy Loam	100	1.1
Below Dam	3	75	1.5	113	7	0.1	11.3	Sandy Loam	100	0.6
Below Dam	3	80	2	160	8	0.12	19.2	Loamy Sand	100	1.0
Below Dam	3	105	2	210	7	0.1	21.0	Loamy Sand	100	1.1
Below CR 6	5	339	7	2,373	6	0.07	166.1	Sandy Loam	100	8.3
Below CR 6	5	270	6	1,620	3	0.03	48.6	Silt Loam	85	2.1
Below CR 6	5	102	10	1,020	5	0.06	61.2	Sandy Loam	100	3.1
Below CR 12	6	105	5	525	7	0.14	73.5	Silt Loam	85	3.1
Below CR 12	6	120	3.5	420	7	0.14	58.8	Sandy Loam	100	2.9
Below CR 12	6	600	1	600	4	0.05	30.0	Silt Loam	85	1.3
Below 6	Below 6	165	5	825	6	0.08	66.0	Silt Loam	85	2.8
Below 6	Below 6	75	7	525	9	0.3	157.5	Silt Loam	85	6.7
Below 6	Below 6	75	5	375	15	0.5	187.5	Silt Loam	85	8.0
Below 6	Below 6	120	2	240	12	0.5	120.0	Silt Loam	85	5.1
Below 6	Below 6	240	7	1,680	10	0.35	588.0	Sandy Loam	100	29.4
Below 6	Below 6	300	7	2,100	12	0.5	1,050.0	Sandy Loam	100	52.5
Below 6	Below 6	240	6	1,440	12	0.5	720.0	Silt Loam	85	30.6
Below 6	Below 6	135	5	675	12	0.5	337.5	Silt Loam	85	14.3
Below 6	Below 6	150	5	750	12	0.5	375.0	Silt Loam	85	15.9
US Hwy 23	Above 7	150	5	750	12	0.5	375.0	Silt Loam	85	15.9
DS Hwy 23	7	60	3	180	11	0.4	72.0	Silt Loam	85	3.1
DS Hwy 23	7	30	7	210	11	0.4	84.0	Silt Loam	85	3.6
DS Hwy 23	7	100	4	400	11	0.4	160.0	Sandy Loam	100	8.0
DS Hwy 23	7	100	3	300	11	0.4	120.0	Sandy Loam	100	6.0
DS Hwy 23	7	40	6	240	12	0.5	120.0	Silt Loam	85	5.1
									TOTAL	232.7

Note: Based on field surveys conducted April 2011.

According to the Wisconsin NRCS and based on their surveys of a number of streams throughout Wisconsin, a stream that is relatively undisturbed and at low risk for erosion typically experiences lateral recession of 0.01 - 0.05 feet per year. Assuming the surveyed sections detailed above were stable and experiencing 0.025 feet erosion loss per year, the total annual soil loss for those locations would be estimated as 21.5 tons per year compared to the current rate of 232.7 tons per year, or 90% less (Table 5.5).

Table 5.5. Estimated annual streambank soil loss assuming stable streambanks, surveyed segments only.

Description	Bio Site	Lateral Recession Rate (Estimated) (Ft / Year)	Estimated Volume (Ft^3) Eroded Annually	Approximate Pounds of Soil per Ft^3	Estimated Soil Loss (Tons/Year)
Below Dam	3	0.025	11.3	100	0.6
Below Dam	3	0.025	5.3	100	0.3
Below Dam	3	0.025	2.8	100	0.1
Below Dam	3	0.025	4.0	100	0.2
Below Dam	3	0.025	5.3	100	0.3
Below CR 6	5	0.025	59.3	100	3.0
Below CR 6	5	0.025	40.5	85	1.7
Below CR 6	5	0.025	25.5	100	1.3
Below CR 12	6	0.025	13.1	85	0.6
Below CR 12	6	0.025	10.5	100	0.5
Below CR 12	6	0.025	15.0	85	0.6
Below 6	Below 6	0.025	20.6	85	0.9
Below 6	Below 6	0.025	13.1	85	0.6
Below 6	Below 6	0.025	9.4	85	0.4
Below 6	Below 6	0.025	6.0	85	0.3
Below 6	Below 6	0.025	42.0	100	2.1
Below 6	Below 6	0.025	52.5	100	2.6
Below 6	Below 6	0.025	36.0	85	1.5
Below 6	Below 6	0.025	16.9	85	0.7
Below 6	Below 6	0.025	18.8	85	0.8
US Hwy 23	Above 7	0.025	18.8	85	0.8
DS Hwy 23	7	0.025	4.5	85	0.2
DS Hwy 23	7	0.025	5.3	85	0.2
DS Hwy 23	7	0.025	10.0	100	0.5
DS Hwy 23	7	0.025	7.5	100	0.4
DS Hwy 23	7	0.025	6.0	85	0.3
				TOTAL	21.5

To estimate the total potential sediment load delivered to the stream from streambank sources, the methodology above was applied to the entire stream length. The Ann River was subdivided into six reaches, and an appropriate annual recession rate estimated for that part of the reach that was not surveyed. Table 5.6 below shows the estimated annual mass of sediment from streambank soil loss, showing the loss calculated from surveyed segments in that reach, and the loss estimated for the balance of the reach.

Table 5.6. Estimated annual streambank soil loss to the Ann River.

Reach	Eroding Bank Length (Feet)	Eroding Bank Height (Feet)	Area of Eroding Streambank (FT^2)	Lateral Recession Rate (Estimated) (FT / Year)	Estimated Volume (FT^3) Eroded Annually	Soil Texture	Approx Pounds of Soil per FT^3	Estimated Soil Loss (Tons/Year)
Reach 1								
Not Surveyed	25,530	2	51,060	0.05	2,553.0	Silt Loam	85	108.5
Surveyed	330	varies						25.7
Reach 1 TOTAL	25,860	2	51,720					134.2
Reach 2								
Not Surveyed	16,286	5	81,430	0.1	8,143.0	Silt Loam	85	346.1
Surveyed	1,650	varies						181.3
Reach 2 TOTAL	17,936	5	89,680					527.4
Reach 3								
Not Surveyed	9,033	3	27,099	0.1	2,709.9	Sandy Loam	100	135.5
Surveyed	825	varies						7.3
Reach 3 TOTAL	9,858	3	29,574					142.8
Reach 4								
Not Surveyed	12,960	3	38,880	0.025	972.0	Sandy Loam	100	48.6
Surveyed	0	varies						0.0
Reach 4 TOTAL	12,960	3	38,880					48.6
Reach 5								
Not Surveyed	16,671	5	83,355	0.0625	5,209.7	Sandy Loam	100	260.5
Surveyed	711	varies						13.4
Reach 5 TOTAL	17,382	5	86,910					273.9
Reach 6								
Not Surveyed	28,232	3	84,696	0.04375	3,705.5	Loamy Sand	100	185.3
Surveyed	410	varies						4.7
Reach 6 TOTAL	28,642	3	85,926					190.0
TOTAL	112,638							1,317.0

5.2.3 Sediment Delivery and Transport

The total annual soil lost from watershed and streambank sources and delivered to the Ann River as calculated in the previous sections is:

Watershed Sources	763 tons/year
Streambank Sources	1,317 tons/year
TOTAL	**2,080 tons/year**

In undisturbed watersheds there is still some minor soil lost every year and delivered to nearby streams. Sediment loss from streambank erosion also occurs in undisturbed streams as channels undergo natural evolution and as the stream meanders within its meander belt. Channels are made and unmade; streams in equilibrium will neither on average aggrade, or experience deposition, nor degrade, or scour. Changes in sediment delivery, particle size, streamflow, or stream slope (Lane 1955) may cause the stream to aggrade or degrade, impacting channel type and morphology. An aggrading stream does not have the power to effectively mobilize and flush streambed particles either by bed load or suspended load. Excessive embeddedness such as that found in the Ann River is often a characteristic of an aggrading stream

The Shields Threshold of Motion Equation (Shields 1936) can be used to determine D_s, the particle size at the threshold of motion, when individual particles on a stream bed are on the verge of motion by streamflow. For a sand-gravel stream in equilibrium at bankfull flow the D_s value is close to the D_{50} value, which is the median particle size.

$$D_s = \tau / ((\rho_s - \rho)\, g\, 0.06)(304.8)$$

D_s=diameter sediment particle (mm)
τ=shear stress=(ρg)(depth)(slope) (lb/ft^2) (N/m^2)
ρ_s=density of sediment (5.15 slugs/ft^3) (2560 kg/m^3)
ρ=density of water (1.94 slugs/ft^3) (1000 kg/m^3)
g=gravitational acceleration (32.2 ft/s^2) (9.81 m/s^2)
0.06 = Shield's parameter typically in the range of 0.04 to 0.07
Conversion constant 304.8 mm/ft or 1000 mm/m

Einstein (1950) developed a method of using the Shields Equation to estimate bedload transport in a way that accounts for the probability that any sediment particle would be mobilized by flow. This method assumes that the streambed material is not uniformly sized and uses channel depth, slope, and sediment size characteristics to estimate the particle size at the threshold of motion. These equations can be used to estimate the rate of bedload transport per unit channel width.

MPCA and SWCD staff evaluated conditions and morphology at four sites using Rosgen's Level II methodology (Rosgen 1996). Based on that data the Ohio DNR STREAM Sediment Equations Model (Ohio DNR 2011) was used to calculate shear stress, particle size at threshold of motion, and rate of bedload transport per unit channel width (Table 5.7).

Table 5.7. Threshold of motion parameters for four sites on Ann River.

Parameter	**Site 3**	**Site 5**	**Site 7**	**Site 8**
Depth (m)	0.64	0.52	0.55	0.637
Slope (m/m)	.00264	.005	0.0025	.00018
Sediment D_{50} (mm)	43.4	43.1	5.49	.18
Shear Stress (lb/ft^2)	0.346	0.533	0.283	0.024
Particle at Threshold of Motion (mm)	17	26	14	1.16
% Particles Smaller	34%	40%	60%	40%
Unit Bedload Transport (m^2/s unit width)	<0.00001	<0.00001	0.00050	<0.00001

At three of the four sites, the size of particle at the threshold of motion is smaller than the D_{50} particle size, which is the median particle size. At those sites, the channel morphology and sediment composition is such that the stream cannot effectively mobilize particles on the streambed, which typically results in aggradation.

All four locations that were evaluated are wide, relatively shallow and low gradient reaches, which limits the ability of the stream to effectively transport sediment as bedload. While there is significant fall from the outflow of Ann Lake to CR 12, below CR 12 the stream flattens out (Figure 5.2) and meanders through a wide floodplain. The very low gradient not only limits the ability of the stream to move particles, but the decrease in stream velocity results in increased particle settling, including fine materials. The D_{50} particle size decreases significantly from 43 mm upstream of CR 23 to 5 mm downstream. Upstream of CR 23 sediments are composed of a mix of cobble and gravel, while below CR 23 the bed materials are primarily fine gravels and sands. The measured mean depth of fines increases abruptly at that point (Figure 5.3)

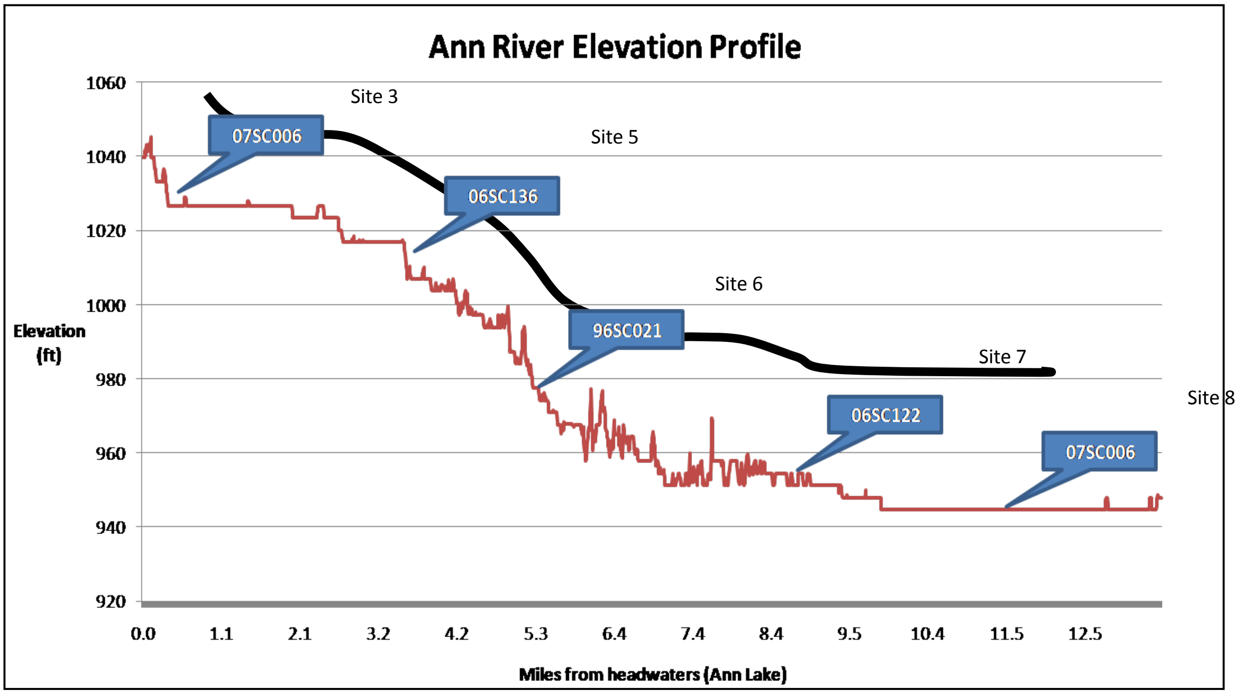

Figure 5.2. Ann River profile taken from a 30-meter DEM model.
Source: Stressor ID Report (Jasperson 2011).

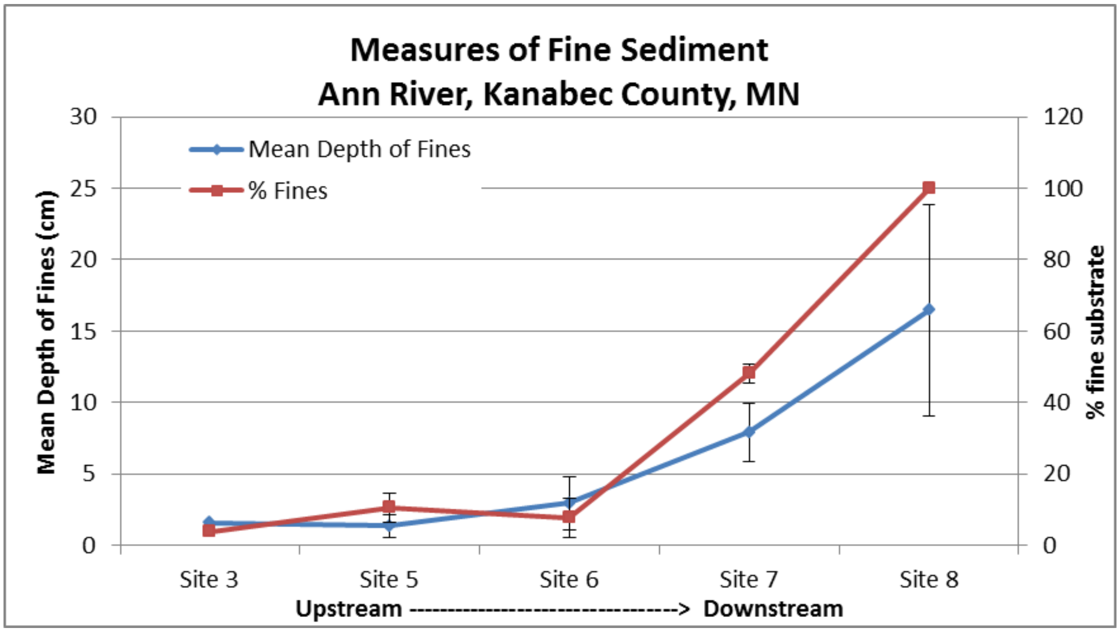

Figure 5.3. Average depths of fines and average % of fine substrate at Ann River biological stations.
Source: Stressor ID Report (Jasperson 2011).

The Stressor ID found that significant characteristics of the fish impairment were lack of simple lithophils, or fish that lay their eggs in the interstices of gravel and coarse sand, and lack of benthic insectivores, which feed on organisms that live in the bottom substrate. This was especially apparent in the biomonitoring sites on the lower river, where the streambed material was composed mainly of fairly uniform fine gravel to sand with fewer particles of larger gravel and cobble size to provide habitat. Substrate variability is present in the upper reaches, but the channel morphometry suggests that the stream lacks the power to effectively flush sediment at low flows, which may increase embeddedness. The impact of streambed quality was less conclusive for macroinvertebrates, mainly due to the limited monitoring data. Channel morphometry – shallow, wide channel and low gradient – limits the Ann River's ability to move and flush sediment accumulated on the streambed, which in turn limits benthic habitat suitability.

5.2.4 Causes of Streambank Erosion

Field data measured at sites on the Ann River experiencing severe erosion and the estimates of sediment delivered from the watershed and from the non-surveyed streambanks indicates that streambank erosion is likely the primary source of excess sediment contributed to the Ann River. The most severe erosion was measured in Reach 2 between Site 6 and CR 23. The stream through this reach is highly meandered and active, with aerial photo evidence of stream migration and oxbow cutoffs. The stream flows through grass/pastureland, with some remnant wooded areas. Many of the severely eroded banks are outside bends, with deposition creating point bars and channel braids. Streambank vegetation is variable, mainly short grasses with sparse trees that do not provide adequate streambank stability. Animals have free access to the stream in this reach, and there are areas where streambanks are denuded of vegetation and physically disturbed. Within the wooded areas accumulated woody debris redirects streamflow toward the streambank.

It is likely that natural fluvial stream migration processes in the Ann River are accelerated by the disturbed riparian conditions. The less stable streambanks are more likely to experience erosion and mass wasting, delivering more sediment to the stream than it can effectively flush. Streambank loss may also be widening the stream, reducing effective stream depth, power, and velocity. Thus riparian disturbance is the likely source of excess sediment in Ann River.

5.3 BIOTIC INTEGRITY TMDL

The Stressor ID identified five stressors affecting biotic integrity in Ann River. Two of these stressors are associated with a specific pollutant –dissolved oxygen and bedded sediment. The water quality monitoring performed for the Stressor ID recorded some periods of low dissolved oxygen and concluded that occasional low levels of dissolved oxygen may be contributing to the biotic impairment. The data was not sufficient to determine whether the impairment listing criteria were violated. Occasional low DO concentrations appear to be related to stagnation resulting from low flows and overwidened channel; temperature; and nutrient enrichment likely resulting from high TP concentrations in Fish Lake outflows.

Minnesota does not currently have a standard for bedded sediment. The Stressor ID concluded that suspended sediment in Ann River falls within the lower percentile of ecoregion reference streams, and that the source of excess bedded sediment is excess sediment delivered from the streambanks and channel itself. That load is used as a surrogate for bedded sediment.

The three other stressors – loss of riparian function, flow alteration, and impoundments - are not associated with a specific pollutant for which a TMDL can be developed. However, based on the Stressor ID, the goals for those stressors are established in Section 5.4 below. Achieving these goals will also address common causes of low DO concentration.

5.3.1 Wasteload Allocations

Wasteload allocations typically include three sources: permitted wastewater dischargers, Municipal Separate Storm Sewer Systems (MS4s), and construction and industrial stormwater. There are currently no permitted wastewater dischargers or MS4s located in the Ann River impaired reach watershed. There is a limited amount of construction activity within the impaired reach watershed each year, so a wasteload allocation of 0.1% has been set aside for that purpose.

5.3.2 Load Allocation

The Load Allocation includes all sources not covered by a state or federal permit. As noted in Section 5.2 above, the primary sources of bedded sediment are watershed load delivered directly from the landscape or conveyed by channels, tiles, or pipes; and streambank load resulting from erosion and mass wasting. Potential sediment delivery for each of these sources was estimated above for current conditions.

Based on the soil erodibility, topography, and cropping practices within the watershed, and the size of the watershed tributary to the impaired reach, the annual volume of sediment contributed from the watershed is estimated to be small compared to the volume estimated to be contributed from the streambanks each year. The Wisconsin NRCS found a range of 0.01 to 0.05 feet of soil loss per year on undisturbed streams, with 0.01 being the most pristine in a minimally altered watershed and 0.05 stable but in a more disturbed watershed. Because the Ann River watershed contains areas that have been impacted and areas that have been minimally impacted, a stable recession rate of 0.025 feet per year was selected to establish the TMDL. Table 5.8 calculates a reduction of 865 tons per year as the difference between estimated current conditions and that stable lateral recession rate of 0.025 feet per year.

Table 5.8. Streambank soil loss calculation.

Reach	Eroding Bank Length (ft)	Eroding Bank Height (ft)	Area of Eroding Bank (ft^2)	Current Condition		TMDL Condition		TMDL Reduction (Tons/yr)
				Lateral Recession Rate (est) (ft/yr)	Soil Loss (Tons/yr)	Lateral Recession Rate (est) (ft/yr)	Soil Loss (Tons/yr)	
Reach 1								
Unsurveyed	25,530	2	51,060	0.05	109			
Surveyed	330	varies			26			
Subtotal	25,860	2	51,720		135	0.025	55	79
Reach 2								
Unsurveyed	16,286	5	81,430	0.1	346			
Surveyed	1,650	varies			181			
Subtotal	17,936	5	89,680		527	0.025	95	432
Reach 3								
Unsurveyed	9,033	3	27,099	0.1	136			
Surveyed	825	varies			7			
Subtotal	9,858	3	29,574		143	0.025	37	106
Reach 4								
Unsurveyed	12,960	3	38,880	0.025	49			
Surveyed	0	varies			0			
Subtotal	12,960	3	38,880		49	0.025	49	0
Reach 5								
Unsurveyed	16,671	5	83,355	0.0625	260			
Surveyed	711	varies			13			
Subtotal	17,382	5	86,910		273	0.025	109	165
Reach 6								
Unsurveyed	28,232	3	84,696	0.04375	185			
Surveyed	410	varies			5			
Subtotal	28,642	3	85,926		190	0.025	107	83
TOTAL	**112,638**				**1,317**		**452**	**865**

5.3.3 Margin of Safety

An explicit margin of safety was used to compute the TMDL. The estimates of streambank erosion and recession rates were based on a limited review of field conditions and aerial photos as well as local knowledge and professional judgment. A margin of safety of 10% of the streambank load was included in the TMDL to account for uncertainties in the estimates used in the model.

5.3.4 Summary of TMDL Allocations

A 44% reduction in sediment loading to Ann River is necessary to achieve the bedded sediment TMDL (Table 5.9). Streambank sources would need to be reduced by 69% to meet the TMDL.

Table 5.9. Ann River Bedded Sediment Total Maximum Daily Load allocations.

Allocation	**Source**	**Existing Bedded Sediment Load**		**Bedded Sediment TMDL (WLA & LA)**		**Load Reduction[2]**	
		(tons/year)	**(tons/day)[1]**	**(tons/year)**	**(tons/day)[1]**	**(tons/year)**	%
Wasteload Allocation	Construction & Industrial Stormwater	2	<0.1	2	0.0	0	0%
Load Allocation	Watershed	763	2.1	763	2.1	0	0%
	Streambank	1,317	3.6	407	1.1	910	69%
MOS				45	0.1		
TOTAL		**2,082**	**5.7**	**1,217**	**3.3**	**910**	**44%**

[1] Annual loads converted to daily by dividing by 365.25 days per year accounting for leap years

[2] Net reduction from current load to TMDL is 865 tons/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 865 + 45 = 910 tons/yr.

5.3.5 Seasonal and Annual Variation

The critical condition for streambank erosion is periods of high flow such as spring snowmelt and large storm events which stress unprotected streambanks and cause erosion and mass wasting, contributing excess sediment to the channel. The daily load reduction targets in this TMDL are calculated from annual rescission rates observed by the Wisconsin NRCS on a variety of streams over numerous years and reflect a wide variety of seasonal and annual variation in conditions. Consequently, using these average rates addresses both seasonal and annual variability as well as the critical condition.

5.3.6 Reserve Capacity

The amount of land in agricultural use in the Ann River watersheds is likely to remain fairly constant over the next several decades. The watershed is comprised mainly of pasture and hay with some land used for row crops (corn and soybeans). While the majority of the landscape is likely to remain in an agricultural land use, it is possible a modest shift between pasture/hay and row crops may occur. Slight shifts in land use should not appreciably change the magnitude of the land use runoff variability that the period of record assumed in the NRCS rescission rates already reflects.

5.4 BIOTIC INTEGRITY NON-TMDL PARAMETER TARGETS

5.4.1 Dissolved Oxygen

Limited analysis of dissolved oxygen data was completed in the Stressor ID. Low oxygen concentrations were recorded during the summer months at some locations; however, the cause(s) of those low readings was not determined. Likely causes include excess nutrient delivery and enrichment from Ann Lake; excess sediment oxygen demand from overwidened channels; and lack of reaeration opportunities. Streamflow alteration due to the dam at Ann Lake may also contribute to the low oxygen levels.

While more data is necessary to better diagnose the cause(s) of periods of low dissolved oxygen, some general goals to increase reaeration can be established for Ann River. Many of the goals to reduce excess sedimentation and improve riparian conditions would also positively impact dissolved oxygen conditions.

- The river passes through some wooded reaches, but especially in the lower stream there is little to no canopy coverage at all. This can lead to excessive stream warming, which decreases the saturation capacity of streamflow. Increased warming can also enhance primary production, which in turn consumes dissolved oxygen. Manage riparian trees and vegetation so that the stream surface is at least 25 percent shaded.

- The overwidened channel often results in very shallow stream depths, increasing streamflow temperature. The overwidened channel also contains more wetted surface area, increasing sediment oxygen demand. Where possible, reconfigure the channel to add a low-flow channel to increase depth and reduce exposure to sediment. This will also increase velocity, which will in turn increase reaeration and improve sediment flushing.

- Reduce sediment and nutrient enrichment from overland flow and streambank erosion by stabilizing streambanks with native buffers. Establish a goal of 100% native vegetation coverage except where stabilized animal access to the stream must be maintained.

5.4.2 Riparian Degradation

Logging and land conversion to pasture and hay has significantly altered the Ann River riparian zone. The Stressor ID Study found that north of CR 23, the riparian zone within 100 meters of the river’s edge was 11-18 percent disturbed, while south of CR 23 the riparian zone was 88-100 percent disturbed. Biomonitoring sites 6 and 7 scored relatively poorly on the Minnesota Stream Habitat Assessment (MSHA) scale. Limited stabilizing native vegetation has also resulted in streambank instability and indications of channel overwidening and channel evolution.

- An aerial photo analysis indicates about 4.1 miles of the Ann River has no significant buffer on either side of the stream, and an additional 2.2 miles is buffered on only one side of the stream. Restore native vegetation on the streambanks and riparian zone to stabilize streambanks, filter runoff, and provide overhanging vegetation, with a goal of providing a buffer at least 50 feet wide on 100% of both sides of the stream.

- Logging and tree removals have reduced inputs of woody debris and other organic inputs. The stream does pass through wooded reaches, which likely do contribute those inputs, which are then transported downstream. However, trees and woody vegetation provide other benefits, including shade, root stability, overhanging vegetation, and root and stump habitat. Include tree and woody plantings when installing or enhancing stream buffers.

- Unrestricted animal access to the stream, especially below Highway 12, has resulted in bare and eroded streambanks as well as sparse vegetative cover in overgrazed areas. Limit animal access to stabilized access points.

5.4.3 Loss of Connectivity-Impoundments and Flow Alteration

The dams at the outlets of Ann Lake and Fish Lake create physical barriers limiting movement between the lakes and the river and create impoundments that may alter the stream's flow regime. There is a lack of data to truly understand the impact of those structures on biotic integrity. The dams also create impoundments and may be influencing streamflow.

- Further study should be undertaken to determine how these structures may be having an impact on Ann River biotic integrity.

- If necessary consider dam modifications or enhancements such as fish ladders or fish bypass passages.

6.0 Implementation

6.1 IMPLEMENTATION FRAMEWORK

The Kanabec and Mille Lacs SWCDs and Kanabec County Environmental Services will coordinate implementation of actions identified in this TMDL and the TMDL Implementation Plan in partnership with the Snake River Watershed Management Board. All actions will be incorporated into the county's Comprehensive Local Water Plan.

6.2 *E. COLI* AND NUTRIENT LOAD REDUCTION STRATEGIES

The following is a description of potential actions for bacterial and nutrient loading to the Ann River, Ann Lake, and Fish Lake. These actions will be further developed in the TMDL Implementation Plan.

Ann Lake. Implementation activities for Ann Lake should focus primarily on internal phosphorus load reductions. The TMDL also requires small watershed load reductions including upgrading all noncompliant SSTSs. Remaining reductions in watershed loading will need to come from land practices including manure and livestock management. Another important factor in restoring Ann Lake will be vegetation management.

Fish Lake. Implementation activities for Fish Lake should focus on a multitude of areas including upgrading SSTSs, manure and livestock management, internal load reductions, and potentially carp management. Load reductions from Ann Lake restoration will also have a large benefit for Fish Lake.

E. coli. The majority of *E. coli* appears to be coming from pastures near the streams and ditches in the watershed. Therefore, BMPs should focus on livestock exclusions, buffers, and manure management.

The estimated total cost of implementing these and other potential BMPs ranges from $300,000 to $500,000.

6.2.1 Installation or Enhancement of Buffers

The largest potential sources of *E. coli* and other bacteria are those activities associated with pasture management. In many locations along the river, cattle grazing have denuded stream banks of stabilizing native vegetation that would otherwise filter runoff from pastures near streams and waterways. Secondarily, BMPs for upland pasture land should also be implemented.

An aerial photo analysis of the stream network in the watershed indicates about 20.7 miles of the higher order streams has no significant buffer on either side of the stream, and an additional 4.3 miles is buffered on only one side of the stream. The estimated cost of installing a 50 foot wide buffer on both sides of all stream segments lacking one is $1.1 million.

6.2.2 Pasture Management

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

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

6.2.3 Manure Management

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

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

Additional technologies will be evaluated including chemical addition to manure prior to field application to reduce phosphorus availability and mobility.

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

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

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

These practices should be applied where appropriate.

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

6.2.4 Septic System Inspections and Upgrades

While failing septic systems do not appear to be a significant source of *E. coli*, Kanabec County and Mille Lacs County should continue to inspect and order upgrades, with priority given to those properties near streams and waterways.

Kanabec County and Mille Lacs County should continue to identify and address systems that are not meeting adopted septic ordinances. Special attention shall be given to systems with high nutrient loading potential based on proximity to the lake, streams and systems that may discharge directly to surface water.

6.2.5 Implement Construction and Industrial Stormwater Regulations

The wasteload allocation for stormwater discharges from sites where there is construction activities reflects the number of construction sites > 1 acre expected to be active in the watershed at any one time, and the Best Management Practices (BMPs) and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local construction stormwater requirements must also be met.

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

6.2.6 Internal Nutrient Load Reductions

Internal nutrient loads will need to be reduced to meet the TMDL allocations presented in this document. There are numerous options for reducing internal nutrient loads ranging from simple chemical inactivation of sediment phosphorus to complex infrastructure techniques including hypolimnetic aeration.

Internal load reduction technical review. Prior to implementation of any strategy to reduce internal loading in Ann Lake and Fish Lake, a technical review needs to be completed to evaluate the cost and feasibility of the lake management techniques available to reduce or eliminate internal loading. Several options could be considered to manage internal sources of nutrients including hypolimnetic withdrawal, alum treatment, vegetation management and hypolimnetic aeration. A technical review should be completed to provide recommendations for controlling internal loading in Ann Lake and Fish Lake. This review will also include the potential impacts of each management option to the wild rice beds in Ann and Fish Lake.

6.2.7 Studies and Biological Management Plans

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

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

Carp Management. One activity should be to partner with the DNR to monitor and manage the fish population to maintain a beneficial community. As the aquatic vegetation changes to a more desirable mix of species, it may be possible to restore a more balanced fish community that includes both panfish and top predators. Options to reduce rough fish populations should be evaluated, and the possibility of fish barriers explored to reduce rough fish access to spawning areas and to minimize rough fish migration between lakes.

Encourage shoreline restoration. Many property owners maintain a turfed edge to the shoreline. Property owners should be encouraged to restore their shoreline with native plants to reduce erosion and capture direct runoff. Shoreline restoration can cost $30-$65 per linear foot, depending on the width of the buffer installed. The Kanabec County SWCD, Mille Lacs County SWCD, and Snake River Watershed Management Board will continue to work with all willing landowners to naturalize their shorelines.

6.2.8 Education

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

6.3 BIOTIC INTEGRITY IMPROVEMENT STRATEGIES

Many of the bacteria load reduction activities identified above such as installation of native buffers and controlling animal access to the streams will also benefit biotic integrity. Implementation should focus on reducing sediment inputs to the stream, primarily through stream restoration and repair.

6.3.1 Stream Restoration

Stream restoration projects should focus on both streambank and streambed improvements. In locations where the channel is overwidened, biorestoration projects to narrow the channel and stabilize the banks will increase velocity, increase flushing, and raise dissolved oxygen. Figure 6.1 illustrates a desirable stream cross section.

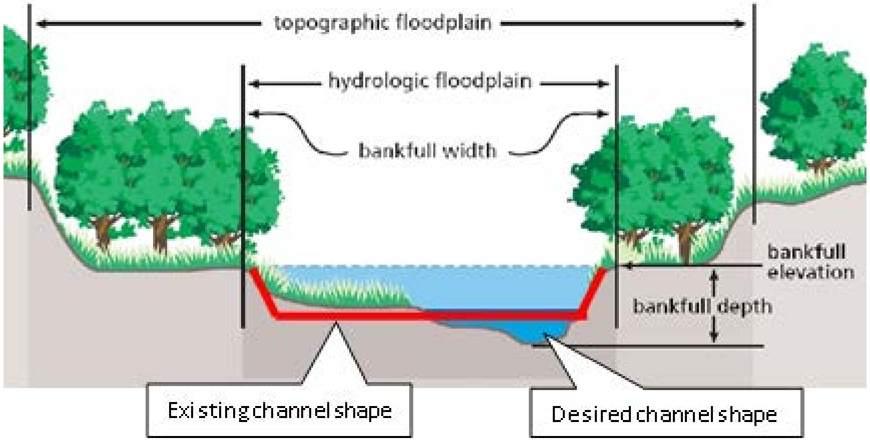

Figure 6.1. Desirable stream cross section with enhanced habitat and a low-flow channel.
Source: Federal Interagency Stream Restoration Working Group.

Figure 6.2 shows the reaches of the Ann River, and Table 6.1 provides an overview of the types of restoration activities that would be most beneficial by reach. The highest priority for stream restoration to reduce excess sediment loading is the reach from approximately biomonitoring station 6 to Highway 23, where a number of stream segments are experiencing severe and ongoing erosion. The immediate goal is to stabilize those sites using a combination of bioengineering, armoring as necessary, and buffer planting. A more systematic survey should be completed to identify other locations where spot erosion is contributing excessive sediment loads.

In the lower river below Highway 23, where fine bedded sediment has accumulated, it may not be feasible to narrow the stream to achieve flushing flows. Upstream sedimentation pools that can be periodically cleaned out could be added to intercept excess sediment prior to discharge downstream. Alternatively, the streambanks could be altered so that the stream has greater access to its floodplain, allowing sediment to drop out in the floodplain rather than the streambed.

Table 6.1. General stream restoration recommended improvements by reach.

Reach	Length (feet)	Recommended Improvements	Estimated Cost
1	12,930	Narrow the stream using coir logs or brush bundles. If necessary dredge fine sediment. Add rock, cobble and gravel to improve streambed. Selectively thin trees to provide dappled light, use harvested trees to add root wads and tree pins for woody substrate and narrow channel.	$100,000
2	8,968	Establish native vegetation in an approximately 500 foot wide wetland meander belt. Plant trees and shrubs in buffer and allow stream to naturally meander. Fence along the belt and provide controlled animal access(es) to stream.	$250,000
3	4,929	Establish native vegetation in a 50-100 foot wide buffer. Repair and stabilize eroded segments. Live stake outer bends. Use brush bundles, coir logs, and other natural materials to capture sediment and naturally narrow the stream. Fence where necessary and provide controlled animal access(es) to stream.	$250,000
4	6,480	Periodically inspect this heavily wooded reach to manage deadfall and spot repair streambanks where necessary.	$25,000
5	8,691	Establish native vegetation in a 50-100 foot wide buffer. Repair and stabilize eroded segments. Spot repair eroded segments. Live stake outer bends. Fence where necessary and provide controlled animal access(es) to stream.	$100,000
6	14,321	Establish native vegetation in a 50-100 foot wide buffer. Repair and stabilize eroded segments. Spot repair eroded segments. Live stake outer bends. Fence where necessary and provide controlled animal access(es) to stream.	$125,000
TOTAL	**56,319**		**$850,000**

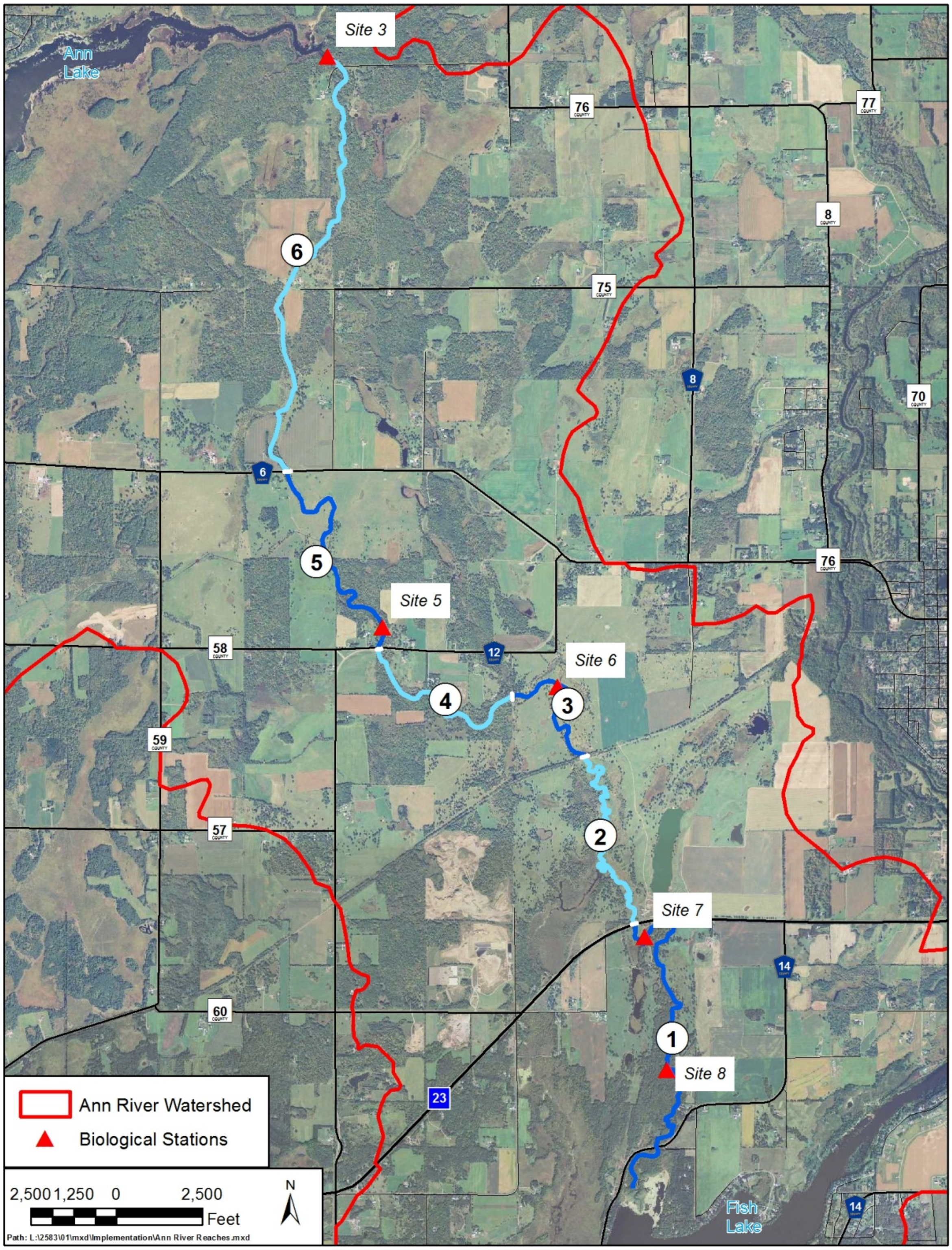

Figure 6.2. Ann River stream reaches.

6.3.2 Installation or Enhancement of Buffers and Riparian Vegetation

Restore native vegetation on the streambanks and riparian zone to stabilize streambanks, filter runoff, and provide overhanging vegetation, with a goal of providing a buffer at least 50 feet wide on 100% of both sides of the stream. Include tree and woody plantings when installing or enhancing stream buffers to increase shading, vegetative material inputs to the stream, and create or enhance both upland and aquatic habitat. This action is also recommended to help reduce bacterial loading. The cost of this action is included in Table 6.1 above.

6.3.3 Limit Animal Access to the Stream

Unrestricted animal access to the stream, especially below Highway 12, has resulted in bare and eroded streambanks as well as sparse vegetative cover in overgrazed areas. Limit animal access to the stream by installing fencing in pastures where access is now unimpeded, and direct animals to stabilized access points. This action is also recommended to help reduce bacterial loading. The cost of this action is included in Table 6.1 above.

6.3.4 Connectedness Restoration

The Ann Lake and Fish Lake dams may be limiting migration between lake and stream habitats, however, there is a lack of data to truly understand the impact of those structures on biotic integrity. The dams also create impoundments and may be influencing streamflow. Further study should be undertaken to determine how these structures may be having an impact on Ann River biotic integrity. Implementation actions may include fish ladders or fish bypass passages, depending on the outcome of future monitoring and feasibility studies. Additional study is necessary to determine what if any actions should be taken. Fish ladders or bypass passages can cost $50,000-100,000 depending on local conditions.

6.4 ADAPTIVE MANAGEMENT

This list of implementation elements and the more detailed implementation plan that will be prepared following this TMDL assessment focuses on adaptive management (Figure 6.2). As the sediment dynamics and other stressors within the stream are better understood, management activities both to reduce oxygen demand and to address the other biotic stressors will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired reaches.

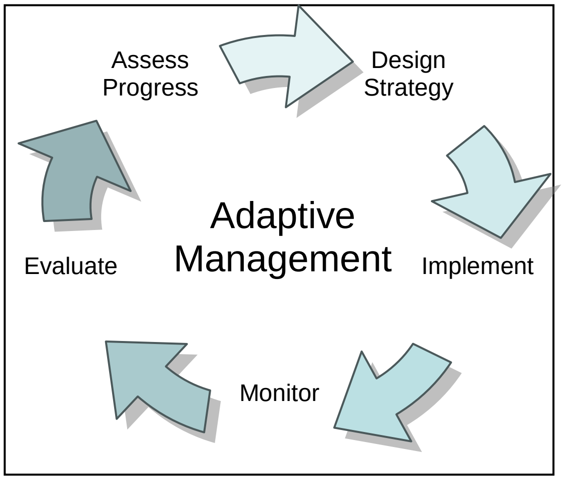

Figure 6.3. Adaptive management.

7.0 Reasonable Assurance

As part of an implementation strategy, reasonable assurances provide a level of confidence that the TMDL allocations will be implemented by federal, state, or local authorities. Implementation of the Ann River Watershed TMDL will be accomplished by both state and local action on many fronts, both regulatory and non-regulatory. Multiple entities in the watershed already work towards improving local water quality. Water quality restoration efforts will be led by the Kanabec SWCD, Mille Lacs SWCD, and the SRWMB; along with assistance from the local communities, and lake and watershed organizations.

7.1 NON-REGULATORY

At the local level, Kanabec SWCD, Mille Lacs SWCD, and SRWMB currently implement programs targeted at water quality improvement and have been actively involved in projects to improve water quality in the past. It is anticipated that their involvement will continue. Potential funding of TMDL implementation projects includes:

- Conservation Reserve Program,
- Federal Section 319 program for watershed improvements,
- Funds ear-marked to support TMDL implementation from the Clean Water, Land, and Legacy constitutional amendment, approved by the Minnesota's citizens in November 2008,
- Local government cost-share funds,
- CWP Grants, and
- CWP (SRF Loan Funds).

The implementation strategies described in this TMDL have demonstrated to be effective in reducing loadings to lakes and streams. The Kanabec SWCD, Mille Lacs SWCD, and SRWMB have programs in place to continue many of the recommended activities; however much of it is dependent upon funding. Monitoring will continue as local and state funding allows, and adaptive management will be in place to evaluate progress made towards achieving the beneficial use of each lake and the Ann River.

7.2 REGULATORY

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.

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.

Kanabec County and Mille County's current septic system ordinance is based on septic system inspection at the time of property transfer or installation of any new or replacement on-site sewage disposal system. From 2007 – 2012, Kanabec County has been successful and receiving and implementing Clean Water Partnership SRF Loan Funds to replace failing and non-compliant systems. This is a program that Kanabec County looks to continue into the future, should funding be available.

Kanabec County and Mille Lacs County are not MPCA delegated partner with the State Feedlot Program and does not employ a County Feedlot Officer; MPCA provides field staff for feedlot permitting and compliance checks on all registered animal operations.

Through other federal, state, and local regulatory programs such as shoreland ordinances, SSTS rules, Wetland Conservation Act, Farm Bill, and other County Ordinances potential sources of phosphorus, sediment, and E. coli are being addressed.

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

7.3 SOIL AND WATER CONSERVATION DISTRICT

The Ann River watershed is located within the jurisdiction of two Soil and Water Conservation Districts (SWCD), the Kanabec SWCD and the Milles Lacs SWCD. Only a small portion in the northern part of the watershed is in the Mille Lacs SWCD area. In general, the SWCDs plan and execute policies, programs, and projects that conserve soil and water resources within their jurisdictions. The SWCDs are involved in implementation of practices that reduce or prevent erosion, sedimentation, siltation, and other pollution in order to protect water and soil resources. The SWCDs frequently provide education, outreach and cost share for many types of projects, such as erosion control structures.

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

The Kanabec SWCD develops an annual work plan that identifies actions for the year that address specific objectives from the Long Range District Comprehensive Plan. District staff and board members have established working relationships with a number of different agencies and groups. These include Kanabec County Environmental Services, the SRWMB, and the NRCS, for example. The SWCD staff and board also maintain regular communication with the County commissioners and State legislators regarding progress, accomplishments, budgets, and services.

The SWCD assists with carrying out the goals and objectives of the Kanabec County Comprehensive Local Water Plan (CLWP), Wetland Conservation Act (WCA), Board of Water and Soil Resources (BWSR) related programs, NRCS, SRWMB, and the East Central Landscape Committee. Coordinating the TMDL for the Ann River subwatershed and Snake River Watershed area is identified in the 2011 annual work plan. SWCD staff and funding have been identified for this task. Additionally, the SWCD outlines a number of other action steps for maintaining and improving surface and groundwater quality, including technical assistance to landowners, implementation of BMPs, and state and local agency partnerships.

Both of the SWCD's have been very successful in the past in implementation BMPs in the past. During the development of this TMDL the Kanabec SWCD worked with landowners to successfully install BMPs like; vegetative swale on a gravel road adjacent to Ann Lake that was contributing sediment and phosphorus to the lake, worked with the MN DNR to install infiltration basins in the Ann Lake Boat Landing to prevent runoff from entering the lake, multiple shoreland stabilization and restorations on both Ann and Fish Lake, and has also worked with a landowner to install an exclusion to keep livestock out of the Ann River.

The Kanabec SWCD will continue to coordinate the implementation of the TMDL and work with partnering agencies to meet the goals and standards recommended in the Ann River Watershed TMDL.

7.4 SNAKE RIVER WATERSHED MANAGEMENT BOARD

The Ann River Watershed is part of the larger Snake River Watershed. The Snake River Watershed Management Board (SRWMB), through a joint powers agreement with Aitkin, Kanabec, Mille Lacs, and Pine Counties, coordinates the counties' comprehensive water plans as they pertain to the area within the Snake River Watershed. This cooperative management allows for more comprehensive protection and enhancement of water and land resources within the watershed.

The SRWMB also has a Citizen's Advisory Committee (CAC) whose membership includes a SWCD supervisor from each county, two citizens, lake association member, and any individual looking to attend the meetings. The CAC meets to address policy issues and specific topics, such as land use management, proposed BMP project requests, water quality monitoring, and education/stewardship, then advises the SRWMB on these issues.

The SRWMB will play a role in the implementation of the Ann River Watershed TMDL by providing a level of coordination across local governments. The SRWMB will also work closely with the SWCD to identify BMP projects and administer grant funding for those projects.

The SRWMB successfully completed a Snake River Watershed CWP Diagnostic and Implementation, and recently completed a Phase II Clean Water Partnership program in the Snake River Watershed. While this project focused on the entire Snake River Watershed, projects were funded and implemented in the Ann River Watershed. These programs have successfully implemented on the ground management practices to reduce sediment, nutrient, bacteria, as well as other issues, and the intent of the SRWMB is to continue the work it has been doing for the Snake River Watershed and the Ann River Watershed.

7.5 KANABEC COUNTY ENVIRONMENTAL SERVICES

Kanabec County Environmental Services administers the County's Comprehensive Local Water Plan (CLWP), dated 2006-2016. The purpose of this plan is to identify existing and potential problems or opportunities for the protection, management, and development of water resources and related land resources in Kanabec County and the Snake River Watershed. Other purposes of the plan are to develop and implement an action plan to promote sound water management decisions, and to achieve effective environmental protection of Kanabec County's water and land resources.

The CLWP outlines several priority concerns identified during the planning process and goals to address those concerns. Priority Concern 1 Goal addresses protecting water resources from erosion, sedimentation, and nutrient loading through BMPs, shoreland regulations, and MPCA stormwater regulations.

7.6 SUSTAINED STATE AND FEDERAL – LOCAL COOPERATION

As identified by the Kanabec SWCD annual work plan, there are many conservation partners and cooperating agencies that the SWCD works with in order to protect and enhance land and water resources. These partnerships were built over time and will be important during the development and implementation of the Ann River Watershed TMDL. The list of partners in the SWCD annual work plan include Board of Soil and Water Resources (BWSR), Natural Resources Conservation Service (NRCS), Farm Service Agency (FSA), Resource Conservation and Development (RC&D) Council, MN DNR, MPCA, Minnesota Department of Agriculture (MDA), Minnesota Department of Health (MDH), and local lake and watershed associations.

The NRCS is housed in the same building as the Kanabec SWCD. This agency is federally funded and works with landowners on projects similar to those the SWCD works on. The two agencies serve a similar purpose to assist landowners with BMP projects, while finding funding and cost share opportunities. This role will be important for the implementation of the TMDL.

8.0 Monitoring

Monitoring in the Snake River Watershed was completed on a regular basis for approximately ten years until 2010. At that time more intensive monitoring began for the TMDL study, which took place in 2008 and 2009. Some monitoring of Ann Lake and Fish Lake was completed in 2010, but no monitoring has occurred in 2011.

Progress of TMDL implementation will be measured through regular monitoring efforts of water quality and total BMPs completed. This will be accomplished through the efforts of the cooperating agencies and groups discussed above. As long as sufficient funding exists, the following monitoring efforts below will be targeted. Since funding is limited for effectiveness monitoring, one avenue that could and may be used in this watershed is the Intensive Watershed Monitoring being conducted by the MPCA. This monitoring was conducted in the Snake River Watershed in 2007 and is expected to be monitored again in 2017 as part of the 10 year cycle. At a minimum this effort will help provide data at a larger scale that may not be available otherwise.

However, all efforts will be made locally to conduct and target monitor should funds and staff time be available.

Lakes Monitoring

Ann Lake and Fish Lake have been monitored by volunteers and staff over the years. This monitoring is planned to continue to keep a record of the changing water quality as funding allows. Lakes are generally monitored for chlorophyll-*a*, total phosphorus, and Secchi disk transparency.

In-lake monitoring will continue as implementation activities are installed across the watershed. These monitoring activities should continue until water quality goals are met. Some tributary monitoring has been completed on the inlets to the lakes and may be important to continue as implementation activities take place throughout the sub-watersheds.

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

Bacteria Monitoring

River monitoring in the larger Snake River Watershed, which includes the Ann River Watershed, has been coordinated largely by the Snake River Watershed Management Board for the last 10 years as part of two Clean Water Partnership Grants, and local funds they have available. Monitoring is also being conducted on a smaller scale because of the Kanabec County Water Plan and the limited funds that has available.

Stream monitoring in the Ann River should at a minimum continue at the most downstream site to continue to build on the currnet dataset and track changes based implementation progress. At a minimum it is recommended that two E. coli samples be collected each month from May through September. As BMP practices are implemented throughout the watershed it is also suggested that monitoring take place in those subwatersheds to track progress towards the TMDL.

Biological Monitoring

Continuing to monitor water quality and biota scores in the listed segments will determine whether or not stream habitat restoration measures are required to bring the watershed into compliance. At a minimum, fish and macroinvertebrate sampling should be conducted by the MPCA, MN DNR, or others every five to ten years during the summer season at each established location until compliance is observed for at least two consecutive summers. It will also be important to continue to conduct streambank assessments before and after any major stabilization BMP is implemented to track if instream erosion is improving, or if more work is needed.

Tracking the implementation of BMPs while continuing to monitor biological conditions in the watershed will assist the stakeholders and public agencies in determining the effectiveness of the implementation plan. If biota scores remain below the confidence intervals, further encouragement of the use of BMPs across the watershed through education and incentives will be a priority. It may also be necessary to begin funding efforts for localized BMPs such as riparian buffer and stream restoration.

9.0 Public Participation

A stakeholder and public engagement and participation process was undertaken for this TMDL to obtain input from, review results with, and take comments from the public and interested and affected agencies regarding the development of and conclusions of the TMDL.

9.1 TECHNICAL ADVISORY COMMITTEE

A Technical Advisory Committee was established so that interested stakeholders could be involved in key decisions during development of the TMDL. Stakeholders represented on the Technical Advisory Committee or asked to comment on drafts of the TMDL and/or Stressor Identification included county and SWCD representatives, Department of Natural Resources staff and MPCA staff, and local officials. Technical Advisory Committee meetings where this TMDL was discussed were held on November 8, 2007; April 21, 2009; November 16, 2010; March 8, 2011; August 30, 2011; March 8, 2012.

9.2 STAKEHOLDER MEETINGS

The general public and the Ann Lake and Fish Lake Associations were invited to a series of stakeholder meetings on this TMDL. These were held on November 29, 2007; March 30, 2009; April 21, 2009; March 21, 2011; July 14, 2011; August 30, 2011; March 21, 2012.

The official TMDL public comment period was held from January 14, 2013 through February 13, 2013.

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11.0 Appendices

Appendix A: Ann and Fish Lake Watershed Stream Flow Processing

Appendix A: Ann and Fish Lake Watershed Stream Flow Processing

Flow Processing Summary

There are four continuous MPCA flow monitoring stations in the Ann River Watershed. These stations operated from early April through early November in 2008 and from late March through mid-November in 2009. There were also seven monitoring stations where individual (gaged) flows were measured periodically in 2008 and 2009. Data gaps and winter measurements for the main-stem Ann River continuous monitoring stations (S003-782 and S003-530) were filled using regression curves with the Snake River long-term continuous monitoring station (S000-198). Next, data gaps and winter measurements for the two continuous monitoring stations upstream of Ann Lake (S004-393 and S004-636) were filled using regression relationships between these stations and the most downstream Ann River site near the inlet of Fish Lake at County Road 14 (S003-782). Finally, daily hydrographs were simulated for the gaged flow monitoring stations using regression relationships between each station and one of the continuous flow monitoring sites. Regressions for each gaged flow station were selected based on proximity to continuous the flow stations and by investigating the strength of each regression relationship (R^2 value). Once all regressions were applied, the final output was an 11-year (2000 through 2010) year-round continuous average daily flow record for each Ann River watershed monitoring station.

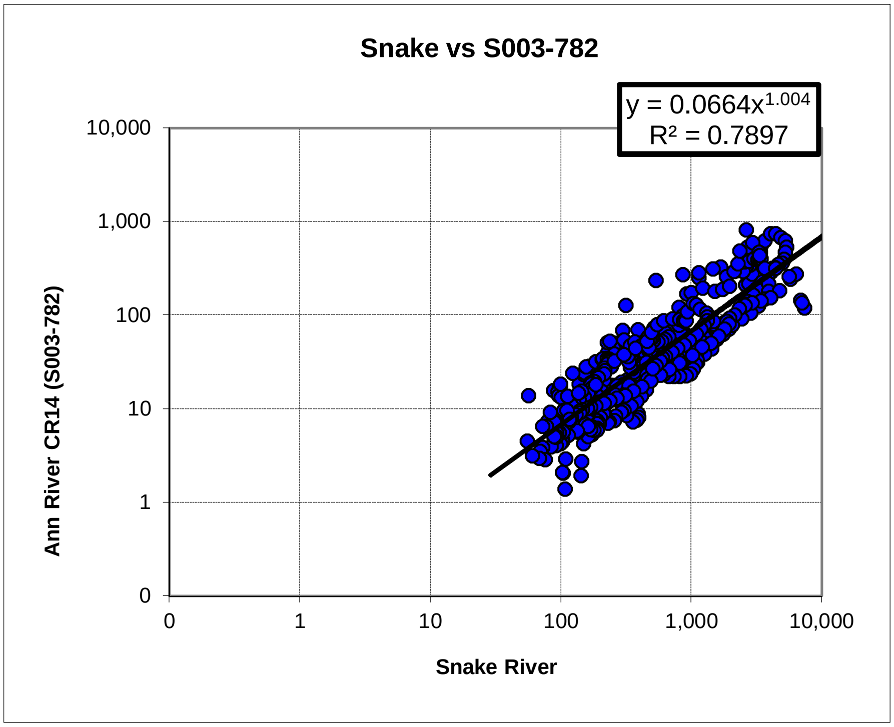
Continuous Monitoring stations

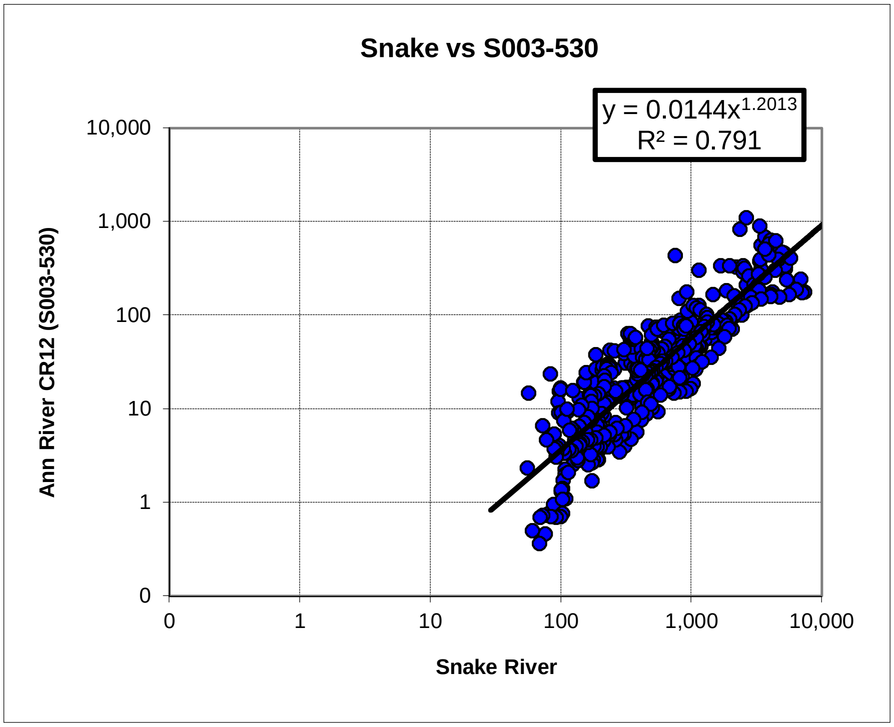
Station ID	Description	Years Monitored	Daily Measurements	Data Gap Station
S000-198	Snake River below Cross Lake	1913-2009	19,702	NA
S003-782	Ann River at Co Rd 14	2008-2009	478	S000-198
S003-530	Ann River at Co Rd 12	2008-2009	480	S000-198
S004-393	Little Ann River at Co Rd 26	2008-2009	536	S000-782
S004-636	Camp Creek at Hwy 47	2008-2009	473	S000-782

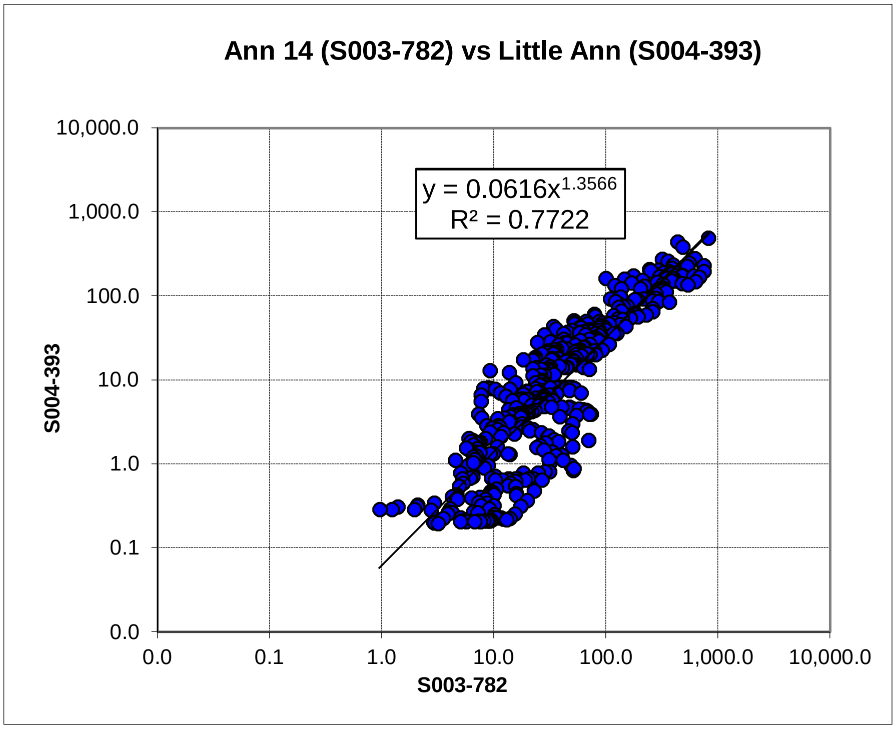
Gaged Flow Monitoring Stations

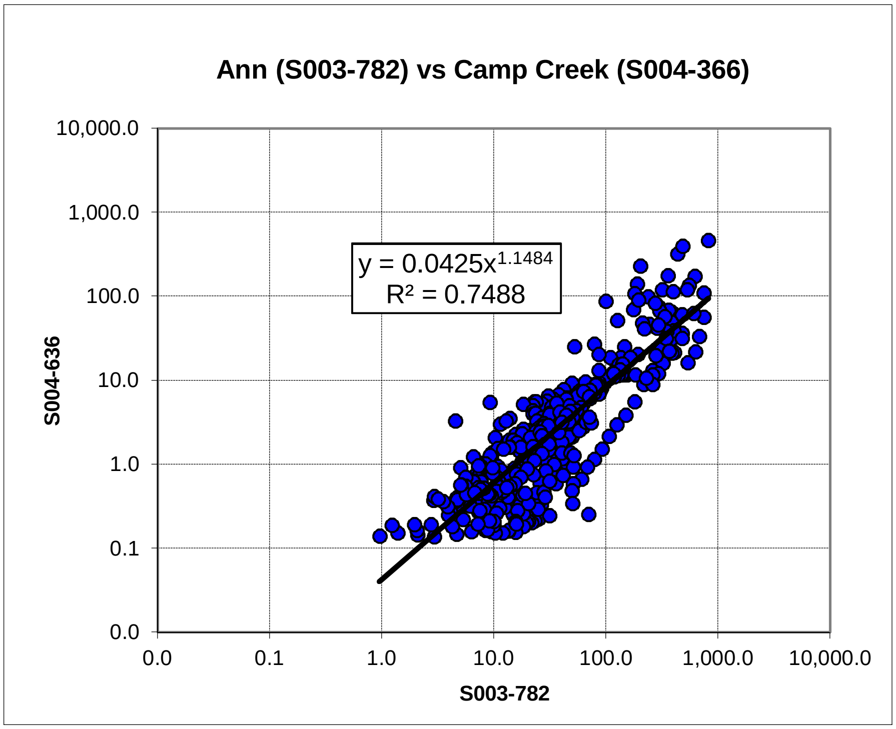
Station ID	Description	Years Monitored	Gaged Flow Measurements	Regression Station
S004-638	Unnamed Stream at Crestview Dr	2008-2009	12	S004-636
S004-637	Spring Brook at Hwy 47	2008-2009	7	S004-393
S004-635	Unnamed Stream at Co Rd 59	2008-2009	12	S003-530
S004-633	Unnamed inlet to Fish at CSAH 14	2008-2009	9	S003-782
S004-936	Unnamed Stream at CSAH 14	2008	5	S003-782
S004-641	Unnamed inlet to Fish at CSAH 14	2008	4	S004-636

Continuous Station Regressions

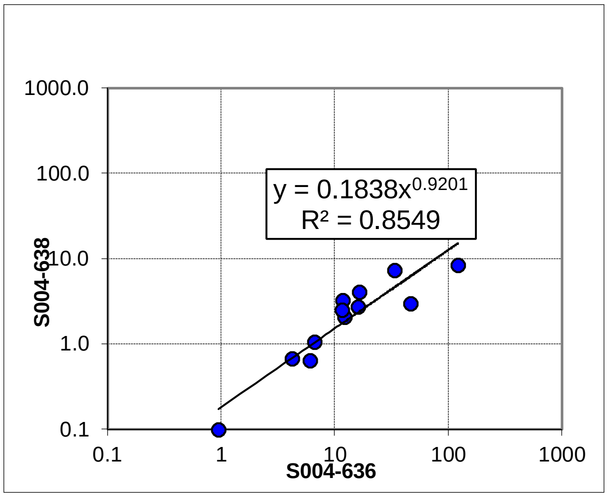

Snake vs S003-782
y = 0.0664x$^{1.004}$
R² = 0.7897
Ann River CR14 (S003-782)
10,000
1,000
100
10
1
0
0
1
10
100
1,000
10,000
Snake River

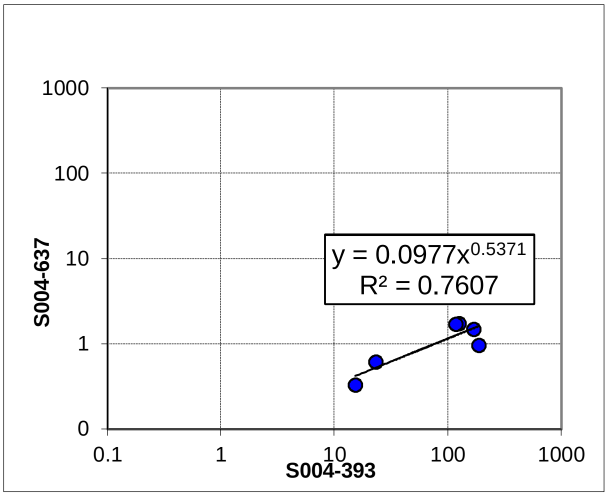

Snake vs S003-530
y = 0.0144x$^{1.2013}$
R² = 0.791
Ann River CR12 (S003-530)
10,000
1,000
100
10
1
0
0
1
10
100
1,000
10,000
Snake River

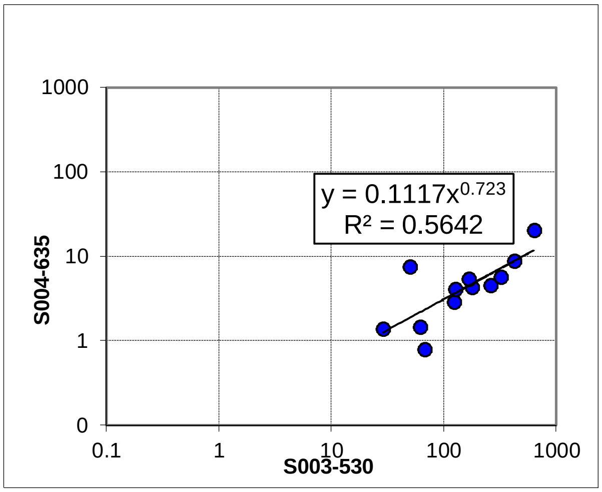

Ann 14 (S003-782) vs Little Ann (S004-393)
y = 0.0616x^1.3566
R² = 0.7722
S004-393
10,000.0
1,000.0
100.0
10.0
1.0
0.1
0.0
0.0
0.1
1.0
10.0
100.0
1,000.0
10,000.0
S003-782

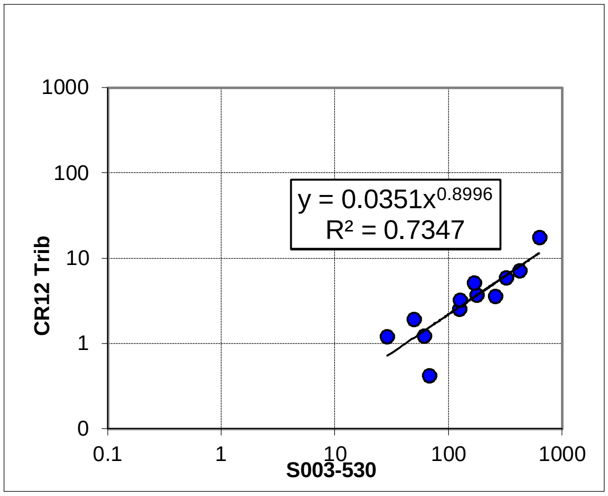

Ann (S003-782) vs Camp Creek (S004-366)
y = 0.0425x^1.1484
R² = 0.7488
S004-636
10,000.0
1,000.0
100.0
10.0
1.0
0.1
0.0
0.0
0.1
1.0
10.0
100.0
1,000.0
10,000.0
S003-782

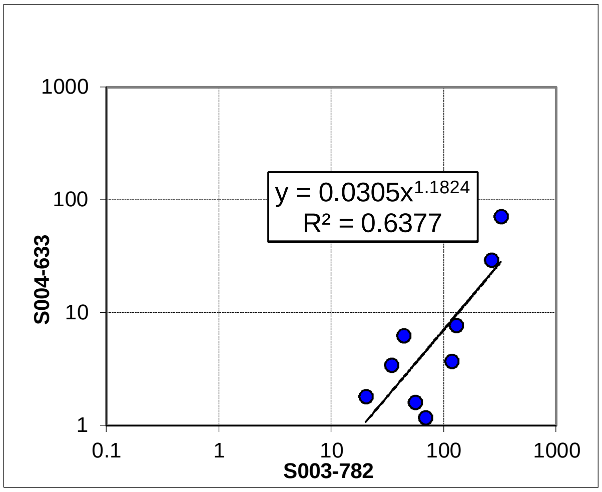
Gaged Station Regressions

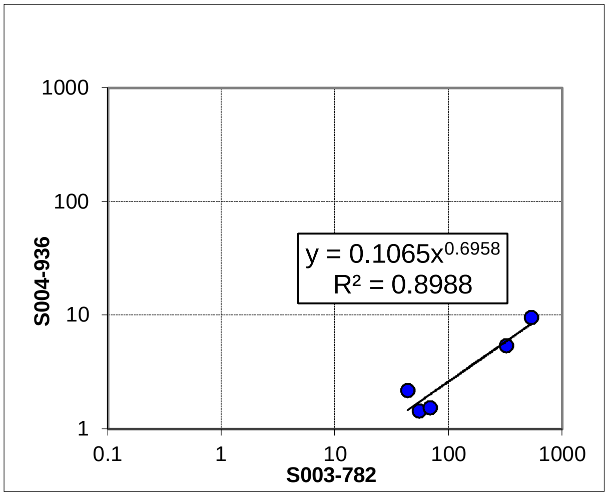


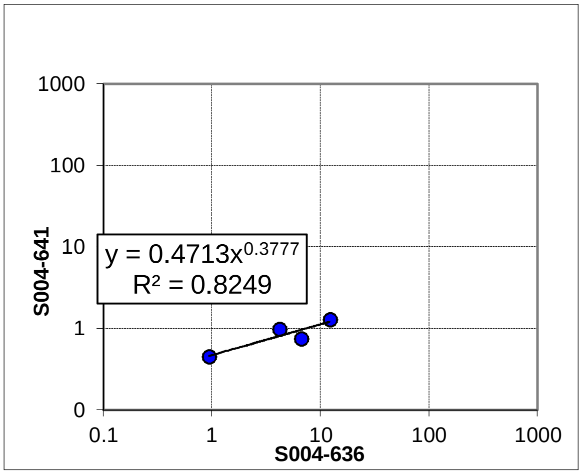











1000
100
10
1
0
0.1
1
10
100
1000
S004-641
S004-636
y = 0.4713x^0.3777
R² = 0.8249

Appendix B: Historic Lake Water Quality Sampling

Appendix B: Historic Lake Water Quality Sampling

Ann Lake

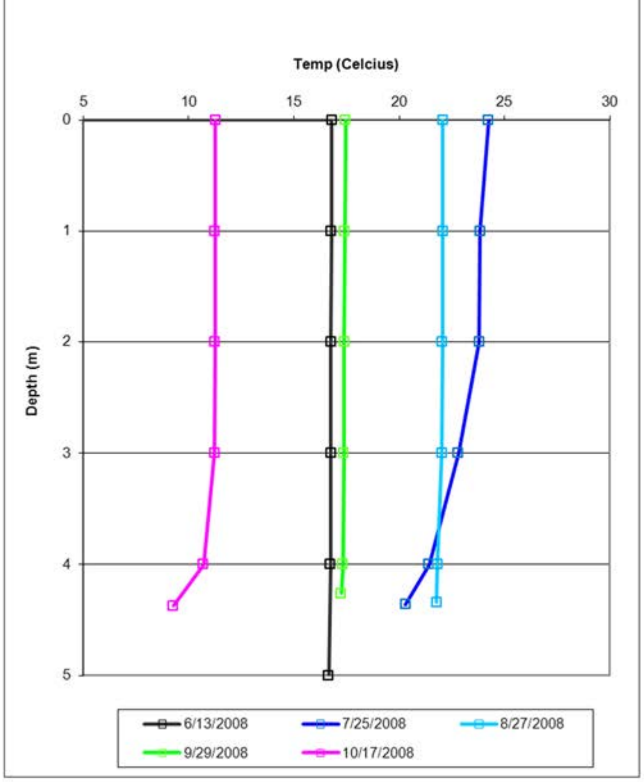
Year	Secchi		Chl a		TP		TKN		TSS	
	N	**Ave (m)**	**N**	**Ave (µg/L)**	**N**	**Ave (µg/L)**	**N**	**Ave (mg/L)**	**N**	**Ave (mg/L)**
1990	--	--	--	--	--	--	--	--	--	--
1991	--	--	--	--	--	--	--	--	--	--
1992	--	--	--	--	--	--	--	--	--	--
1993	4	1.05	4	40	4	70	4	1.32	4	9
1994	--	--	--	--	--	--	--	--	--	--
1995	--	--	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--	--	--
1998	10	0.93	3	46	3	110	--	--	--	--
1999	--	--	4	23	4	81	--	--	--	--
2000	--	--	3	76	3	121	--	--	--	--
2001	2	0.54	2	49	2	104	--	--	--	--
2002	3	0.61	3	36	3	87	--	--	--	--
2003	4	1.03	1	4	1	63	--	--	--	--
2004	8	0.91	--	--	--	--	--	--	--	--
2005	6	0.95	--	--	--	--	--	--	--	--
2006	7	0.72	--	--	--	--	--	--	--	--
2007	7	1.04	--	--	1	3,265	--	--	--	--
2008	16	0.90	8	38	9	94	8	1.24	8	9
2009	18	1.08	9	25	9	83	9	1.39	9	11
2010	6	1.01	4	39	4	59	--	--	--	--

Fish Lake

Year	Secchi		Chl a		TP		TKN		TSS	
	N	Ave (m)	N	Ave (µg/L)	N	Ave (µg /L)	N	Ave (mg/L)	N	Ave (mg/L)
1990	--	--	--	--	--	--	--	--	--	--
1991	17	0.60	--	--	--	--	--	--	--	--
1992	20	0.48	3	116	3	155	3	2.1	3	28
1993	13	0.68	4	77	4	100	4	1.8	4	14
1994	14	0.63	--	--	--	--	--	--	--	--
1995	--	--	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--	--	--
1998	5	0.55	3	58	3	378	--	--	--	--
1999	--	--	2	70	2	115	--	--	--	--
2000	--	--	2	80	2	124	--	--	--	--
2001	--	--	1	74	1	92	--	--	--	--
2002	2	0.55	2	51	2	150	--	--	--	--
2003	4	1.18	1	8	1	142	--	--	--	--
2004	4	1.00	1	62	1	2,252	1	33.46	1	659
2005	3	0.85	--	--	--	--	--	--	--	--
2006	4	0.69	--	--	--	--	--	--	--	--
2007	15	0.55	--	--	1	1,530	--	--	--	--
2008	11	0.73	8	54	8	112	8	1.45	8	14
2009	14	0.74	8	37	8	108	8	1.71	8	18
2010	20	0.94	4	40	4	61	--	--	--	--

Appendix C: Temperature and Dissolved Oxygen Profiles

Appendix C: Temperature and Dissolved Oxygen Profiles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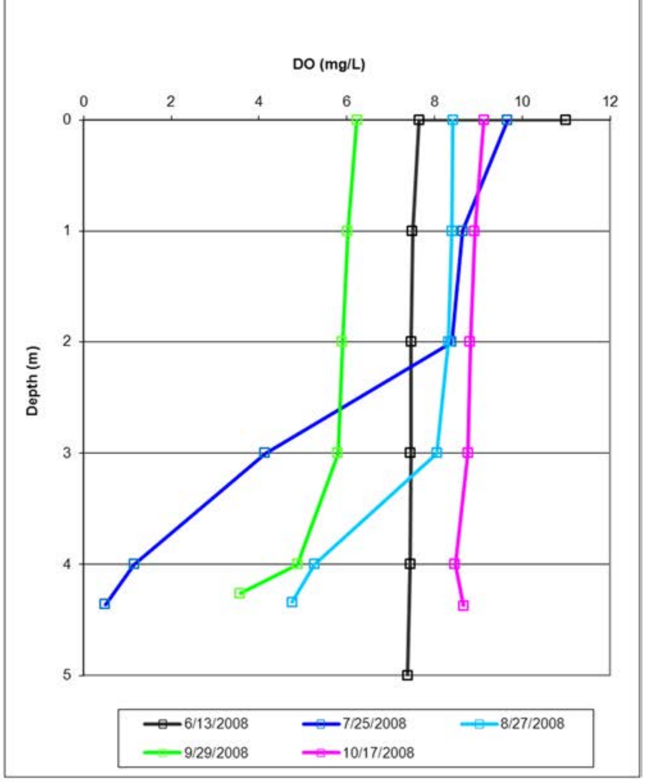
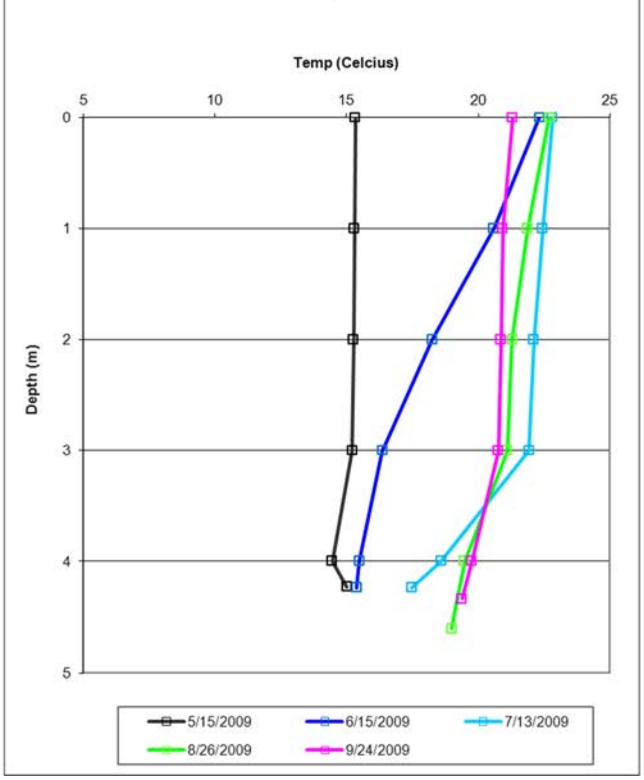

Ann Lake 2008 Dissolved Oxygen Profiles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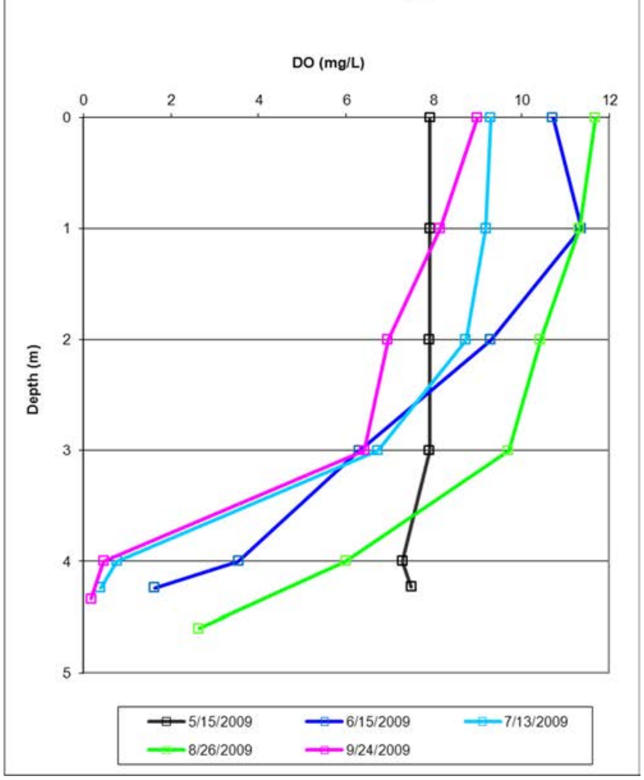
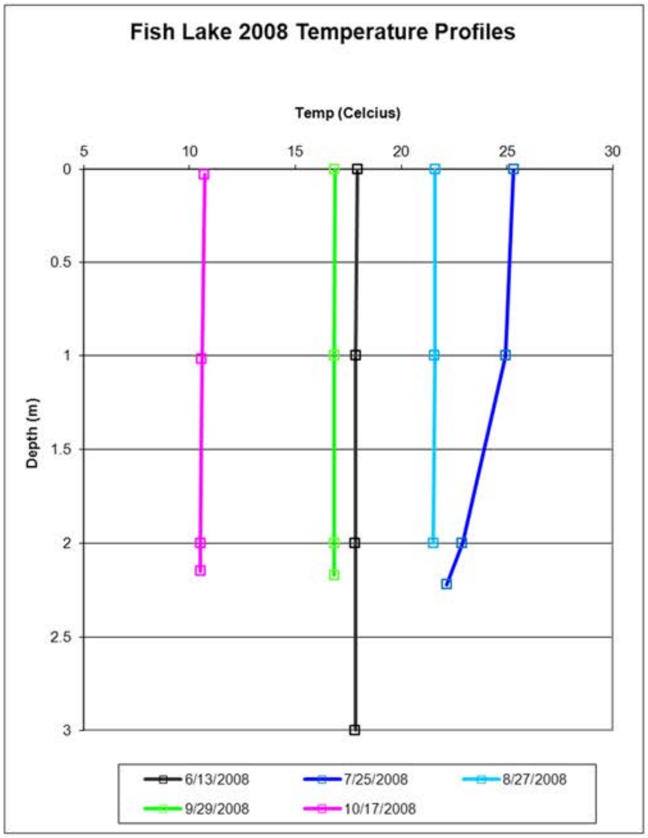
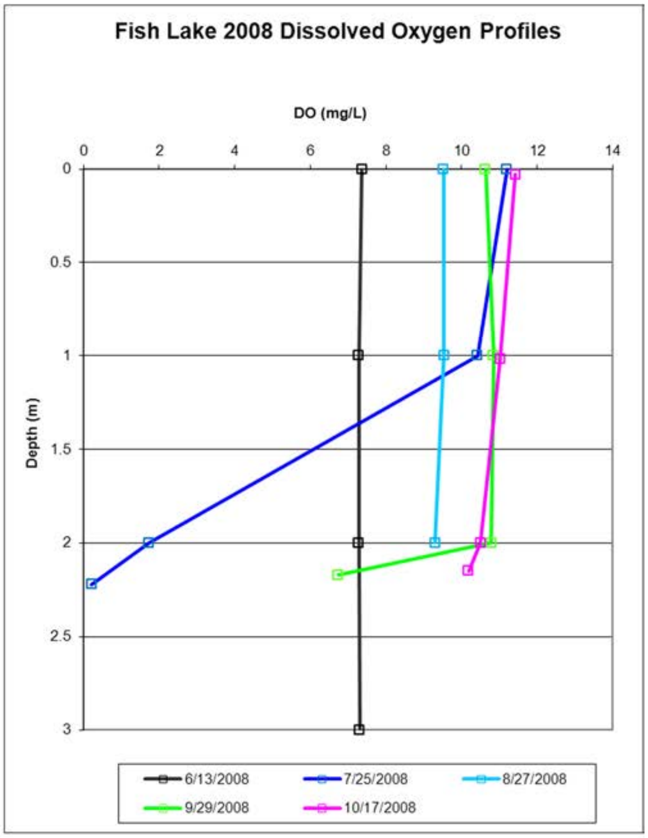
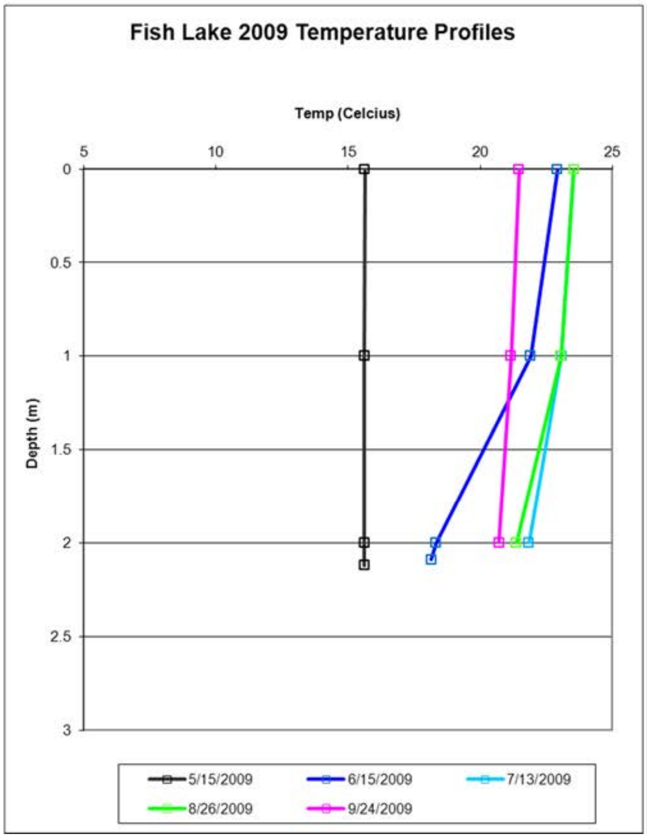
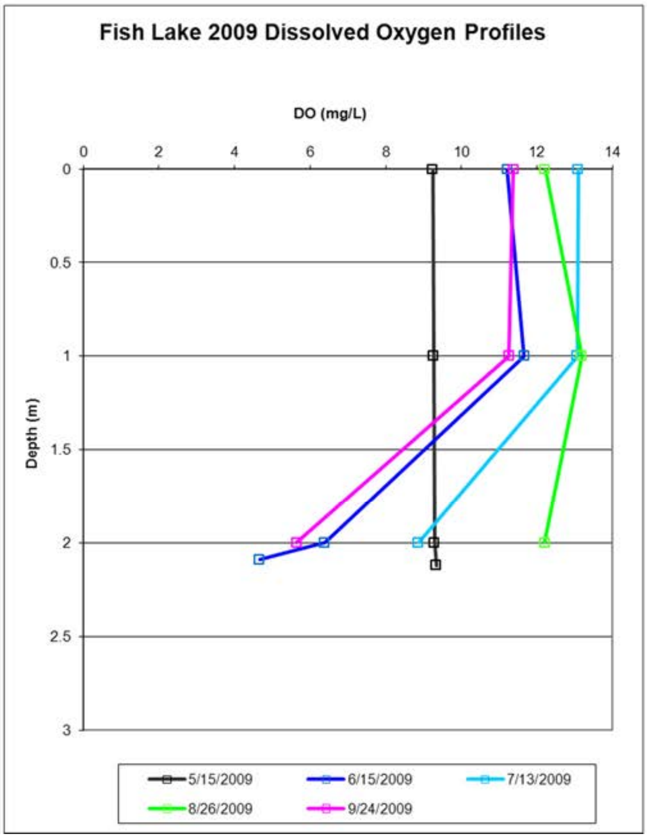

Ann Lake 2009 Dissolved Oxygen Profiles


Fish Lake 2008 Temperature Profiles

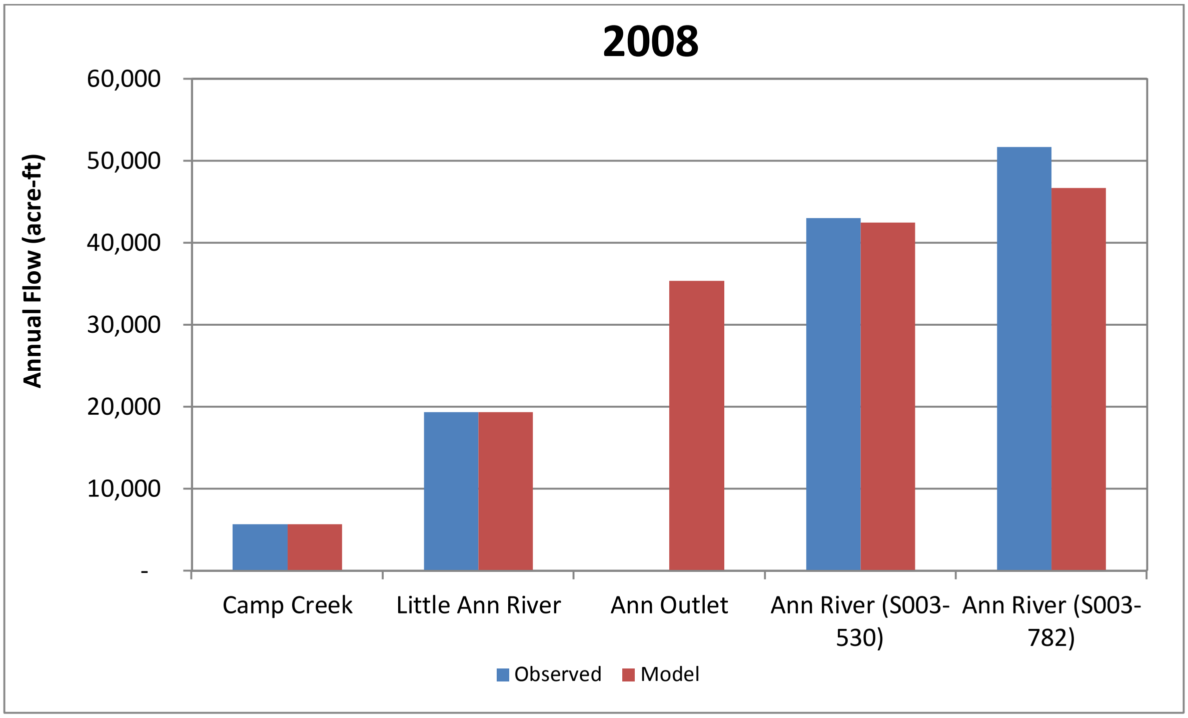

Fish Lake 2008 Dissolved Oxygen Profiles

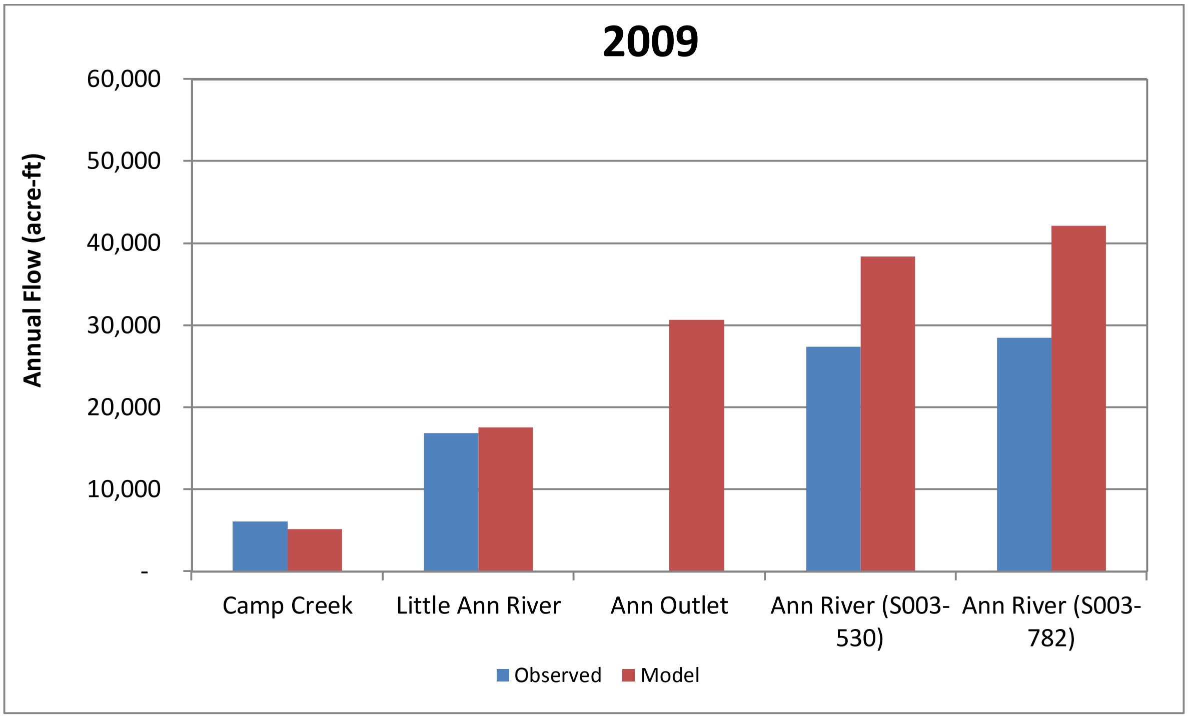

Fish Lake 2009 Temperature Profiles


Fish Lake 2009 Dissolved Oxygen Profiles

Appendix D: Watershed Runoff Model Calibration

Appendix D: Watershed Runoff Model Calibration





Appendix E: Unit Area Load Model HRU Loading Rates

Appendix E: Unit Area Load Model HRU Loading Rates

Landuse	Slope (%)	Delivery Potential (Erosion Potential-water capacity)	P-Loading (lbs/acre/year)
Alfalfa/Wheat/Rye	<4	Low-Low	0.9
		Low-Moderate	0.9
		Low-High	0.9
		Moderate Low	0.9
		Moderate-Moderate	0.9
		Moderate-High	1.2
		High-Low	0.9
		High-Moderate	1.2
		High-High	1.2
	4-8	Low-Low	0.9
		Low-Moderate	0.9
		Low-High	1.2
		Moderate-low	0.9
		Moderate-Moderate	1.2
		Moderate-High	1.5
		High-Low	1.2
		High-Moderate	1.5
		High-High	1.5
	>8	Low-Low	1.2
		Low-Moderate	1.5
		Low-High	1.5
		Moderate-Low	1.5
		Moderate-Moderate	1.5
		Moderate-High	2.3
		High-Low	1.5
		High-Moderate	2.3
		High-High	2.3
Corn/Soybean	<4	Low-Low	1.3
		Low-Moderate	1.3
		Low-High	1.3
		Moderate Low	1.3
		Moderate-Moderate	1.3
		Moderate-High	3.1
		High-Low	1.3
		High-Moderate	3.1
		High-High	3.1
	4-8	Low-Low	1.3
		Low-Moderate	1.3

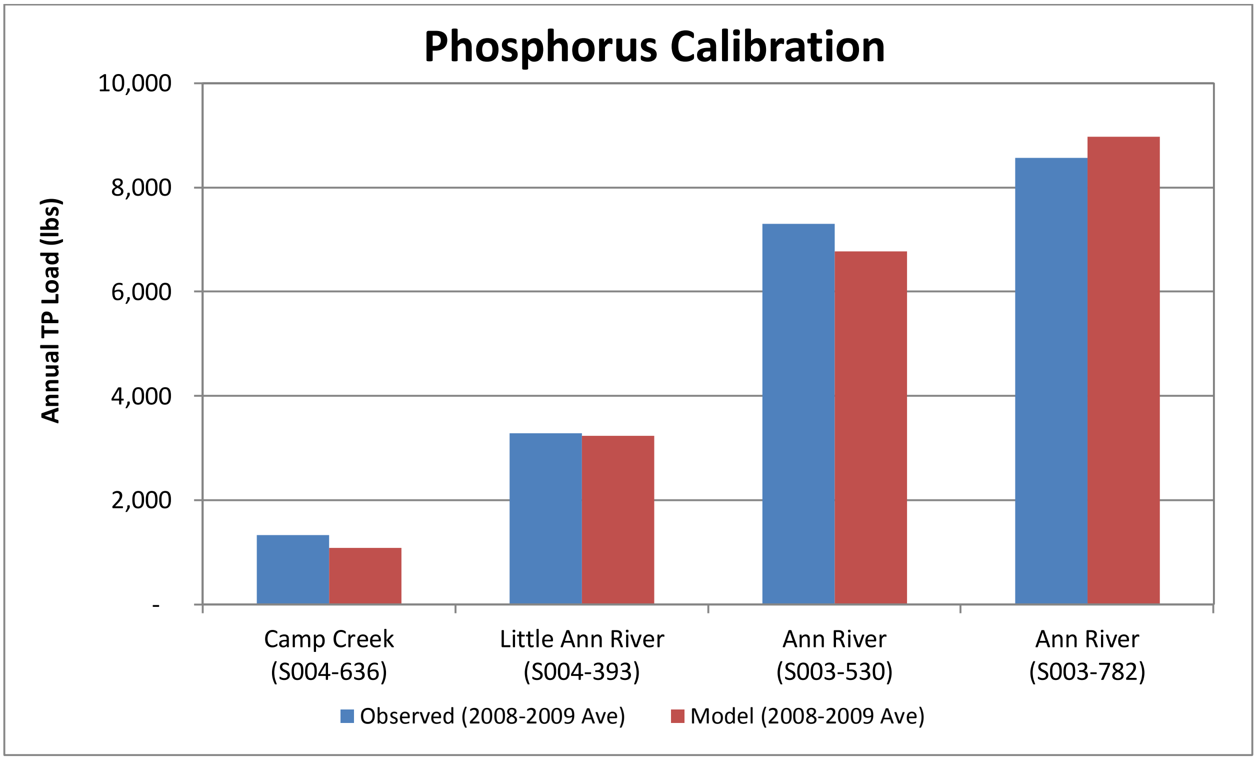
Landuse	Slope (%)	Delivery Potential (Erosion Potential-water capacity)	P-Loading (lbs/acre/year)
Corn/Soybean	4-8	Low-High	3.1
		Moderate-low	1.3
		Moderate-Moderate	3.1
		Moderate-High	4.3
		High-Low	3.1
		High-Moderate	4.3
		High-High	4.3
	>8	Low-Low	3.1
		Low-Moderate	4.3
		Low-High	4.3
		Moderate-Low	4.3
		Moderate-Moderate	4.3
		Moderate-High	5.5
		High-Low	4.3
		High-Moderate	5.5
		High-High	5.5
General Agriculture	<4	Low-Low	0.7
		Low-Moderate	0.7
		Low-High	0.7
		Moderate Low	0.7
		Moderate-Moderate	0.7
		Moderate-High	1.5
		High-Low	0.7
		High-Moderate	1.5
		High-High	1.5
	4-8	Low-Low	0.7
		Low-Moderate	0.7
		Low-High	1.5
		Moderate-low	0.7
		Moderate-Moderate	1.5
		Moderate-High	2.2
		High-Low	1.5
		High-Moderate	2.2
		High-High	2.2
	>8	Low-Low	1.5
		Low-Moderate	2.2
		Low-High	2.2
		Moderate-Low	2.2
		Moderate-Moderate	2.2

Landuse	Slope (%)	Delivery Potential (Erosion Potential-water capacity)	P-Loading (lbs/acre/year)
General Agriculture	>8	Moderate-High	2.8
		High-Low	2.2
		High-Moderate	2.8
		High-High	2.8
Pasture/Hay	<4	Low-Low	0.1
		Low-Moderate	0.1
		Low-High	0.1
		Moderate Low	0.1
		Moderate-Moderate	0.1
		Moderate-High	0.3
		High-Low	0.1
		High-Moderate	0.3
		High-High	0.3
	4-8	Low-Low	0.1
		Low-Moderate	0.1
		Low-High	0.3
		Moderate-low	0.1
		Moderate-Moderate	0.3
		Moderate-High	0.8
		High-Low	0.3
		High-Moderate	0.8
		High-High	0.8
	>8	Low-Low	0.3
		Low-Moderate	0.8
		Low-High	0.8
		Moderate-Low	0.8
		Moderate-Moderate	0.8
		Moderate-High	1.3
		High-Low	0.8
		High-Moderate	1.3
		High-High	1.3
Forested			0.170
High Density Urban			1.3
Medium Density Urban			1.0
Low Density Urban			0.1
Transportation			1.3
Wetlands/Open Water			0.0

Note: A calibration factor of 1.4 was applied to literature loading rates in order to adjust model loads to match observed loads

Appendix F: Unit Area Load Model Calibration

Appendix F: Unit Area Load Model Calibration



Note: Observed phosphorus loads were calculated by multiplying annual flow volumes (modeled) by monitored flow weighted mean TP concentrations

Appendix G: Watershed Runoff and Phosphorus Loads by Subwatershed

Appendix G: Watershed Runoff and Phosphorus Loads by Subwatershed

Subwatershed	**2008**		**2009**	
	Runoff (acre-ft)	**TP Load (lbs)**	**Runoff (acre-ft)**	**TP Load (lbs)**
Little Ann River	20,578	3,525	18,639	3,598
Camp Creek	5,688	1,144	5,163	1,193
West Wetland (Ann)	1,300	219	1,183	200
Spring Brook	2,184	273	1,960	256
East Trib. (Ann)	3,788	1,102	3,422	558
*Ann Lake Direct	1,820	348	1,561	348
Ann Lake Total	**35,358**	**6,611**	**31,928**	**6,158**
Ann River	11,336	4,047	10,225	4,047
West Wetland (Fish)	2,588	303	2,306	314
Devil's Lake	1,120	165	983	144
*Turner Rd. Trib.	724	477	659	477
*Fish Lake Direct	1,247	340	1,063	340
Fish Lake Total	**17,015**	**5,332**	**15,236**	**5,322**

*Phosphorus load estimated using UAL phosphorus model (no monitored TP data available)

Appendix H: Ann Lake Internal Phosphorus Loading Study

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Ann Lake, Minnesota

22 April, 2011

William F. James
ERDC Eau Galle Aquatic Ecology Laboratory
W. 500 Eau Galle Dam Road
Spring Valley, Wisconsin 54767

OBJECTIVES

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

APPROACH

Laboratory-derived rates of P release from sediment under oxic and anoxic conditions: Replicate sediment cores were collected by Wenck Associates from stations located in the central basin of Ann Lake in February, 2011, for determination of rates of P release from sediment under oxic and anoxic conditions. All cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from each lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 to 25 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling air (oxic) or nitrogen (anoxic) through an air stone placed just above the sediment surface in each system.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005).

Rates of P release from the sediment (mg m^{-2} d^{-1}) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: The upper 10 cm of an additional core collected from the lake was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P, total nitrogen (N), total iron (Fe), total manganese (Mn), and total calcium (Ca; all expressed at mg/g). A known volume of sediment was dried at 105 ^{o}C for determination of moisture content and sediment density and burned at 500 ^{o}C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total N, P, Fe, Mn and Ca using standard methods (Plumb 1980; APHA 2005).

Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

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

RESULTS AND INTERPRETATION

Phosphorus mass and concentration increased linearly and rapidly in the overlying water column of sediment systems maintained under anoxic conditions during the first 7 days of incubation, then leveled off and remained either constant or declined slightly until the end of the study period (Figure 1). Maximum concentrations of soluble reactive P approached 1.5 $mg \cdot L^{-1}$ near the end of the study. The mean anoxic P release rate was high at 15.0 (± 2.5 S.E.) $mg \cdot m^{-2} \cdot d^{-1}$ and fell above the upper quartile compared to the median anoxic P release rate measured in other eutrophic systems in the Minneapolis-St. Paul regional area (Figure 2).

Under oxic conditions, soluble reactive P mass and concentration increased linearly during the first 25 days of incubation, and then declined slightly until the end of the study (Figure 3). Mass and concentration increases in the overlying water column were much lower compared to anoxic incubations. However, soluble reactive P concentrations approached 0.10 $mg \cdot L^{-1}$ in the overlying water by day 25 of incubation. The mean oxic P release rate of 0.2 (± <0.1 S.E.) was similar to the median rate measured for other eutrophic systems in the Minneapolis-St. Paul regional area (Figure 2).

The sediment at the central station in Ann Lake exhibited a high moisture content and low sediment density, indicating fine-grained, flocculent sediment (Table 1). Loss-on-ignition organic matter content was moderate at 18%. The total P concentration of the sediment was relatively high at 1.82 $mg \cdot g^{-1}$ (Table 2) and fell above the upper quartile when compared to other eutrophic lakes in the region (Figure 4).

The biologically-labile (i.e., subject to recycling back to the overlying water column; loosely-bound P, iron-bound P, and labile organic P) P concentration accounted for ~ 58% of the total sediment P (Figure 5; Table 2). Redox-sensitive P (i.e., active in anoxic P release from the sediment; loosely-bound and iron-bound P) represented most of the biologically-labile P (93%) and 54% of the total P (Table 2). Iron-bound P dominated the biologically-labile P fraction at ~88% and the concentration fell well above the upper quartile compared to other lakes in the region (Figure 4). Loosely-bound P and labile organic P represented ~5 and 7% of the biologically-labile P, respectively.

Biologically-refractory sediment P (i.e., more inert to recycling and subject to burial; aluminum-bound P, calcium-bound P, and refractory organic P) represented 42% of the total sediment P (Figure 5; Table 2). Aluminum-bound P accounted for 44%, and calcium-bound P and refractory organic P fraction each accounted for ~23 and 33% of the biologically-refractory P.

Ann Lake sediment exhibited a high total Fe concentration (Table 2) which fell above the upper quartile compared to other lake sediments in the region (Figure 6). Concentrations of sediment total Ca were very low at 7.0 $mg \cdot g^{-1}$ (Table 2), relative to other lakes in the region (Figure 6). The sediment total Fe:P ratio was high at 18 (Table 2). Ratios > 10 have been associated with regulation of P release from sediments under oxic conditions (Jensen et al. 1992).

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Psenner, R., and Puckso, R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Biel. Erg. Limnol. 30:43-59.

Table 1. Textural characteristics for sediments collected in Ann Lake.

Station	Moisture Content (%)	Bulk Density (g/cm^3)	Sediment Density (g/cm^3)	Loss-on-ignition (%)
Central	85.2	1.080	0.174	18.3

Table 2. Mean (1 standard error in parentheses; n=2 to 3) rates of phosphorus (P) release, concentrations of biologically labile and refractory P, and metals concentrations for sediments collected in Ann Lake. DW = dry mass, FW = fresh mass, N = nitrogen, Fe = iron, Mn = manganese, Ca = calcium.

Station	Diffusive P Flux		Redox-sensitive and biologically labile P				Refractory P		
	Oxic (mg m^{-2} d^{-1})	Anoxic (mg m^{-2} d^{-1})	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (mg/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
Central	0.2 (<0.1)	15.0 (2.5)	0.050	0.934	135	0.073	0.332	0.177	0.252

Station	Total P	Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Central	1.818	0.984	54.1%	1.057	58.1%	0.761	41.9%

Station	Total N (mg/g DW)	Total Fe (mg/g DW)	Total Mn (mg/g DW)	Total Ca (mg/g DW)	Fe:P
Central	7.858	33.31	1.11	6.97	18.3

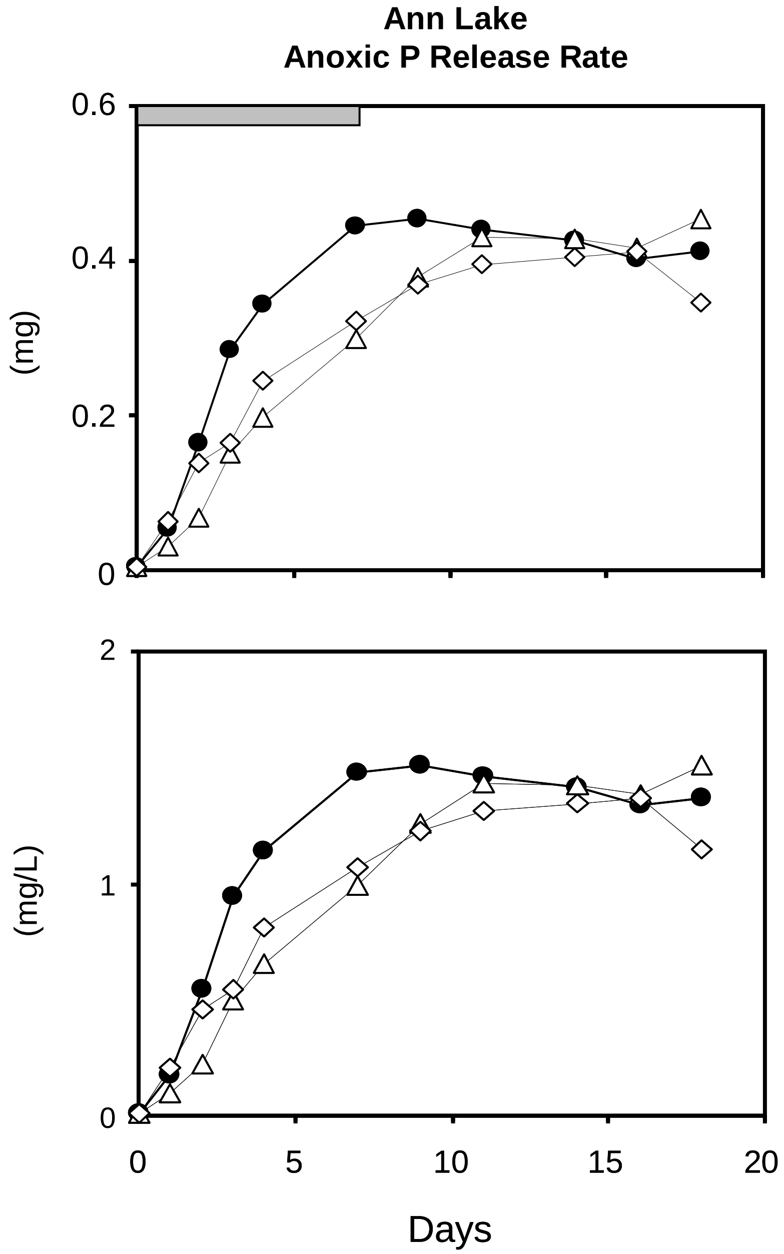

Figure 1. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under anoxic conditions versus time for sediment cores collected in Ann Lake. Grey horizontal bar denotes region of linear increase in phosphorus concentration used in the calculation of rates.

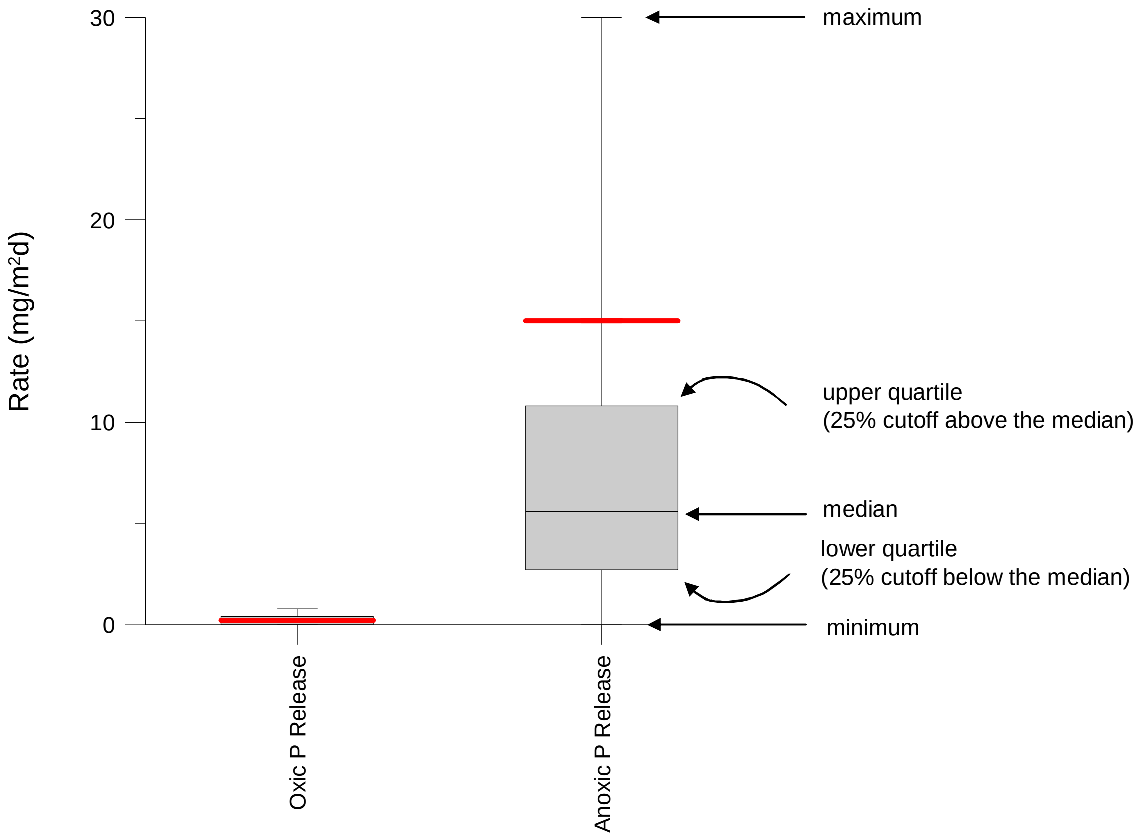

Figure 2. Box and whisker plot comparing the oxic and anoxic phosphorus (P) release rate measured for Ann Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area.

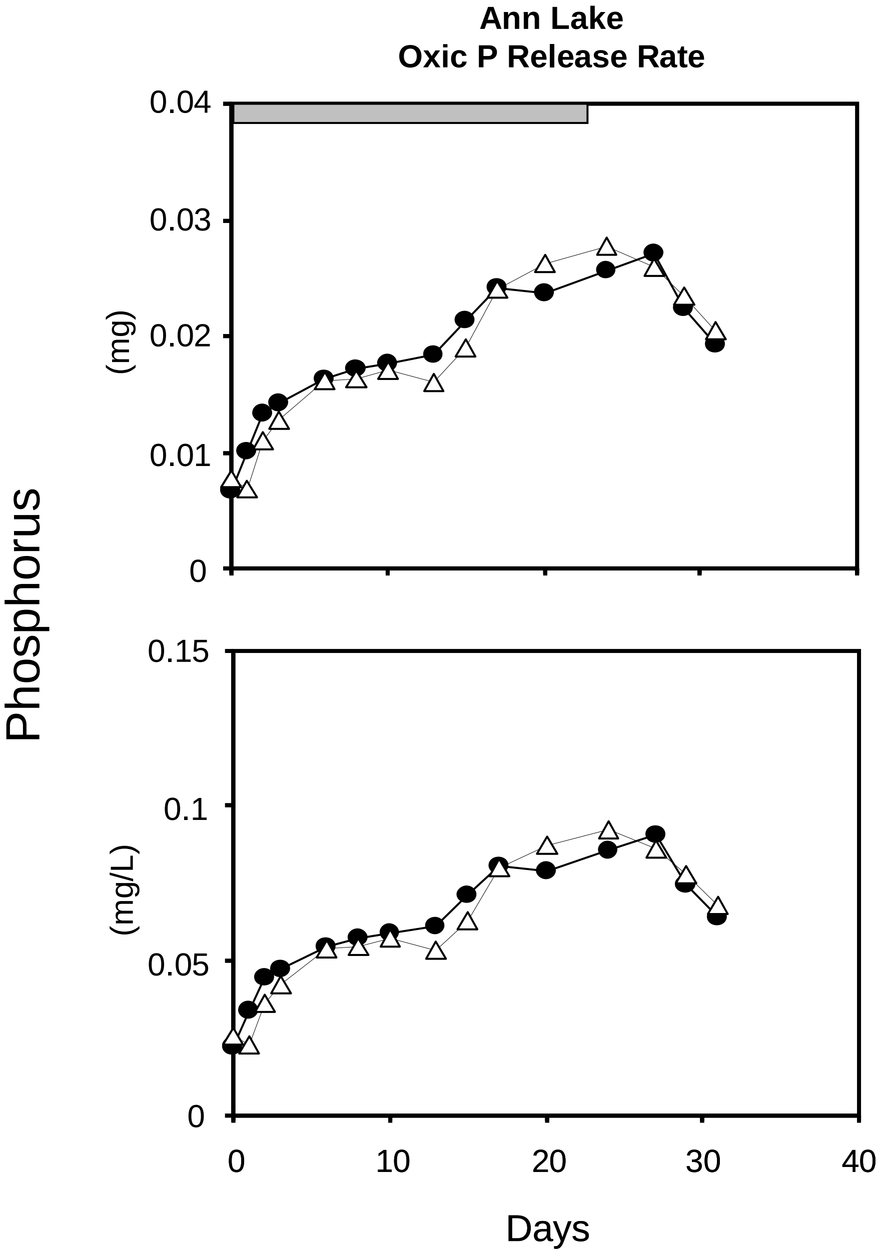

Figure 3. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under oxic conditions versus time for sediment cores collected in Ann Lake. Grey horizontal bar denotes region of linear increase in phosphorus concentration used in the calculation of rates.

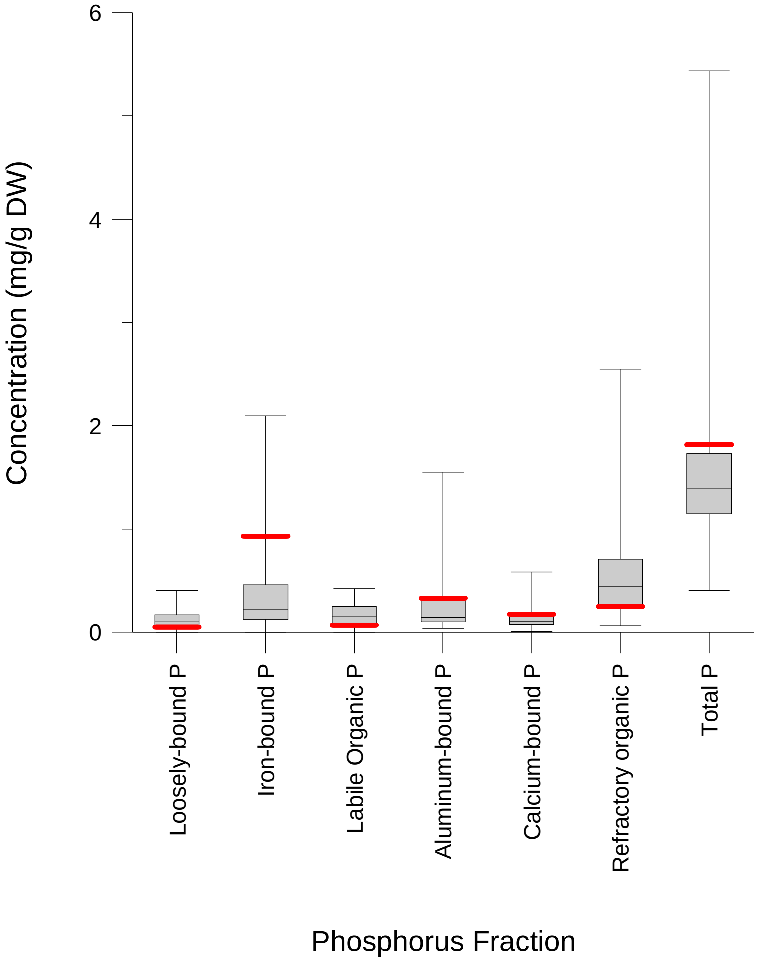

Figure 4. Box and whisker plots comparing various sediment phosphorus (P) fractions measured for Ann Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area. Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling) and aluminum-bound, calcium-bound, and refractory organic P are more are more inert to transformation (i.e., subject to burial). See Figure 2 for legend.

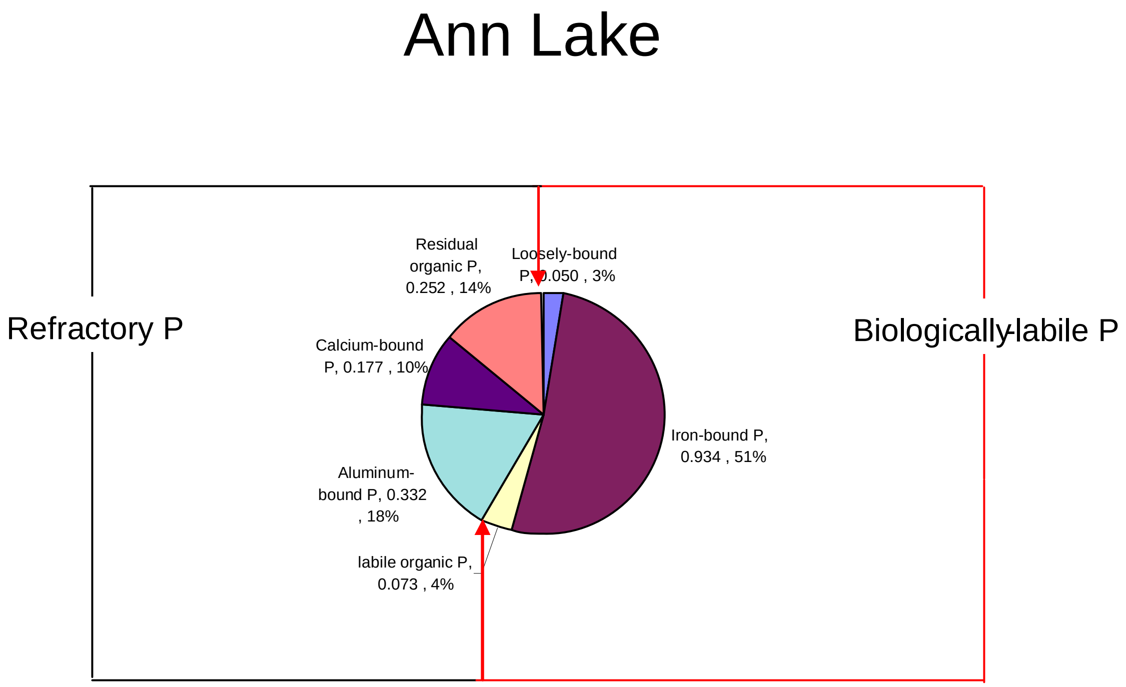

Figure 5. Total phosphorus (P) composition for sediment collected in Ann Lake. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration ($mg \cdot g^{-1}$) and percent total P, respectively.

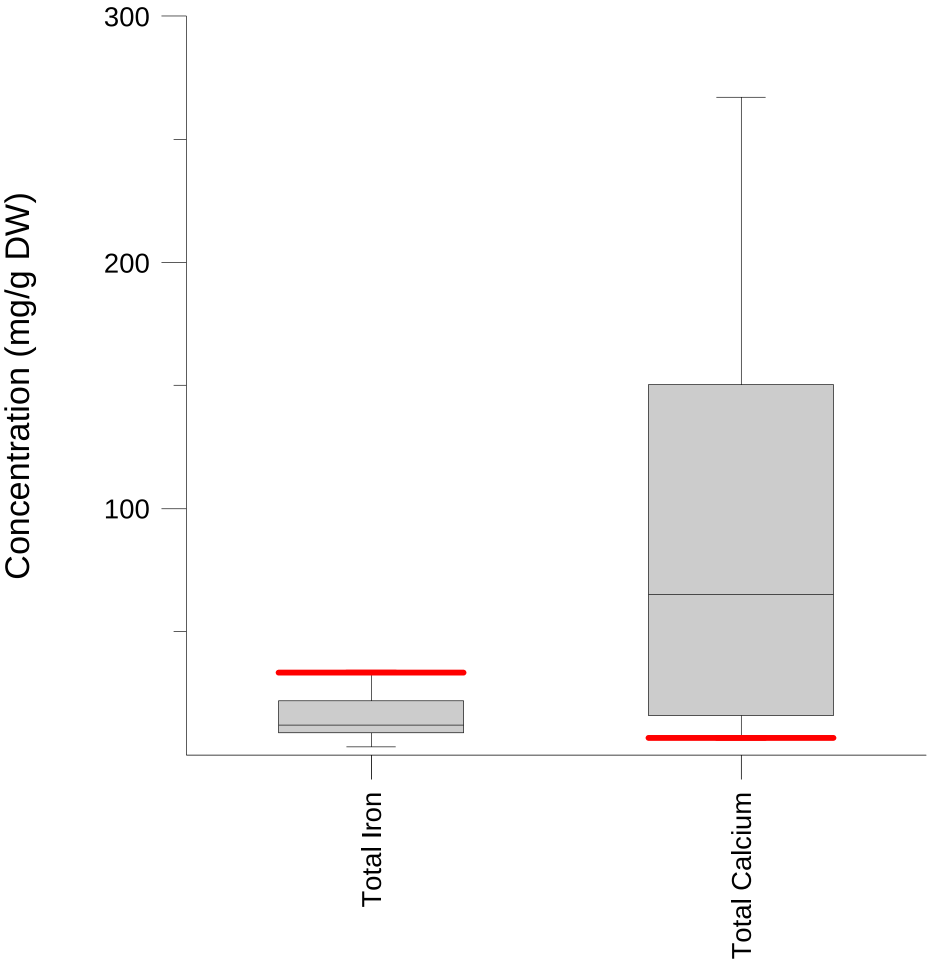

Figure 6. Box and whisker plots comparing sediment total iron and calcium concentrations measured for Ann Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area. See Figure 2 for legend.

Appendix I: Fish Lake Internal Phosphorus Loading Study

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Fish Lake, Minnesota

22 April, 2011

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OBJECTIVES

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

APPROACH

Laboratory-derived rates of P release from sediment under oxic and anoxic conditions: Replicate sediment cores were collected by Wenck Associates from a central station in Fish Lake in February, 2011, for determination of rates of P release from sediment under oxic (triplicates) and anoxic (triplicates) conditions. All cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from each lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 to 25 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling air (oxic) or nitrogen (anoxic) through an air stone placed just above the sediment surface in each system.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005).

Rates of P release from the sediment (mg m^{-2} d^{-1}) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: The upper 10 cm from an additional core collected from the lake was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P, total nitrogen (N), total iron (Fe), total manganese (Mn), and total calcium (Ca; all expressed at mg/g). A known volume of sediment was dried at 105 ^{o}C for determination of moisture content and sediment density and burned at 500 ^{o}C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total N, P, Fe, Mn and Ca using standard methods (Plumb 1980; APHA 2005). Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

RESULTS AND INTERPRETATION

Phosphorus mass and concentration increased linearly in the overlying water column of sediment systems incubated under anoxic conditions over a 15 day period (Figure 1). The soluble reactive P concentration increased to greater than 0.60 to 1.00 mg·L^{-1} in replicate incubation systems by day 15. The mean anoxic P release rate was 5.4 (± 0.8

S.E.) mg·m^{-2}·d^{-1}, which was relatively high and comparable to the median anoxic P release rate measured in other eutrophic systems in the Minneapolis-St. Paul regional area (Figure 2). Under oxic conditions, soluble reactive P mass and concentration initially declined in the overlying water column to near zero, then increased linearly between ~ day 15 and 30, depending on the replicate core (Figure 3). Mass and concentration increases were much lower compared to anoxic incubations. The soluble reactive P concentration approached or exceeded 0.025 to 0.030 mg·L^{-1} toward the end of the incubation period. The mean oxic P release rate was 0.3 (± 0.1 S.E.) mg·m^{-2}·d^{-1}, which fell slightly above the median rate measured for other eutrophic systems in the Minneapolis-St. Paul regional area (Figure 2).

The sediment at the central station in Fish Lake exhibited a high moisture content and low sediment density, indicating fine-grained, flocculent sediment (Table 1). Loss-on-ignition organic matter content was moderate at 21.2%. The total P concentration of the sediment was moderate at ~ 1.32 mg·g^{-1} (Table 2) compared to other eutrophic lakes in the region (Figure 4). The biologically-labile (i.e., subject to recycling; loosely-bound P, iron-bound P, and labile organic P) P concentration accounted for ~33% of the total sediment P (Figure 5 and Table 2). Redox-sensitive P (i.e., loosely-bound and iron-bound P) represented most of the biologically-labile P (71%) and ~ 23% of the total P (Table 2). Iron-bound P dominated both the biologically-labile P and redox-sensitive P fraction at 69% and 97%, respectively. Labile organic P represented ~ 30% of the biologically-labile P fraction. The loosely-bound P concentration was very low by comparison.

Biologically-refractory sediment P (i.e., more inert to recycling and subject to burial; aluminum-bound P, calcium-bound P, and refractory organic P) represented ~ 67% of the total sediment P (Figure 5 and Table 2). The refractory organic P fraction accounted for the greatest percentage of biologically-refractory P (63%). Aluminum-bound P and calcium-bound P accounted for 14% and 23% of the biologically-refractory P. Fish Lake sediment also exhibited a high total Fe concentration (Table 2) which fell above the upper quartile compared to other lake sediments in the region (Figure 6). In contrast, concentrations of sediment total Ca were moderately low at 18.5 mg·g^{-1} (Table 2), relative to other lakes in the region (Figure 6). The sediment total Fe:P ratio was very high at 43.5 (Table 2). Ratios > 10 have been associated with regulation of P release from sediments under oxic conditions (Jensen et al. 1992).

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Psenner, R., and Puckso, R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Biel. Erg. Limnol. 30:43-59.

Table 1. Textural characteristics for sediments collected in Fish Lake.

Station	Moisture Content (%)	Bulk Density (g/cm^3)	Sediment Density (g/cm^3)	Loss-on-ignition (%)
Central	87.5	1.065	0.134	21.2

Table 2. Mean (1 standard error in parentheses; n=3) rates of phosphorus (P) release, concentrations of biologically labile and refractory P, and metals concentrations for sediments collected in Fish Lake. DW = dry mass, FW = fresh mass, N = nitrogen, Fe = iron, Mn = manganese, Ca = calcium.

Station	Diffusive P Flux		Redox-sensitive and biologically labile P				Refractory P		
	Oxic (mg m^{-2} d^{-1})	Anoxic (mg m^{-2} d^{-1})	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (mg/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
Central	0.3 (<0.1)	5.4 (0.8)	0.009	0.298	37	0.127	0.126	0.200	0.560

Station	Total P	Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	(mg/g DW)	(%)	(mg/g DW)	(%)	(mg/g DW)	(%)
Central	1.319	0.307	23.3%	0.434	32.9%	0.886	67.1%

Station	Total N (mg/g DW)	Total Fe (mg/g DW)	Total Mn (mg/g DW)	Total Ca (mg/g DW)	Fe:P
Central	9.774	57.39	1.62	18.48	43.5

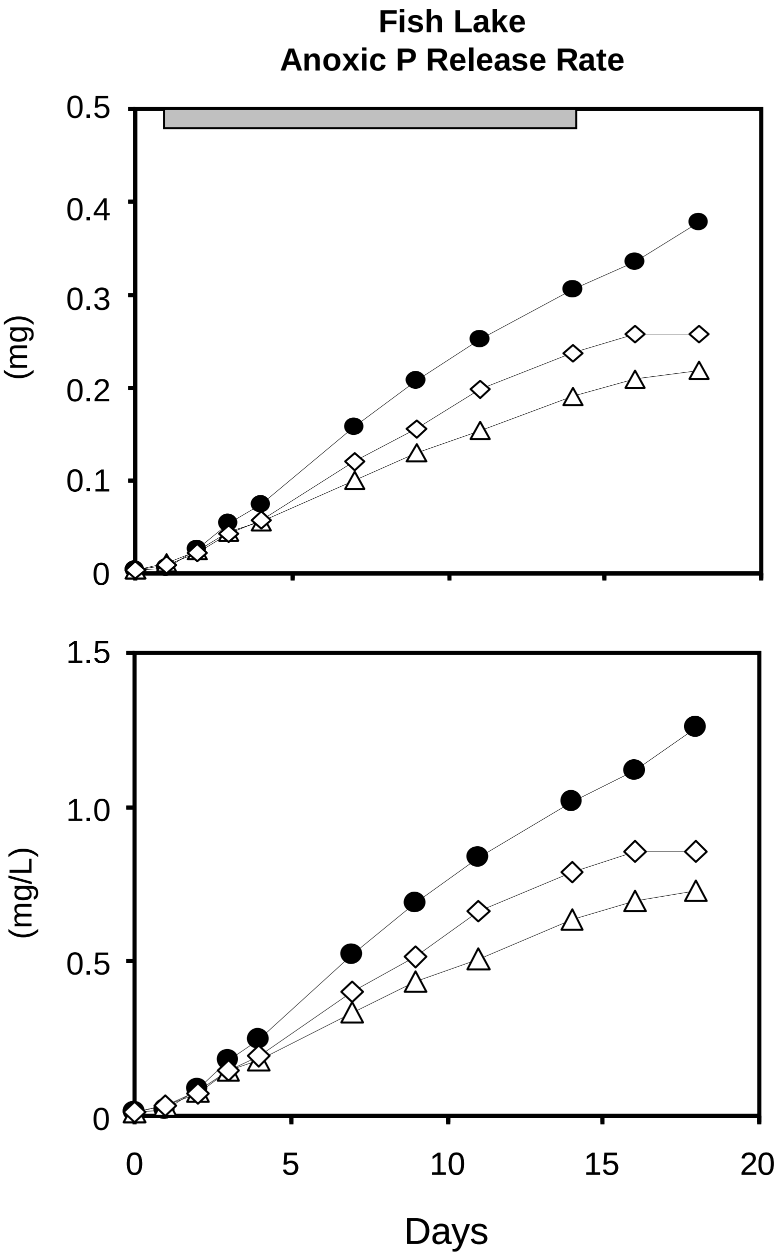

Figure 1. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under anoxic conditions versus time for sediment cores collected in Fish Lake. Grey horizontal bar denotes region of linear increase in phosphorus concentration used in the calculation of rates.

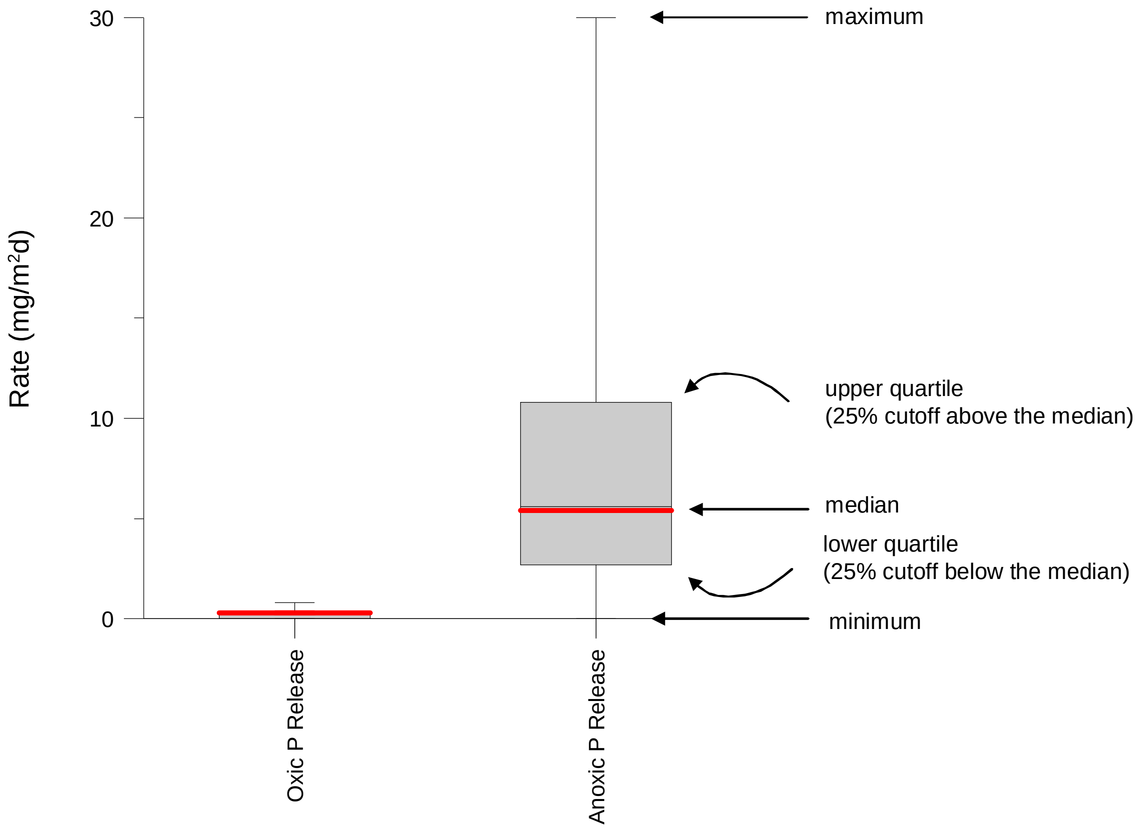

Figure 2. Box and whisker plot comparing the oxic and anoxic phosphorus (P) release rate measured for Fish Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area.

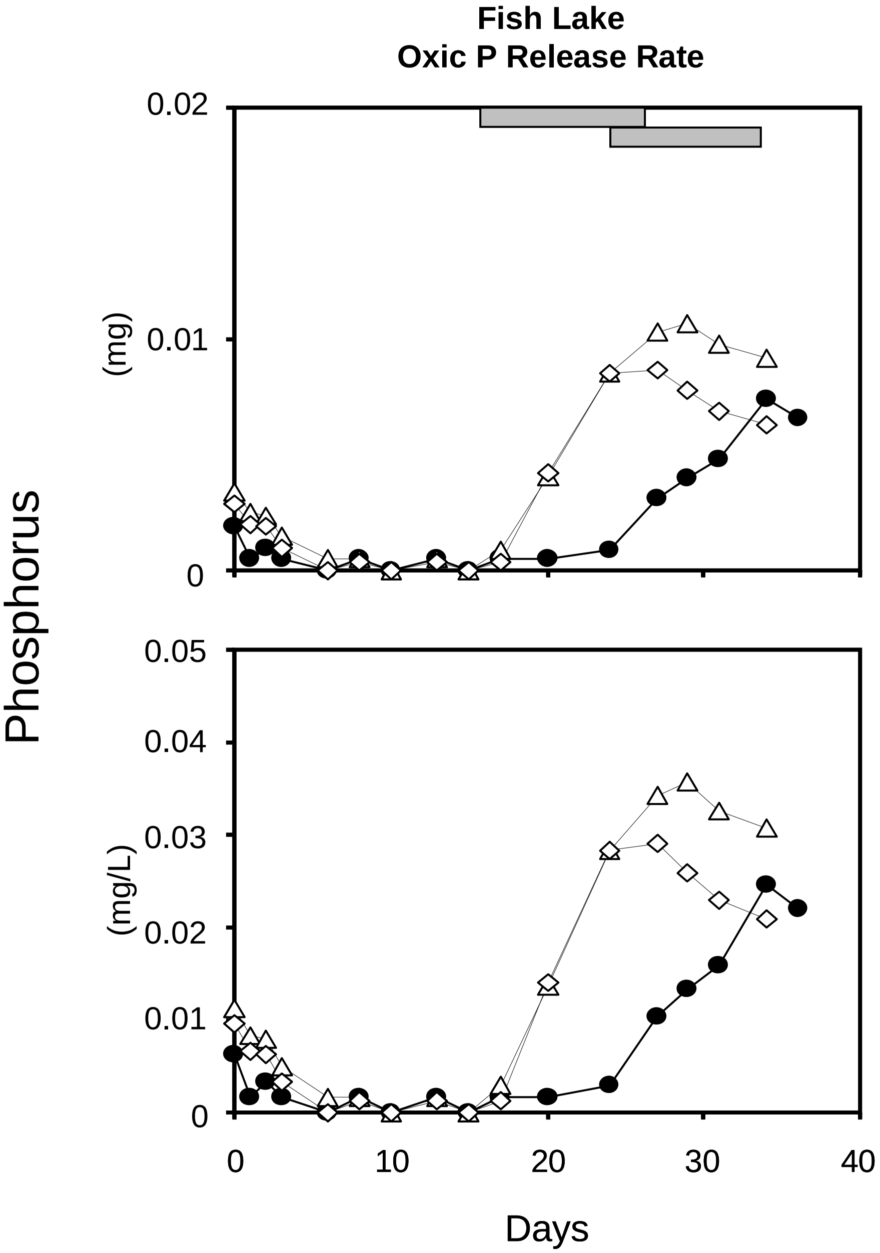

Figure 3. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under oxic conditions versus time for sediment cores collected in Fish Lake. Grey horizontal bar denotes region of linear increase in phosphorus concentration used in the calculation of rates.

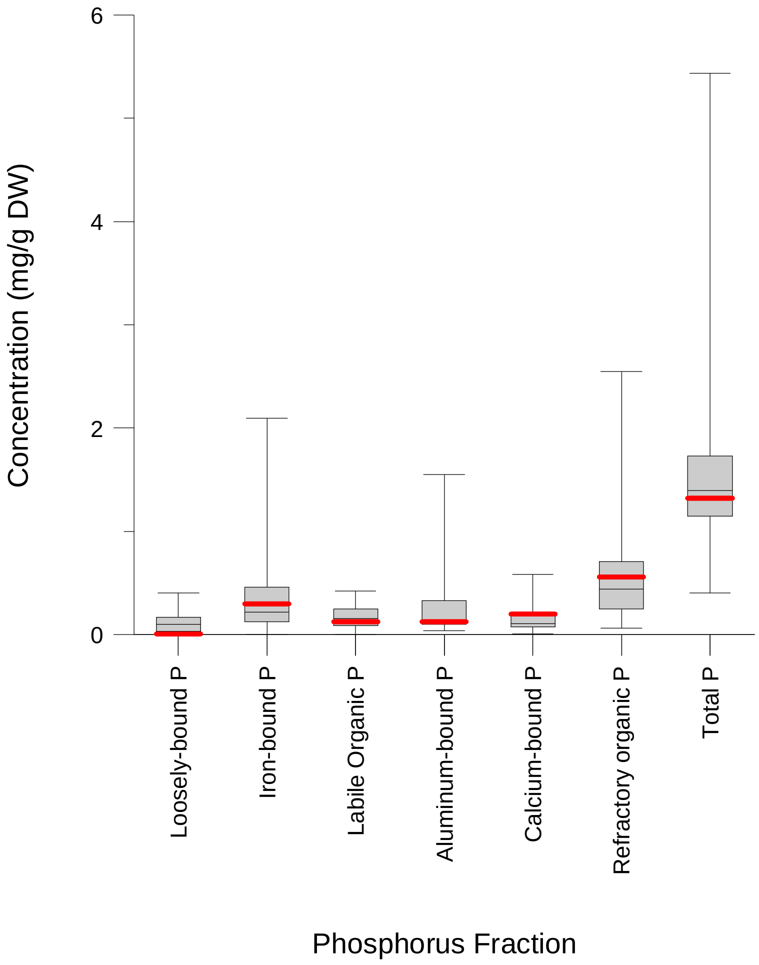

Figure 4. Box and whisker plots comparing various sediment phosphorus (P) fractions measured for Fish Lake sediments (red lines) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area. Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling) and aluminum-bound, calcium-bound, and refractory organic P are more are more inert to transformation (i.e., subject to burial). See Figure 2 for legend.

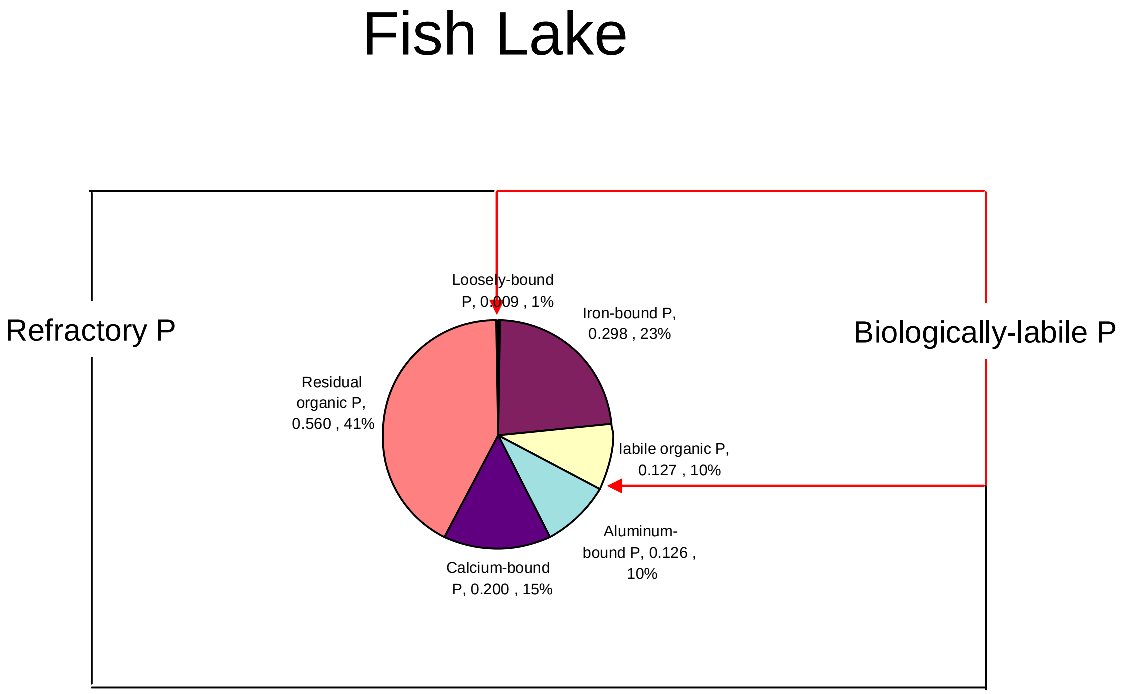

Figure 5. Total phosphorus (P) composition for sediment collected in Fish Lake. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration ($mg \cdot g^{-1}$) and percent total P, respectively.

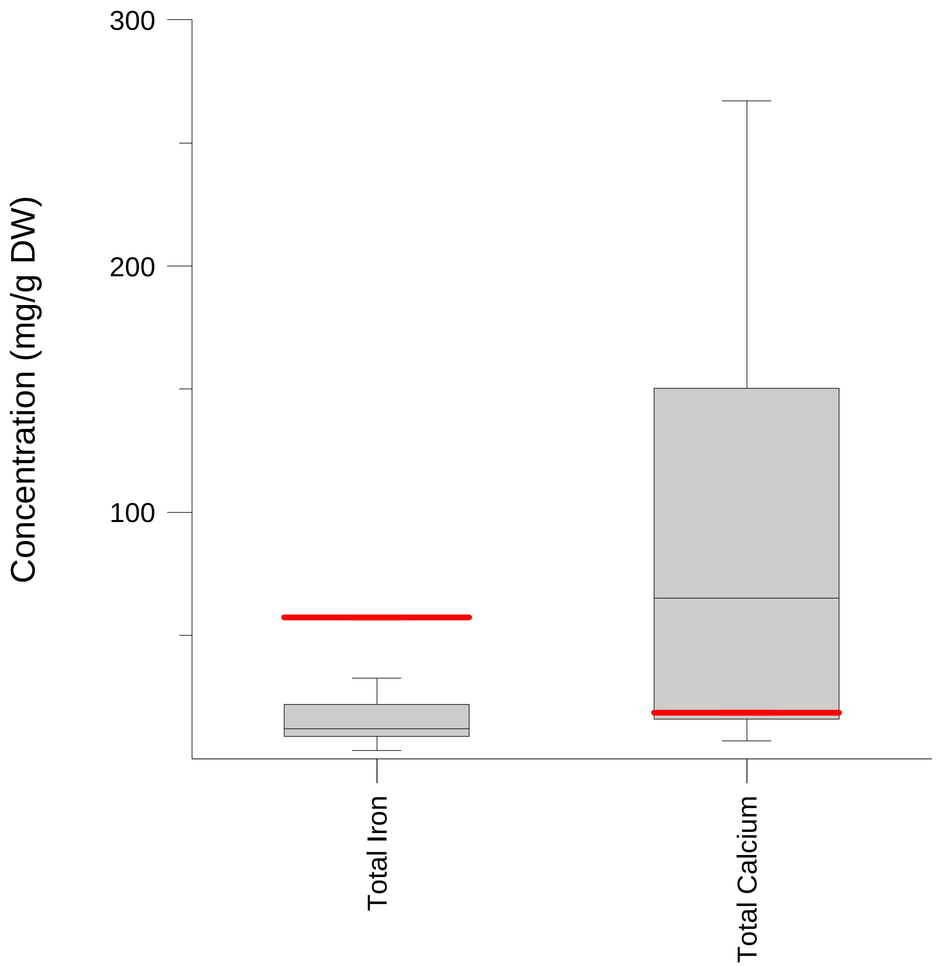

Figure 6. Box and whisker plots comparing sediment total iron and calcium concentrations measured for Fish Lake sediments (red lines) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area. See Figure 2 for legend.

Appendix J: BATHTUB Model

Average Loading Summary for Fish Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Watershed Total			15,384	120	1.0	5,014
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*0*	*0*	*15,384*	*119.8*		*5,013.7*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Ann River	2,993,856					370.0
2	West Wetland	775,724					41.0
3	SE Wetland	110,521					
4	Turner Rd. Trib.	176,475					0.0
5	Fish Direct	434,337					493.0
	Summation	*4,490,912*	*0*				*904.0*

Inflow from Upstream Lakes

	Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1		34,694.9	55.8	1.0	5,266
2			-	1.0	
3			-	1.0	
	Summation	*34,695*	*55.8*		*5,266*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
418	31.4	31.4	--	0.24	1.0	99.9

Dry-year total P deposition = 0.222
Average-year total P deposition = 0.239
Wet-year total P deposition = 0.259
(Barr Engineering 2004)

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
418	0.0	0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
418		5.40	1.0	1,425

Net Discharge [ac-ft/yr] = 50,079 | **Net Load [lb/yr] = 12,709**

NOTES

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

Average Lake Response Modeling for Fish Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	12,709	[lb/yr]
		Q (lake outflow) =	50,085	[ac-ft/yr]
		V (modeled lake volume) =	2,010	[ac-ft]
		T = V/Q =	0.04	[yr]
		P_i = W/Q =	93	[ug/l]
Model Predicted In-Lake [TP]			**93.3**	**[ug/l]**
Observed In-Lake [TP]			**107.5**	**[ug/l]**

TMDL Loading Summary for Fish Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Ann River	12,116	10.7	10,780	79	0.6	2,317
2	West Wetland	3,139	9.4	2,447	43.2	1.0	288
3	SE Wetland	447	8.3	310	56.4	1.0	48
4	Turner Rd. Trib.	714	11.6	691	76.1	0.3	143
5	Fish Direct	1,758	7.9	1,155	75.6	0.7	238
	Summation	*18,174*	*48*	*15,384*			*3,033.2*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Ann River	12,116				0.0	0.0
2	West Wetland	3,139				0.0	0.0
3	SE Wetland	447					
4	Turner Rd. Trib.	714				0.0	0.0
5	Fish Direct	1,758				0.0	0.0
	Summation	*18,174*	*0*				*0.0*

Inflow from Upstream Lakes

	Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Devil's Lake	1,052	48.6	0.9	139
2	Ann Lake	33,643.35	48.6	0.9	4,447
3			-	1.0	
	Summation	*34,695*	*48.6*		*4,586*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
418	28.0	28.0	0.00	0.24	1.0	99.9

Dry-year total P deposition = 0.222

Average-year total P deposition = 0.239

Wet-year total P deposition = 0.259

(Barr Engineering 2004)

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
418	0.0	0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]		Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
1.69	122	Oxic	0.3	1.0	136
1.69	75.5	Anoxic	1.4	1.0	323
Summation					460

Net Discharge [ac-ft/yr] =	**50,079**	**Net Load [lb/yr] =**	**8,179**

NOTES

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

TMDL Lake Response Modeling for Fish Lake

Modeled Parameter **Equation** **Parameters** **Value [Units]**

TOTAL IN-LAKE PHOSPHORUS CONCENTRATION

$$\boxed{P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}}$$

as f(W,Q,V) from Canfield & Bachmann (1981)

C_P = 0.00 [--]

C_{CB} = 0.162 [--]

b = 0.458 [--]

W (total P load = inflow + atm.) = 3,710 [kg/yr]

Q (lake outflow) = 61.8 [10^6 m^3/yr]

V (modeled lake volume) = 2.5 [10^6 m^3]

T = V/Q = 0.04 [yr]

P_i = W/Q = 60 [µg/l]

Model Predicted In-Lake [TP] **60.0** **[ug/l]**

Observed In-Lake [TP] **60.0** **[ug/l]**

Average Loading Summary for Ann Lake

Water Budgets	Phosphorus Loading

Inflow from Drainage Areas

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Watershed Total			32,402	65	1.0	5,728
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*0*	*0*	*32,402*	*65.0*		*5,728.4*

Failing Septic Systems

Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Little Ann River	4,945,320					114.0
2 Camp Creek	1,518,463					32.0
3 East Trib. Ann	862,892					56.0
4 Ann Direct	617,516					211.0
5 Spring Brook	578,968					32.0
Summation	*8,523,159*	*0*				*445.0*

Inflow from Upstream Lakes

Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1			1,241.4	62.0	1.0	209
2				-	1.0	
3				-	1.0	
Summation			*1,241*	*62.0*		*209*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
773	31.4	31.4	--	0.24	1.0	184.8
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
773	0.0		0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
773				15	1.0	5,496
		Net Discharge [ac-ft/yr] =	**33,643**		**Net Load [lb/yr] =**	**12,064**

NOTES

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

Average Lake Response Modeling for Ann Lake

Modeled Parameter	**Equation**	**Parameters**	**Value [Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	0.91 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	5,477 [kg/yr]
		Q (lake outflow) =	41.5 [10^6 m^3/yr]
		V (modeled lake volume) =	6.2 [10^6 m^3]
		T = V/Q =	0.15 [yr]
		P_i = W/Q =	132 [ug/l]
Model Predicted In-Lake [TP]			**88.5 [ug/l]**
Observed In-Lake [TP]			**88.5 [ug/l]**

TMDL Loading Summary for Ann Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Little Ann River	20,013	11.8	19,609	65	1.0	3,448
2	Camp Creek	6,145	10.6	5,425	76.3	1.0	1,125
3	East Trib. Ann	3,492	12.4	3,605	78.1	1.0	766
4	Ann Direct	2,499	8.1	1,690	29.8	1.0	137
5	Spring Brook	2,343	10.6	2,072	41.2	1.0	232
	Summation	*34,492*	11.3	*32,402*			*5,709.3*

Failing Septic Systems

	Name	Area [ac]	[lb/yr]
1	Little Ann River	20,013	114.0
2	Camp Creek	6,145	32.0
3	East Trib. Ann	3,492	56.0
4	Ann Direct	2,499	211.0
5	Spring Brook	2,343	32.0
	Summation	*34,492*	*0.0*

Inflow from Upstream Lakes

	Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	West Ann Lake	1,241	60.0	1.0	203
2			-	1.0	
3			-	1.0	
	Summation	*1,241*	*60.0*		*203*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
773	28.0	28.0	0.00	0.24	1.0	184.8

Dry-year total P deposition = 0.222
Average-year total P deposition = 0.239
Wet-year total P deposition = 0.259
(Barr Engineering 2004)

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
773	0.0	0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]		Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
3.13	122	Oxic	0.2	1.0	168
3.13	51.6	Anoxic	4.0	1.0	1,424
Summation					1,592

Net Discharge [ac-ft/yr] =	**33,643**
Net Load [lb/yr] =	**7,689**

NOTES

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

TMDL Lake Response Modeling for Ann Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.91	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,488	[kg/yr]
		Q (lake outflow) =	41.5	[10^6 m^3/yr]
		V (modeled lake volume) =	6.2	[10^6 m^3]
		T = V/Q =	0.15	[yr]
		P_i = W/Q =	84	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Appendix K: Sediment Equation

Site 3: 06SC138

Threshold of Motion		metric units		conversion	English units with grain size in mm	
depth	d	**0.64**	m	3.28	2.1	ft
slope	S	**0.00264**	m/m	1	0.00264	ft/ft
diameter sediment	d_s	**0.0434**	m	1000	43	mm
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
density fluid	ρ_f	1000	kg/m^3	0.00194	1.94	slugs/ft^3
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	slugs/ft^3
specific weight of water	γ	9810	N/m^3		62.5	lb/ft^3
		1000	kg$_f$/m^3			
shear stress	τ	16.6	N/m^2		0.346	lb/ft^2
		1.7	kg$_f$/m^2			
Shields parameter	τ_{*c}	0.024	dimensionless		0.024	dimensionless
Particle at threshold of motion	D_{cr}	0.017	m		0.06	ft

Bedload per unit channel width		metric units		conversion	English units with grain size in mm		check back to SI	
depth	d	**0.64**	m	3.28	2.1	ft		
slope	S	**0.00264**	m/m		0.00264	ft/ft		
diameter sediment	d_s	**0.0434**	m		43	mm		
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2		
density fluid	ρ_f	1000	kg/m^3	0.00194	1.94	slugs/ft^3		
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	slugs/ft^3		
relative density	s	2.65	dimensionless		2.65	dimensionless		
shear stress	τ	16.6	N/m^2		0.346	lb$_f$/ft^2		
dimensionless parameter	Ψ	42.38			42.39			
bed-load transport (Meyer-Peter)	Φ	#NUM!			#NUM!			
	q_s	**#NUM!**	m^2/s		**#NUM!**	ft^2/s	#NUM!	m^2/s
bed-load transport (Einstein$_{42}$)	Φ	0.000			0.000			
	q_s	**0.00000**	m^2/s		**0.00000**	ft^2/s	5E-09	m^2/s
bed-load transport (Einstein$_{50}$)	Φ	FALSE			FALSE			
	q_s	**0.00000**	m^2/s		**0.00000**	ft^2/s	0	m^2/s
Ackers and White	n	0.034			0.034			
	U	1.12	m/s		3.67	ft/s		
	q_b	**#NUM!**	m^2/s		**#NUM!**	ft^2/s	#NUM!	m^2/s

Site 3: 06SC138

Resistance Manning's and D'Arcy-Weisba		metric units		conversion	English units with grain size in mm	
depth	d	**0.64**	m	3.28	2.1	ft
slope	S	**0.00264**	m/m	1	0.00264	ft/ft
diameter sediment	d_s	**0.0434**	m	1000	43	mm
max depth	d_{max}	**1.03**	m	3.28	3.4	
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
Resistance factor = sqrt(8/*f*)						
Colebrook-White Eq (Hey 1979) for D_{84}	u/u*	10.0			10.0	
Leopold, Wolman & Miller (1964) for D_{84}	u/u*	10.0			10.0	
Griffiths (1981) for D_{50}	u/u*	8.7			8.7	
Manning's roughness coefficient (n):						
Colebrook-White Eq (Hey 1979) for D_{84}	n	0.0297			0.0298	
Leopold, Wolman & Miller (1964) for D_{84}	n	0.0296			0.0297	
Griffiths (1981) for D_{50}	n	0.0341			0.0342	
D'Arcy-Weisbach friction factor:						
Colebrook-White Eq (Hey 1979) for D_{84}	f	0.0804			0.0804	
Leopold, Wolman & Miller (1964) for D_{84}	f	0.0800			0.0800	
Griffiths (1981) for D_{50}	f	0.1058			0.1058	

Site 5: 06SC136

Threshold of Motion		metric units		conversion	English units with grain size in mm	
depth	d	**0.52**	m	3.28	1.7	ft
slope	S	**0.005**	m/m	1	0.005	ft/ft
diameter sediment	d_s	**0.0431**	m	1000	43	mm
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
density fluid	ρ_f	1000	kg/m^3	0.00194	1.94	slugs/ft^3
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	slugs/ft^3
specific weight of water	γ	9810	N/m^3		62.5	lb/ft^3
		1000	kg$_f$/m^3			
shear stress	τ	25.5	N/m^2		0.533	lb/ft^2
		2.6	kg$_f$/m^2			
Shields parameter	τ_{*c}	0.037	dimensionless		0.037	dimensionless
Particle at threshold of motion	D_{cr}	0.026	m		0.09	ft

Bedload per unit channel width		metric units		conversion	English units with grain size in mm		check back to SI	
depth	d	**0.52**	m	3.28	1.7	ft		
slope	S	**0.005**	m/m		0.005	ft/ft		
diameter sediment	d_s	**0.0431**	m		43	mm		
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2		
density fluid	ρ_f	1000	kg/m^3	0.00194	1.94	slugs/ft^3		
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	slugs/ft^3		
relative density	s	2.65	dimensionless		2.65	dimensionless		
shear stress	τ	25.5	N/m^2		0.533	lb$_f$/ft^2		
dimensionless parameter	Ψ	27.35			27.36			
bed-load transport (Meyer-Peter)	Φ	#NUM!			#NUM!			
	q_s	**#NUM!**	m^2/s		**#NUM!**	ft^2/s	#NUM!	m^2/s
bed-load transport (Einstein$_{42}$)	Φ	0.000			0.000			
	q_s	**0.00000**	m^2/s		**0.00002**	ft^2/s	2E-06	m^2/s
bed-load transport (Einstein$_{50}$)	Φ	FALSE			FALSE			
	q_s	**0.00000**	m^2/s		**0.00000**	ft^2/s	0	m^2/s
Ackers and White	n	0.035			0.035			
	U	1.31	m/s		4.30	ft/s		
	q_b	**#NUM!**	m^2/s		**#NUM!**	ft^2/s	#NUM!	m^2/s

Site 5: 06SC136

Resistance Manning's and D'Arcy-Weisba		metric units		conversion	English units with grain size in mm	
depth	d	**0.52**	m	3.28	1.7	ft
slope	S	**0.005**	m/m	1	0.005	ft/ft
diameter sediment	d_s	**0.114**	m	1000	114	mm
max depth	d_{max}	**0.7**	m	3.28	2.3	
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
Resistance factor = sqrt(8/*f*)						
Colebrook-White Eq (Hey 1979) for D_{84}	u/u*	6.9			6.9	
Leopold, Wolman & Miller (1964) for D_{84}	u/u*	7.1			7.1	
Griffiths (1981) for D_{50}	u/u*	5.8			5.8	
Manning's roughness coefficient (n):						
Colebrook-White Eq (Hey 1979) for D_{84}	n	0.0415			0.0416	
Leopold, Wolman & Miller (1964) for D_{84}	n	0.0405			0.0406	
Griffiths (1981) for D_{50}	n	0.0490			0.0492	
D'Arcy-Weisbach friction factor:						
Colebrook-White Eq (Hey 1979) for D_{84}	f	0.1678			0.1678	
Leopold, Wolman & Miller (1964) for D_{84}	f	0.1600			0.1600	
Griffiths (1981) for D_{50}	f	0.2345			0.2345	

Site 7: 06SC122

Threshold of Motion		metric units		conversion	English units with grain size in mm	
depth	d	**0.55**	m	3.28	1.8	ft
slope	S	**0.00251**	m/m	1	0.00251	ft/ft
diameter sediment	d_s	**0.00549**	m	1000	5	mm
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
density fluid	ρ_f	1000	kg/m^3	0.00194	1.94	$slugs/ft^3$
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	$slugs/ft^3$
specific weight of water	γ	9810	N/m^3		62.5	lb/ft^3
		1000	kg_f/m^3			
shear stress	τ	13.5	N/m^2		0.283	lb/ft^2
		1.4	kg_f/m^2			
Shields parameter	τ_{*c}	0.152	dimensionless		0.152	dimensionless
Particle at threshold of motion	D_{cr}	0.0139	m		0.05	ft

Bedload per unit channel width		metric units		conversion	English units with grain size in mm		check back to SI	
depth	d	**0.55**	m	3.28	1.8	ft		
slope	S	**0.00251**	m/m		0.00251	ft/ft		
diameter sediment	d_s	**0.00549**	m		5	mm		
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2		
density fluid	ρ_f	1000	kg/m^3	0.00194	1.94	$slugs/ft^3$		
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	$slugs/ft^3$		
relative density	s	2.65	dimensionless		2.65	dimensionless		
shear stress	τ	13.5	N/m^2		0.283	lb_f/ft^2		
dimensionless parameter	Ψ	6.56			6.56			
bed-load transport (Meyer-Peter)	Φ	0.274			0.274			
	q_s	**0.0004**	m^2/s		**0.0048**	ft^2/s	4E-04	m^2/s
bed-load transport (Einstein$_{42}$)	Φ	0.165			0.165			
	q_s	**0.00027**	m^2/s		**0.00291**	ft^2/s	3E-04	m^2/s
bed-load transport (Einstein$_{50}$)	Φ	0.307			0.306			
	q_s	**0.00050**	m^2/s		**0.00540**	ft^2/s	5E-04	m^2/s
Ackers and White	n	0.022			0.022			
	U	1.55	m/s		5.10	ft/s		
	q_b	**0.00015**	m^2/s		**0.00164**	ft^2/s	2E-04	m^2/s

Site 7: 06SC122

Resistance Manning's and D'Arcy-Weisbac		metric units		conversion	English units with grain size in mm	
depth	d	**0.55**	m	3.28	1.8	ft
slope	S	**0.00251**	m/m	1	0.00251	ft/ft
diameter sediment	d_s	**0.00549**	m	1000	5	mm
max depth	d_{max}	**0.7**	m	3.28	2.3	
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
Resistance factor = sqrt(8/*f*)						
Colebrook-White Eq (Hey 1979) for D_{84}	u/u*	14.6			14.6	
Leopold, Wolman & Miller (1964) for D_{84}	u/u*	14.8			14.8	
Griffiths (1981) for D_{50}	u/u*	13.4			13.4	
Manning's roughness coefficient (n):						
Colebrook-White Eq (Hey 1979) for D_{84}	n	0.0198			0.0199	
Leopold, Wolman & Miller (1964) for D_{84}	n	0.0195			0.0196	
Griffiths (1981) for D_{50}	n	0.0216			0.0217	
D'Arcy-Weisbach friction factor:						
Colebrook-White Eq (Hey 1979) for D_{84}	f	0.0377			0.0377	
Leopold, Wolman & Miller (1964) for D_{84}	f	0.0366			0.0366	
Griffiths (1981) for D_{50}	f	0.0449			0.0449	

Site 8: 98SC019

Threshold of Motion		metric units		conversion	English units with grain size in mm	
depth	d	**0.637**	m	3.28	2.1	ft
slope	S	**0.00018**	m/m	1	0.00018	ft/ft
diameter sediment	d_s	**0.00549**	m	1000	5	mm
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
density fluid	ρ_f	1000	kg/m^3	0.00194	1.94	slugs/ft^3
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	slugs/ft^3
specific weight of water	γ	9810	N/m^3		62.5	lb/ft^3
		1000	kg$_f$/m^3			
shear stress	τ	1.1	N/m^2		0.024	lb/ft^2
		0.1	kg$_f$/m^2			
Shields parameter	τ_{*c}	0.013	dimensionless		0.013	dimensionless
Particle at threshold of motion	D_{cr}	0.00116	m		0.00	ft

Bedload per unit channel width		metric units		conversion	English units with grain size in mm		check back to SI	
depth	d	**0.637**	m	3.28	2.1	ft		
slope	S	**0.00018**	m/m		0.00018	ft/ft		
diameter sediment	d_s	**0.00549**	m		5	mm		
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2		
density fluid	ρ_f	1000	kg/m^3	0.00194	1.94	slugs/ft^3		
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	slugs/ft^3		
relative density	s	2.65	dimensionless		2.65	dimensionless		
shear stress	τ	1.1	N/m^2		0.024	lb$_f$/ft^2		
dimensionless parameter	Ψ	79.00			79.02			
bed-load transport (Meyer-Peter)	Φ	#NUM!			#NUM!			
	q_s	**#NUM!**	m^2/s		**#NUM!**	ft^2/s	#NUM!	m^2/s
bed-load transport (Einstein$_{42}$)	Φ	0.000			0.000			
	q_s	**0.00000**	m^2/s		**0.00000**	ft^2/s	1E-16	m^2/s
bed-load transport (Einstein$_{50}$)	Φ	FALSE			FALSE			
	q_s	**0.00000**	m^2/s		**0.00000**	ft^2/s	0	m^2/s
Ackers and White	n	0.022			0.022			
	U	0.46	m/s		1.51	ft/s		
	q_b	**#NUM!**	m^2/s		**#NUM!**	ft^2/s	#NUM!	m^2/s

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Resistance Manning's and D'Arcy-Weisbach		metric units		conversion	English units with grain size in mm	
depth	d	**0.637**	m	3.28	2.1	ft
slope	S	**0.00018**	m/m	1	0.00018	ft/ft
diameter sediment	d_s	**0.00549**	m	1000	5	mm
max depth	d_{max}	**1.64**	m	3.28	5.4	
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
Resistance factor = sqrt(8/*f*)						
Colebrook-White Eq (Hey 1979) for D_{84}	u/u*	15.5			15.5	
Leopold, Wolman & Miller (1964) for D_{84}	u/u*	15.2			15.2	
Griffiths (1981) for D_{50}	u/u*	13.7			13.7	
Manning's roughness coefficient (n):						
Colebrook-White Eq (Hey 1979) for D_{84}	n	0.0191			0.0192	
Leopold, Wolman & Miller (1964) for D_{84}	n	0.0195			0.0196	
Griffiths (1981) for D_{50}	n	0.0216			0.0217	
D'Arcy-Weisbach friction factor:						
Colebrook-White Eq (Hey 1979) for D_{84}	f	0.0333			0.0333	
Leopold, Wolman & Miller (1964) for D_{84}	f	0.0348			0.0348	
Griffiths (1981) for D_{50}	f	0.0426			0.0426	