Mississippi River (St. Cloud) Watershed Total Maximum Daily Load

Mississippi River at County Road 24 in Clearwater, Minnesota

CLEAN
WATER
LAND &
LEGACY
AMENDMENT

wq-iw8-46e

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Mississippi River (St. Cloud) Watershed TMDLs

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Appendix B- Rice Creek Turbidity Analysis Technical Memo

Appendix C- Rice Creek DO Modeling Technical Memo

Appendix D- Battle Brook DO Modeling Technical Memo

Appendix E- Clearwater River Watershed DO Modeling Technical Memo

Appendix F- DO TMDL Allowable Load Calculations Technical Memo

TMDL SUMMARY TABLE

EPA/MPCA Required Elements	Summary				TMDL Page #
Location	Central Minnesota, Upper Mississippi River Basin				
303(d) Listing Information	**Water body**	**Lake No./HUC**	**Pollutant/Stressor**	**Listing Year**	
	Donovan Lake	05-0004-02	Excess Nutrients	2010	P. 15
	Julia Lake	71-0145-00	Excess Nutrients	2008	
	Briggs Lake	71-0146-00	Excess Nutrients	2008	
	Rush Lake	71-0147-00	Excess Nutrients	2008	
	Birch Lake	71-0157-00	Excess Nutrients	2006	
	Orono Lake (Lower)	71-0013-02	Excess Nutrients	2008	
	Orono Lake (Upper)	71-0013-01	Excess Nutrients	2008	
	Fish Lake	86-0183-00	Excess Nutrients	2008	
	Mink Lake	86-0229-00	Excess Nutrients	2008	
	Somers Lake	86-0230-00	Excess Nutrients	2008	
	Silver Lake	86-0140-00	Excess Nutrients	2008	
	Indian Lake	86-0223-00	Excess Nutrients	2008	
	Locke Lake	86-0168-00	Excess Nutrients	2006	
	Battle Brook	07010203-535	Aquatic Macroinvertabrate bio-assessment (Low DO)	2006	
	Clearwater River	07010203-511	Dissolved Oxygen	2006	
	Rice Creek	07010203-512	Dissolved Oxygen/Turbidity	2006	
Applicable Water Quality Standards/Numeric targets	Criteria set forth in Minn. R. 7050, See Section 1.1.				P.15
Loading Capacity (expressed as daily load)	The loading capacities for the lake impairments are provided in Section 4.12 and for the stream impairments in Section 5.8 and 6.5.				P. 52, 69,73
Wasteload Allocation	See Section 3.1				P. 23
Load Allocation	Load allocations (LA) for the lake impairments are provided in Section 4.12 and for the stream impairments in Section 5.8 and 6.5.				P. 52, 69,73
Margin of Safety	See Section 3.3				P. 29
Seasonal Variation	Lake Nutrients: See Section 4.1.2 DO: See Section 5.3 Turbidity: See Section 6.4				P. 32, 60, 72
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 standards. See Section 8.1.				P. 75

EPA/MPCA Required Elements	Summary	TMDL Page #
Monitoring	Intensive watershed monitoring (IWM) will occur on a 10-year schedule. Long term load monitoring at watershed outlets is currently occurring. Recommendations for local monitoring are made in Section 7.	P. 74
Implementation	This report sets forth an implementation framework to achieve the TMDLs. See Section 8.	P. 75
Public Participation	See Section 8.11. Public Comment Period: October 13, 2014 – November 12, 2014 Comments received: One comment letter was received from the public comment period which made suggestions to enhance the formatting and include additional maps.	P. 86

Acronym List

AUID	Assessment Unit Identification Determination
BMP	Best Management Practice
BWSR	Minnesota Board of Water and Soil Resources
CAFO	Concentrated Animal Feeding Operations
CBOD	Carbonaceous Biochemical Oxygen Demand
CLP	Curly-leaf pondweed
CRN	Central River Nutrient
CSAH	County State-Aid Highways
CWA	Clean Water Act
CWL	Clean Water Legacy
CWLA	Clean Water Legacy Act
DNR	Minnesota Department of Natural Resources
DO	Dissolved Oxygen
EDA	Environmental Data Access
EPA	Environmental Protection Agency
ERWA	Elk River Watershed Association
EQIP	Environmental Quality Incentives Program
GIS	Geographic Information System
HSPF	Hydrologic Simulation Program FORTRAN
IBI	Index of Biological Integrity
IWM	Intensive Watershed Monitoring
LA	Load Allocation
LB	Pounds
LC	Loading Capacity
LGU	Local Unit of Government
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MR-SC	Mississippi River-Saint Cloud Watershed
MS4	Municipal Separate Storm Sewer Systems
NBOD	Nitrogenous Biochemical Oxygen Demand
NCHF	North Central Hardwood Forest
NLCD	National Land Cover Database
NPDES	National Pollution Discharge Elimination System
NPDES/SDS	National Pollution Discharge Elimination System/State Disposal System
NRCS	Natural Resources Conservation Service
NTU	Nephelometric Turbidity Unity
SOD	Sediment Oxygen Demand
SSTS	Subsurface Sewage Treatment Systems
SWCD	Soil and Water Conservation District
SWPPP	Stormwater Pollution Prevention Plans
TMDL	Total Maximum Daily Load

TP	Total Phosphorous
TSS	Total Suspended Solids
USGS	United States Geologic Survey
Wenck	Wenck Associates, Inc.
WLA	Wasteload Allocation
WQBEL	Water Quality Based Effluent Limit
WRAPS	Watershed Restoration and Protection Plan Strategy
WWTF	Waste Water Treatment Facilities

EXECUTIVE SUMMARY

Section 303(d) of the Federal Clean Water Act (CWA) requires the Minnesota Pollution Control Agency (MPCA) to identify water bodies that do not meet water quality standards and to develop total maximum daily pollutant loads for those water bodies. A total maximum daily load (TMDL) is the amount of a pollutant that a water body can assimilate without exceeding the established water quality standard for that pollutant. The TMDL is divided into wasteload allocations (WLA) for point or permitted sources, load allocation (LA) for nonpoint sources, which includes natural background, and margin of safety (MOS).

These TMDL studies were prepared by Sherburne Soil and Water Conservation District (SWCD) staff cooperatively with partner agencies within the Mississippi River-St. Cloud (MR-SC) Watershed with assistance from Wenck Associates, Inc. (Wenck). The TMDL study addresses two low dissolved oxygen (DO), one aquatic macroinvertabrate, one turbidity, and thirteen lake eutrophication impairments in the MR-SC Watershed. Addressing multiple impairments in one TMDL study is consistent with Minnesota's Water Quality Framework that seeks to develop watershed wide protection and restoration strategies rather than focus on individual reach impairments.

The MR-SC Watershed resides in the Upper Mississippi River basin, drains approximately 717,770 acres and includes portions of six counties (Figure 1-1). The 8 digit Hydrologic Unit Code (HUC) number is 07010203. The entire watershed is contained within the Northern Hardwood Forest Level III Ecoregion.

This study used a variety of individual methods to evaluate current loading, contributions by the various pollutant sources as well as the allowable pollutant loading capacity (LC) of the impaired water bodies. These methods included lake response models (excess nutrients), QUAL2K (DO), and load duration curves (turbidity).

A general strategy for implementation to address the impairments is included. Nonpoint sources will be the focus of implementation efforts. Nonpoint contributions are not regulated and will need to proceed on a voluntary basis. Permitted point sources should comply with the MPCA National Pollutant Discharge Elimination System (NPDES) Permit (Permit) programs.

1. INTRODUCTION

The CWA Section 303(d) requires states to publish, every two years, a list of surface waters that do not meet water quality standards and do not support their designated uses. These waters are then classified as impaired. Once a water body is placed on the impaired waters list, a TMDL study must be developed. The TMDL provides a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards.

The passage of Minnesota's 2006 Clean Water Legacy Act (CWLA) provided a policy framework and resources to state and local governments to accelerate efforts to monitor, access, and restore impaired waters and to protect unimpaired waters. The result has been a comprehensive watershed approach that integrates water resource management efforts with local government and local stakeholders and develops restoration and protection studies for Minnesota's 81 major watersheds. For the entire MR-SC major watershed (Figure 1.2), the IWM work begun in 2009 and findings were made available in 2011; subsequent assessments resulted in additional impairment listings in 2012 that are not addressed in this document. Waters listed via the IWM process will be addressed in the next 10-year cycle. Thus; TMDL calculations were completed for waters listed as impaired up to the 2010 303(d) list. The information gained and strategies developed in this process should serve to help improve the streams and lakes for which TMDL calculations are not being made and to protect unimpaired water bodies.

The TMDLS included in this report were done in conjunction with MR-SC Watershed Restoration and Protection Plan Strategy (WRAPS) process. Surface waters addressed in this document were listed on or before the 2010 impaired waters list, those listed after 2010 will be addressed with the 2019 WRAPS cycle. The implementation strategies prescribed in this report were incorporated into the WRAPS report and helped to inform target area prioritizing.

1.1 Applicable Water Quality Standards

The criteria used for determining stream reach and lake impairments are outlined in the MPCA's document Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) report and 303(d) list (MPCA 2011b). The applicable water body classifications and water quality standards are specified in Minn. R. ch. 7050. Minn. R. ch. 7050.0470, lists water body classifications and Minn. R. ch. 7050.2222, lists applicable water quality standards. The impaired waters covered in the TMDL are classified as 2B and 2C waters which are protective of aquatic life and recreation. Relative to aquatic life and recreation, the designated beneficial uses for 2B and 2 C waters are as follows:

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

> Class 2C waters - The quality of Class 2C surface waters shall be such as to permit the propagation and maintenance of a healthy community of indigenous fish, and their habitats. These waters shall be suitable for boating and other forms of aquatic recreation for which the waters may be usable.

The water quality standards that apply to the MR-SC stream reaches in the TMDL report are shown in Table 1.1. Lake water quality standards are specific to ecoregion and lake type (depth). The water quality standards that apply to the lakes in this TMDL report are shown in Table 1.1 and Table 1.2. For more detailed information refer to the MPCA TMDL protocols specific to the parameter of interest (MPCA 2007b; MPCA 2007c; MPCA 2008).

Table 1.1 - MN Water Quality Standards for Stream Reaches in the TMDL

Parameter	**Water Quality Standard**	**Units**	**Criteria**	**Period of Time Standard Applies**
Turbidity	Not to exceed 25	NTU	Upper 10th percentile	Year round
Dissolved Oxygen	Daily minimum of 5.0	Mg/L	100 percent of days above 7Q10 flow; 50%of days at 7Q10 flow	Year round

The MPCA has proposed amendments to replace the existing turbidity standards with regionally-based Total Suspended Solids (TSS) standards (MPCA 2011). The proposed regional standard for the turbidity impaired reach of Rice Creek is 30 mg/L, the Central River Nutrient (CRN) region threshold. The CRN threshold was used to calculate the load reductions for the turbidity TMDL.

Table 1.2 - MN Water Quality Standards for Lakes in this TMDL

Ecoregion/Type	**Total Phosphorus Standard (µg/L)**	Chlorophyll-*a* **standard (µg/L)**	**Secchi Depth (m)**	**Period of Time Standard Applies**
NCHF/Deep Lakes	<40	<15	$\geq$1.6	June 1-September 30
NCHF/Shallow Lakes	<60	<20	>1.0	June 1-September 30

NCHF- North Central Hardwood Forest

In addition to meeting phosphorus limits, chlorophyll-*a* and Secchi transparency standards must also be met. In developing the lake nutrient standards for Minnesota Lakes (Minn. R. ch. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (MPCA 2005). Clear relationships were established between the causal factor total phosphorus (TP) and the response variables chlorophyll-*a* and Secchi transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the chlorophyll-*a* and Secchi standards will likewise be met.

This TMDL report applies to three impairment listings for three stream reaches and 13 lake impairment listings in the MR-SC major watershed HUC 07010203.

Figure 1.1. Supporting documentation of the impairments can be found in the MPCA WRAP related documents (MPCA 2012a; MPCA 2012b; MPCA 2012c).

Table 1.3 - MR-SC Lake and Stream impairment listings

Reach	Description	Use Class	Year Listed	Assessment Unit ID/DNR Lake #	Affected use	Impairment addressed
Battle Brook	CD 18 to Elk LK	2C	2006	07010203-535	Aquatic Life	Aquatic macroinvertabrate bio-assessments (Low DO)
Clearwater River	CD 44 to LK Betsy	2B	2006	07010203-511	Aquatic Life	Dissolved Oxygen
Rice Creek	Rice LK to Elk R	2C	2006	07010203-512	Aquatic Life	Dissolved Oxygen/Turbidity
Donovan Lake (Main Bay)	Lake or Reservoir	2B	2010	05-0004-02	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Julia Lake	Lake or Reservoir	2B	2008	71-0145-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Briggs lake	Lake or Reservoir	2B	2008	71-0146-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Rush Lake	Lake or Reservoir	2B	2008	71-0147-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Birch Lake	Lake or Reservoir	2B	2006	71-0057-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Orono Lake (Lower)	Lake or Reservoir	2B	2008	71-0013-02	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Orono Lake (Upper)	Lake or Reservoir	2B	2008	71-0013-01	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Fish Lake	Lake or Reservoir	2B	2008	86-0183-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Mink Lake	Lake or Reservoir	2B	2008	86-0229-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Somers Lake	Lake or Reservoir	2B	2008	86-0230-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Silver Lake	Lake or Reservoir	2B	2008	86-0140-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Indian Lake	Lake or Reservoir	2B	2008	86-0223-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Locke Lake	Lake or Reservoir	2B	2006	86-0168-00	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators

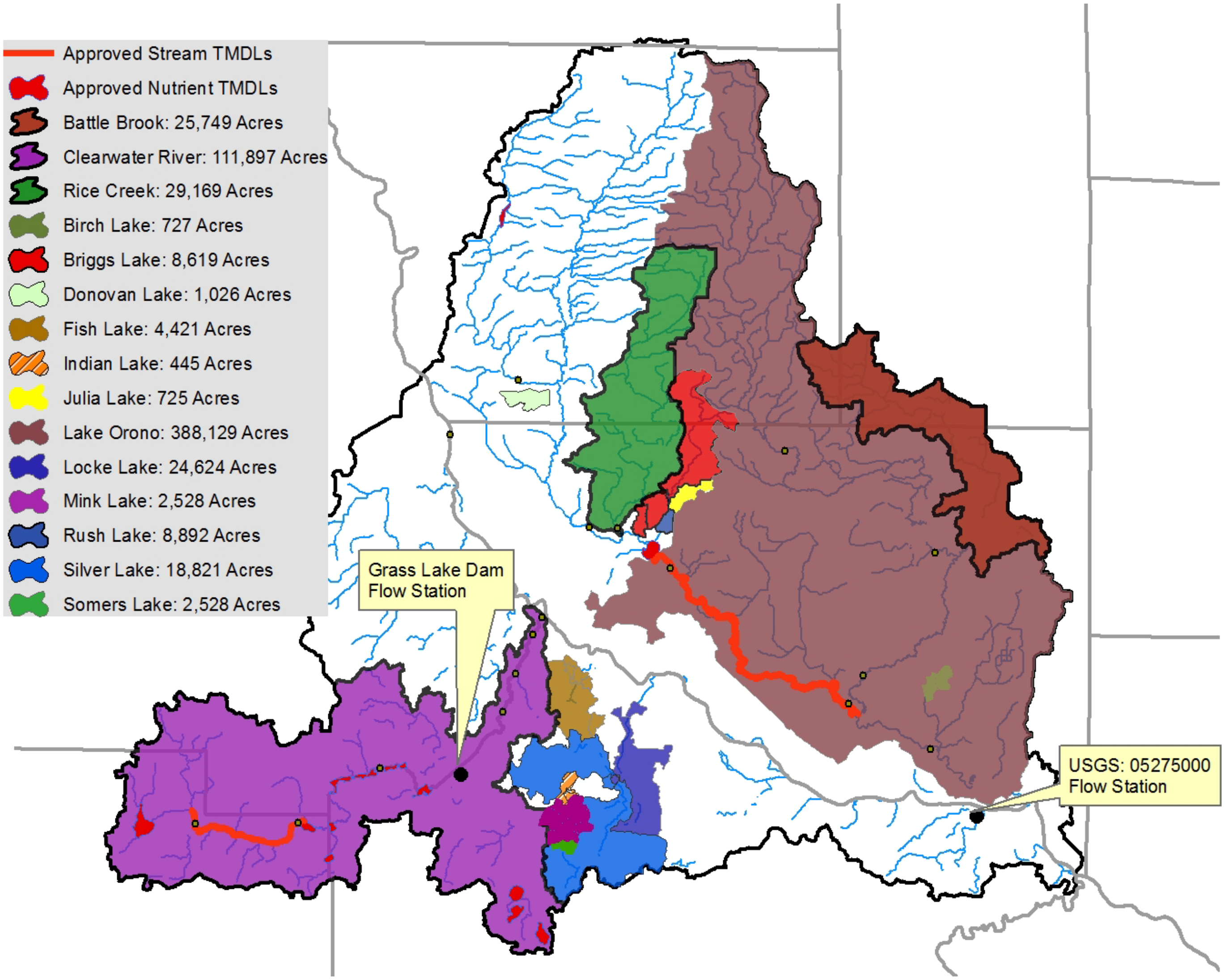


Figure 1-1 - Relative location and size of TMDL watersheds, Approved TMDL locations, and long term flow gauging locations

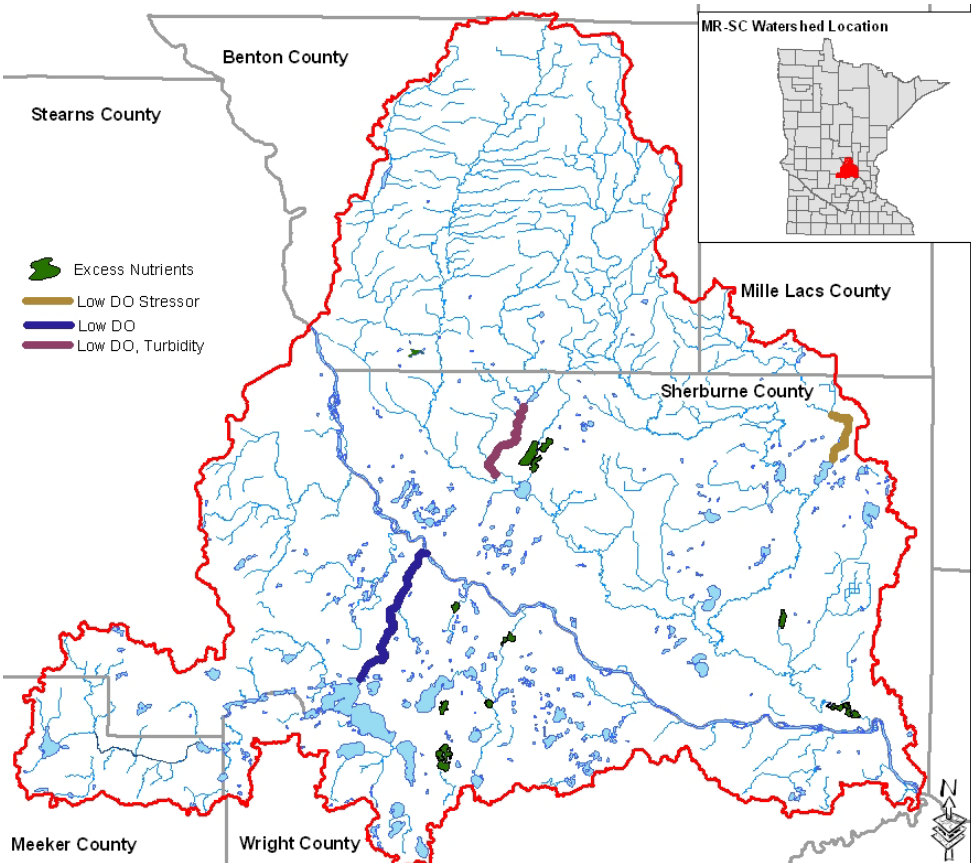


Figure 1-2 - Map of MR-SC Watershed Indicating location and nature of Impairments

1.2 Priority Ranking

The MPCA's projected scheduled start dates for these TMDLs, as indicated on Minnesota's 303(d) impaired waters list, is 2009. This coincides with the start of the MR-SC Watershed Restoration and Protection Strategy (WRAPS) process, a comprehensive assessment and planning procedure that will be applied to each of Minnesota's 81 major watersheds. 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.

2 WATERSHED CHARACTERISTICS

2.1 Mississippi River (St. Cloud) Watershed (MR-SC)

The MR-SC Watershed covers 717,479 acres in central Minnesota within the Upper Mississippi River Basin. The watershed originates at the confluence of the Sauk and Mississippi Rivers (upstream of CSAH 3, near St. Cloud, Minnesota). This portion of the Mississippi River flows approximately 50 miles southeast, where it joins up with the North Fork of the Crow River. The watershed includes all or parts of seven counties in central Minnesota: Benton, Meeker, Mille Lacs, Morrison, Sherburne, Stearns and Wright counties; respectively. The watershed is entirely contained within the North Central Hardwood Forests (NCHF) Ecoregion (Figure 2.1).

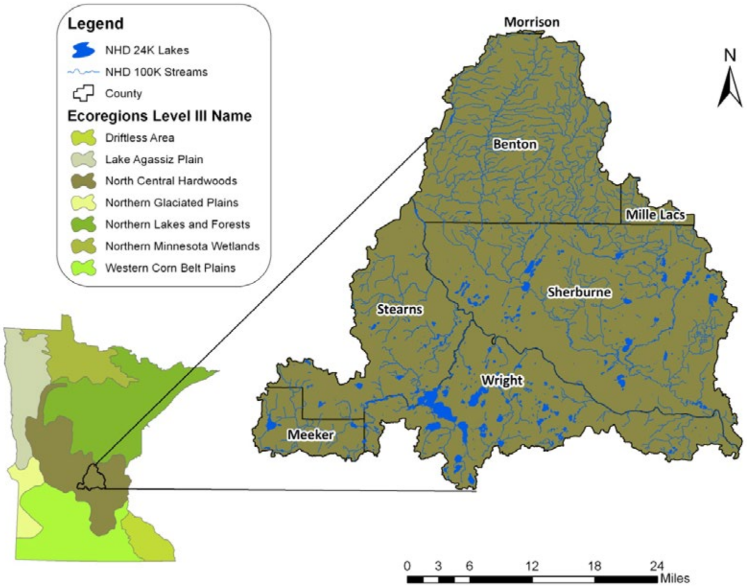


Figure 2-1 - The MR-SC Watershed is within the North Central Hardwoods Ecoregion of Central Minnesota

The MR-SC Watershed contains a myriad of land use types. The dominant land use type in this watershed is cropland (39%) which is often irrigated through center pivot irrigation systems. While the watershed is dominated by cropland, the other significant land use types are pastureland (22%) and forested lands (18%). For more detailed information on characteristics of the MR-SC Watershed, refer to the MR-SC Watershed Monitoring and Assessment Report (MPCA 2012a). Refer to impairment Sections Four, Five, and Six for individual enumeration of land use specific to each impaired water.

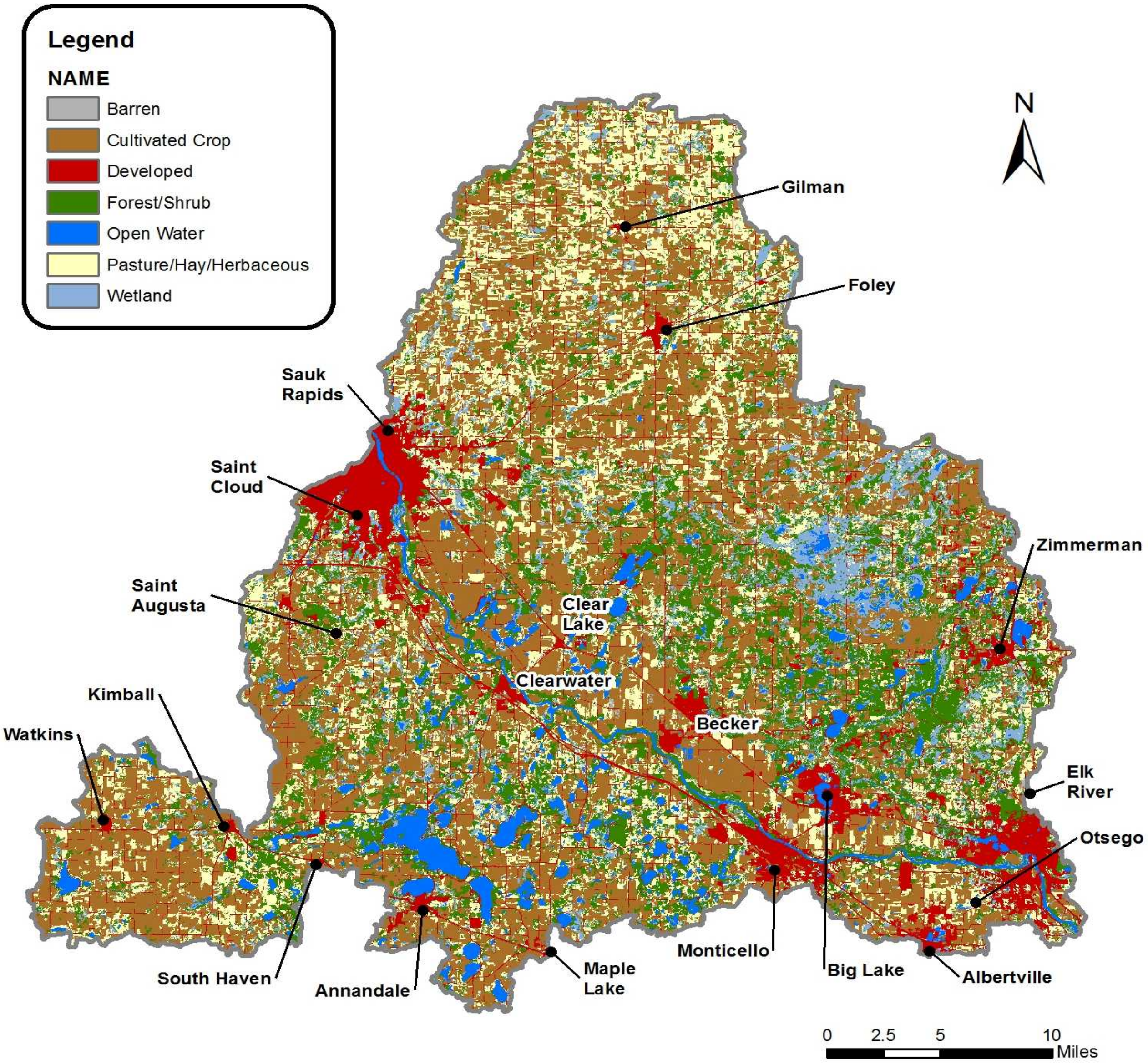


Figure 2-2 Land Use in the MR-SC Watershed Land Use statistics are based on 2011 National Land Classification System

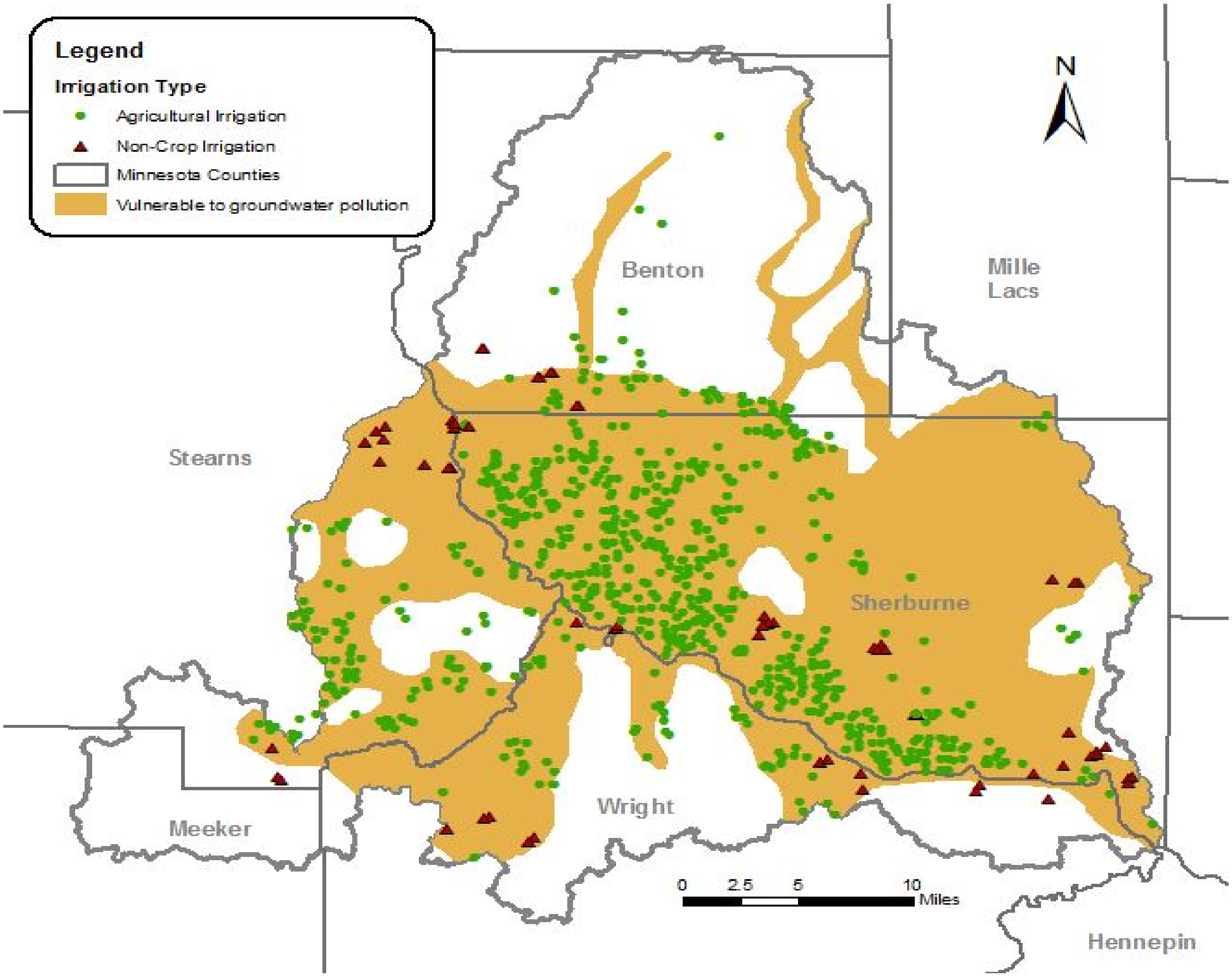


Figure 2-3: Active Water Appropriation Permit Locations for Irrigation (crop and non-crop) in the MR-SC Watershed (December 2014)

2.2 Data Used in the TMDL

This TMDL incorporates monitoring conducted for this report in conjunction with the Mississippi River (St. Cloud) Major WRAPS project as well as previous studies. Lakes TMDL data was limited to existing information most closely focusing on the previous 10 years (2001-2011). Limited additional information was collected in 2012 to fill gaps in data in relation to the (DO) and Turbidity Impairments. Monitoring data is summarized in the 2012 MR-SC Lakes Assessment Report, MR-SC Watershed Assessment and MR-SC Stressor ID Reports as well as the technical memorandums completed by Wenck which can be found in the appendices of this document.

Chemical and physical monitoring data used in the development of the TMDLs was conducted by Sherburne, Benton and Wright SWCDs, CRWD, MPCA, Outdoor Corps, Citizen's Lake and Stream Monitoring Partnership volunteers, Department of Natural Resources (DNR) and United States Geologic Survey (USGS).

3 DISCUSSION OF TMDL COMPONENTS

A TMDL for a waterbody that is impaired as a result of excessive loading of a particular pollutant can be described by the following equation:

$$\text{TMDL} = \sum LA + \sum WLA + \text{MOS} + \text{RC}$$

Where

$\sum LA =$ LA, or the sum of the unpermitted sources including background sources such as precipitation and groundwater contribution as well as unpermitted watershed source like some agricultural, residential and urban land uses. Specifically,

LA= Atmospheric Contribution +Groundwater+ Watershed Load + Tributary Loads +Internal Loads.

$\sum WLA =$ WLA, or the sum of the permitted sources including waste water treatment facilities (WWTF), MS4s, and permitted CAFOs.

MOS= Margin of Safety
RC= Reserve Capacity

Per Code of Federal Regulations (40CFR 130.2(1)), TMDLs can be expressed in terms of mass per time, toxicity of other appropriate measures. For the MR-SC impairments addressed in this report, the TMDLs, allocations and MOS are expressed in mass/day. Each of the TMDL components is discussed in greater detail below.

3.1 Wasteload Allocations

The WLA includes permitted discharges such as Wastewater Treatment Facilities (WWTFs), industrial point source discharges and regulated stormwater discharges from construction and industrial facilities and Municipal Separate Storm Sewer Systems (MS4s). Stormwater discharges are regulated under the state's NPDES program, and allocations of nutrient reductions are considered as a portion of the WLA that must be divided among permit holders. Below is a description of the sources included in the nutrient TMDL WLAs in Table 3.1.

3.1.1 Stormwater

3.1.1.1 Municipal

Stormwater from MS4s can transport phosphorus to surface water bodies during or shortly after storm events. The Stormwater Program for MS4s is designed to reduce the amount of pollution that enters surface and ground water from storm sewer systems to the maximum extent practicable. The MS4 Permits require the implementation of Best Management Practices (BMPs) to address WLAs. In addition, the owner or operator is required to develop a Stormwater Pollution Prevention Plan (SWPPP) that incorporates BMPs applicable to their MS4. The SWPPP must cover six minimum control measures:

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

Nutrient TMDLs: MS4 permit holders in the Lake TMDL watersheds and the permit ID numbers assigned to these permit holders are as follows:

Table 3.1 - MS4 permit holder's in the impaired watersheds

Permit Holder	Permit Number	Area (Acres) developed only	TMDL Watershed Location
Big Lake Township	MS400234	686	Birch Lake
Benton County MS4	MS440067	12	Donovan Lake
St. Cloud City MS4	MS400052	66	Donovan Lake
Minden Township MS4	MS400147	68	Donovan Lake
MNDOT Outstate District MS4 (non-traditional)	MS400180	12	Donovan Lake
Elk River City MS4	MS400089	11,406	Orono Lake
Big Lake Township MS4	MS400234	17,468	Orono Lake
Big Lake City MS4	MS400249	3,356	Orono Lake

Existing water quality data quantified total nutrient loads well, but did not partition loads specifically to sources; thus, it is recommended these MS4s be assigned a categorical WLA calculated from the permitted MS4 area and the total watershed area and expressed as a percentage. The resulting WLA was increased by 1% to account for future growth.

DO TMDLs: There are no municipal stormwater WLAs assigned to the DO TMDLs.

Turbidity TMDL: There are no municipal stormwater WLAs assigned to the Turbidity TMDL.

3.1.1.2 Construction Stormwater

Construction Stormwater permit application records indicate less than 1% of land use in the study area has been subject to construction over the last 10 years. The WLA for Stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other Stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern.

Construction and industrial sites may contribute phosphorus via sediment runoff during stormwater events. These areas within the MR-SC Watershed must comply with the requirements of the MPCA's NPDES Stormwater Program. The NPDES program requires construction sites to create a SWPPP that summarizes how stormwater will be minimized from the site. The MPCA expects that those MS4 communities with existing SWPPPs will update their SWPPP following the approval of the TMDL.

Nutrient TMDLS: The construction stormwater allocation is 1% of the watershed allocation, the allocation to the category is made after the MOS is subtracted from the total LC.

DO TMDLs: The WLA for construction stormwater discharge permits is 1.5% of the total WLA assigned.

Turbidity TMDL: The WLA for construction stormwater discharge permits is 1.5% of the total WLA assigned.

3.1.1.3 Industrial Stormwater

The National Pollution Discharge Elimination System(NPDES)/State Disposal System (SDS) Industrial Stormwater Multi-Sector General Permit (Permit #MNR050000) re-issued in April 2010 applies to facilities with Standard Industrial Classification Codes in 29 categories of industrial activity with the potential for significant materials and activities to be exposed to stormwater. Significant material include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite.

Industrial stormwater must receive a WLA only if the pollutant is part of benchmark monitoring for an industrial site in the watershed of an impaired water body (as detailed in the MPCA's September, 2011 memo, "Guidance for Setting TMDL Wasteload Allocations for Regulated Stormwater").

The Multi-Sector General Permit identifies a phosphorus benchmark monitoring value for facilities within certain sectors that are known to be phosphorus sources. The MPCA's permitted sources database shows there are no facilities in the TMDL watersheds with NPDES/SDS Industrial Stormwater Multi-Sector General Permits having phosphorus benchmarks. Therefore, TMDLs do not include an individual industrial stormwater WLA.

Within the TMDL watersheds, there are no sites that are covered under the Nonmetallic Mining & Associated Activities General NPDES/SDS (MNG490000).

Nutrient TMDLs, DO TMDLs & Turbidity TMDL: There are no industrial stormwater WLAs assigned to these TMDLs.

3.1.2 Wastewater Treatment Facilities

The WWTF are NPDES/SDS permitted facilities that process primarily wastewater from domestic sanitary sewer sources (sewage). These include city or sanitary district treatment facilities, wayside rest areas, national or state parks, mobile home parks and resorts.

Nutrient TMDLs: Table 3.2 shows the relevant WWTFs for this TMDL study and in the watershed they are located.

Table 3.2 - Relevant WWTF permits in the TMDL Watersheds

Facility	Permit Number	Watershed	City	Discharge Information
Aspen Hills WWTF	MN0066028	Orono Lake	Big Lake Township	Effluent surface discharge
Becker Municipal WWTF	MN0025666-SD-1	Orono Lake	Becker	Combined discharge
Zimmerman WWTF	MN0042331	Orono Lake	Zimmerman	Existing Stabilization Pond Facility & proposed Mechanical Class B Facility

A Water Quality Based Effluent Limit (WQBEL) was completed by the MPCA in August 2012, for Zimmerman, Becker Municipal, and Aspen Hills WWTFs (MPCA 2012e). The purpose of the WQBEL was to provide TP WQBEL recommendations for affected NPDES Permittees upstream of Lake Orono. The recommendations of the WQBEL were used in the determination of the effluent limits for the facilities as described below.

Table 3.3 - Current and permitted phosphorus loads for Aspen Hills, Becker Municipal and Zimmerman WWTFs

Facility	Design Flow (mgd)	Average Reported Flow (mgd)	Current Concentration permitted (mg/L)	Average Reported Concentration (mg/L)	Current P Load Permitted (lb/year)	Average P Load reported (lb/year)
Aspen Hills WWTF (2004-2012)	0.0195	0.0124	1.0	.912	60	24.9
Becker Municipal WWTF (2002-2012)	2.15	1.090	1.0	.608	2,575	1,460.5
Zimmerman WWTF (2002-2012	0.452	0.397	1.0	.601	1,376	526.1

Four scenarios were run using BATHTUB to investigate the effect of load reductions on the eutrophic state of Orono Lake (Figure 3.1). Based on the scenarios, the effluent limits in the WQBEL were determined to be appropriate for this TMDL. This scenario incorporates a balanced approach were both point and nonpoint source reductions are implemented. Refer to Section 4.12 *Total Phosphorus TMDL Allocations for MR-SC Watershed Lakes.*

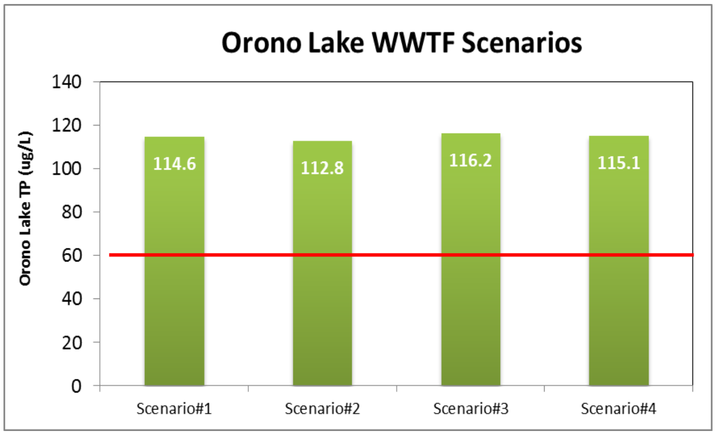


Figure 3-1 - WWTF load reduction scenarios. The red line is the total phosphorus standard for Orono Lake

Scenario 1: Current effluent conditions
Scenario 2: WWTFs removed
Scenario 3: WWTFs current limits
Scenario 4: WWTFs WQBEL

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

3.1.3 Livestock Facilities with NPDES Permits

A feedlot designated as a Concentrated Animal Feeding Operation (CAFO) is required to operate in accordance with a NPDES Permit. The feedlot meets the definition of a CAFO as defined in Federal Regulations (40 CFR: 122.23(b)(4)); or the feedlot is capable of holding 1,000 or more animal units (AU) (as defined under Minn. R. 7020.0300, subp. 5) or the manure storage area is capable of storing the manure generated by 1,000 AU or more.

Table 3.4 - Confined Animal Feeding Operations (CAFOs) within the Impaired Watersheds

CAFO NPDES Permit Holder	Permit Number	Animal Units	Watershed Location
Goenner Poultry LLC	MNG441109	396	Orono Lake
Eiler Bros.	MNG440909	1060	Orono Lake
Duane Winkleman Farm	MNG440909	864	Orono Lake

3.1.4 Straight Pipe Septic Systems

Straight pipe septic systems are illegal and therefore receive a WLA of zero. According to Minn. Stat. 115.55, subd. 1, a straight pipe "means a sewage disposal system that includes toilet waste and transports raw or partially settled sewage directly to a lake, a stream, a drainage system, or ground surface". Straight-pipe septic systems are illegal and unpermitted; the number of straight-pipe systems was not specifically enumerated for the TMDLs but they are likely to exist in the watershed.

3.2 Load Allocation

Excessive Nutrients: The LAs includes all non-permitted sources including stormwater runoff not covered by a state or federal permit. Once the WLA and MOS were determined for each watershed, the remaining LC was considered the LA.

Non-permitted sources that have the potential to contribute to excessive nutrients include
Crop farming, rural and urban residential runoff, degraded wetlands, non-CAFO livestock facilities and pastures (MPCA permitted/registered feedlots), groundwater, atmospheric deposition and internal nutrient recycling.

DO: The LA is oxygen demand from non-point sources such as headwater (defined as receiving water at the upstream boundary condition), tributary and groundwater sources and from the sediments.

Oxygen demanding sources in the watersheds addressed here include wetland sediment oxygen demand (SOD) and watershed nutrient runoff from: crop farming, feedlots and pastures, residential and urban stormwater, and septic systems.

Turbidity: The LA is the remaining load after all upstream boundary conditions and WLAs are subtracted from the total load capacity of each flow. The focus of LA is on in-stream sources and nonpoint (watershed) sources.

Watershed sources include those sources outside of the stream channel such as: field and gully erosion, livestock over-grazing in riparian areas, stormwater from construction, impervious services and agricultural land use (crop and feedlots).

In-stream sources are internal sources of turbidity that include sediment suspension, bank erosion and failure, and in-channel algal production.

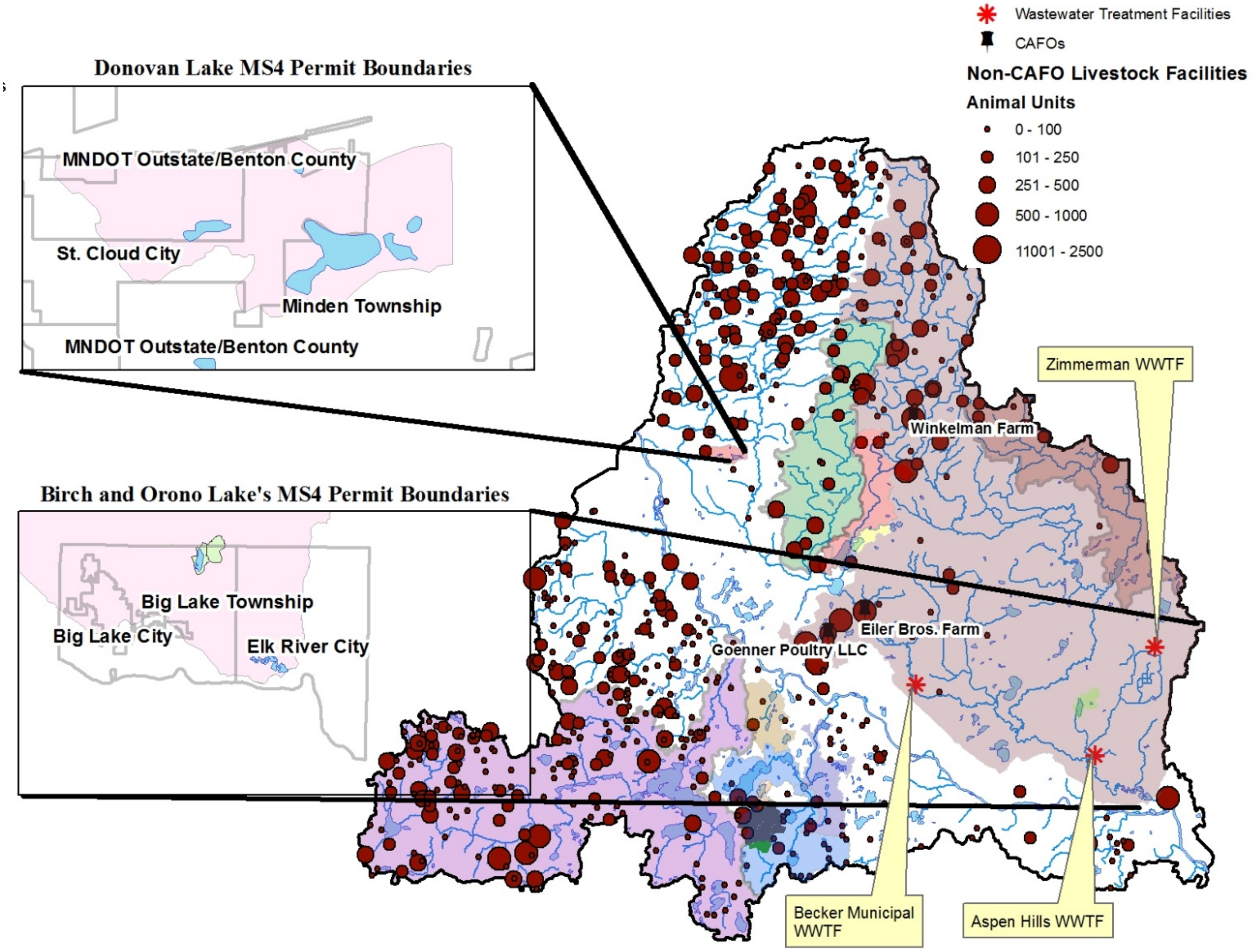


Figure 3-2 - Point Source and Non-CAFO Livestock Facility Location

3.3 Margin of Safety

Excessive Nutrients: The purpose of the MOS is to account for uncertainty that the allocations will result in attainment of water quality standards and, in this case, uncertainties in the model based on limited flow and water quality data. For the lake TMDLs a 10% explicit MOS was applied. This explicit MOS is considered to be appropriate based on the generally good agreement between the water quality models predicted and observed values. Since the models reasonable reflect the conditions in the lakes and their watersheds, the 10% MOS is considered to be adequate to address the uncertainty in the TMDLs, based upon the data available. Therefore, the load capacity that is calibrated to attain the in-lake phosphorus concentration standard is reduced by 10%.

DO: In many of the scenarios, large watershed reductions alone do not fully mitigate the DO impairment. Therefore, to achieve the TMDL, simultaneous improvements to headwater conditions and reductions in watershed loads and wetland SOD are required to provide an implicit MOS.

Turbidity: Using the CRN Region threshold of 30 mg/L to calculate the reductions is conservative. The CRN Region threshold for TSS will replace the existing turbidity standards and is described in the MPCA proposed river eutrophication standards, for more information visit: http://www.pca.state.mn.us/6paqdkc. This method implicitly accounted for the MOS in that the turbidity TMDL is conservative because load reductions prescribed are much higher than those indicated by the site specific TSS surrogate.

3.4 Consideration of Growth (Reserve Capacity)

Potential changes in population and land use over time in the MR-SC Watershed could result in changing sources of pollutants.

Excessive Nutrients: A reserve capacity is not explicitly allocated. However, the construction stormwater allocation was set at 1% to account for growth. There are no planned WWTF expansions in the impaired watersheds at this time, any proposed expansion would have to comply with permit limits that are equivalent to current WLA or realize load reduction elsewhere in the watersheds as described in the load transfer description below.

DO: A reserve capacity is not explicitly enumerated for the following reason: the dominant land use to each listed reach is agricultural. Development or conversion of agricultural lands to residential (high or low density) would likely come with reductions in CBOD and NBOD and an increase in flows, which should improve aeration by increasing velocity. For this reason, reserve capacity is essentially negative in that any planned developments should reduce loads that impact DO.

Turbidity: A reserve capacity is not explicitly allocated. However, 1.5% of the LC was allocated as WLA, which was determined to be appropriate to cover construction stormwater permits in the watershed and implicitly, growth.

Possible changes and how they may or may not impact TMDL allocations are discussed below.

3.4.1 Load Transfer

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

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be given additional WLA to accommodate the growth. This will involve transferring LA to WLA.

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 a WLA transfer.

5. A new MS4 or other Stormwater-related point source is identified. In this situation, a transfer must occur from the LA.

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

3.4.2 New and Expanding Discharges

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

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

2. The MPCA permit program will notify the MPCA TMDL program upon receipt of the request/application, and provide the appropriate information, including the proposed discharge volumes and the pollutant loads.

3. The TMDL Program staff will provide the permit writer with information on the TMDL WLA to be published with the permit’s public notice.

4. The supporting documentation (fact sheets, statement of basis, effluent limits summary sheet) for the proposed permit will include information about the pollutant discharge requirements, noting that the effluent limit is below the in-stream target and the increased discharge will maintain water quality standards. The public will have the opportunity to provide comments on the new proposed permit, including the pollutant discharge and its relationship to the TMDL.

5. The MPCA TMDL program will notify the EPA TMDL program of the proposed action at the start of the public comment period. The MPCA permit program will provide the permit language with attached fact sheets (or other appropriate supporting documentation) and new pollutant information to the MPCA TMDL program and the EPA TMDL program.

6. The EPA will transmit any comments to the MPCA Permits and TMDL programs during the public comment period, typically via e-mail. The MPCA will consider any comments provided by the EPA and by the public on the proposed permit action and WLA and responds accordingly, conferring with the EPA if necessary.

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

8. The EPA will document the update to the WLA in the administrative record for the TMDL. Through this process EPA will maintain an up-to-date record of the applicable WLA for permitted facilities in the watershed.

4 LAKES, EXCESS NUTRIENT IMPAIRMENTS

4.1 Total Maximum Daily Load Calculations

Nutrient loads in the 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.

4.1.1 Loading Capacity: Lake Response Model

The model chosen to quantify the LC was BATHTUB (Version 6.1). 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 loads are determined on an annual or seasonal basis and the summer season is critical for lake use and ecological health. Several models are available for use within the BATHTUB model. The Canfield-Bachmann natural lake model was chosen for the phosphorus model. The chlorophyll-*a* response model used was model 1 from the BATHTUB package, which accounts for nitrogen, phosphorus, light, and flushing rate. Secchi depth was predicted using the "VS. CHLA & TURBIDITY" equation. For more information on these model equations, see the BATHTUB model documentation (Walker 1999). Model coefficients are also available in the model for calibration or adjustment based on known cycling characteristics. The coefficients generally were left at the default values except for the Secchi/chl-a slope, which was decreased from 0.025 to 0.015 based on the relationship from Minnesota Lakes (Heiskary and Wilson 2005).

To arrive at both load and WLAs, a phosphorus budget was developed from average input for each source using available data from 2001 through 2011. To determine the total LC, the current nutrient budget and lake response modeling (average of 2001-2011) were used as the starting point. The nutrient inputs were then systematically reduced until the model predicted that the lakes met the appropriate TP standard. Once the TP goal is met, both the chlorophyll-*a* and Secchi response models are reviewed to ensure both response variables are predicted to meet the state standards as well. Direct atmospheric depositions and groundwater were left unchanged because this source is impossible to control.

4.1.2 Critical Conditions and Seasonal Variation

The critical period for lakes is the summer growing season. Minnesota lakes typically demonstrate the impacts of excessive nutrients during the summer recreation season (June 1 to September 30) including excessive algal blooms and fish kills. Water quality monitoring in the lakes included in this TMDL suggest the in-lake TP concentrations vary over the course of the growing season, generally peaking in mid to late summer. As such, lake goals are focused on growing season TP, Secchi transparency and chlorophyll-*a* concentrations.

4.2 Modeling Approach and Phosphorus Budget Components

The data described below was used to establish the current annual phosphorus budget for the lakes and was input into a lake response model to predict lake response. A BATHTUB lake response model was constructed using the nutrient budget developed using the methods described in the sections below. For each of the impaired lakes, between 4 and 10 years of in-lake water quality data were available between the years of 2001-2011, against which to calibrate and validate the model.

4.2.1 Watershed Runoff and Phosphorus Load

Average annual watershed runoff was estimated from long term data records at two locations, one north of the Mississippi River at the USGS station 05275000 located on the Elk River and the other south of the Mississippi River at the Grass Lake Dam, river mile 9.5 on the Clearwater River (Table 4.1). Both long term stations were considered to be appropriate and representative for watershed runoff for lakes with unmonitored inflows/outflows. The location of the long term flow gauging stations can be seen in Figure 1.2. The USGS station runoff was used to calculate water budgets in the lakes north of the Mississippi River (and Fish Lake) and the Grass Lake dam runoff was used for lakes south of the Mississippi River.

Phosphorus loading from subwatersheds was calculated by multiplying measured flow weighted mean phosphorus concentration for each year by runoff volume. In the cases where watershed monitoring data was not available, average monitoring data from nearby subwatersheds with similar land use/ecoregion/and soil type conditions were used to calculate phosphorus loading. Calculated subwatershed phosphorus loads were then input into the BATHTUB model (Appendix A, Lake TMDL supporting Documents).

Table 4.1 - Average Annual runoff (inches) calculated from long term flow gauging stations for TMDL lakes

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Elk River (05275000)	8.1	11.7	7.1	6.3	8.7	5.6	4.8	5.7	5.7	8.7	12.7
Grass Lake Dam (CR 9.5)	2.8	7.6	6.5	2.8	8.6	4.2	3.0	2.0	7.6	13.1	18.8

4.2.2 Subsurface Sewage Treatment Systems (SSTS)

Failing SSTS can be a significant source of phosphorus to surface waters. Past studies and conversations with local zoning authorities indicate the potential range of failure rates as follows: 10%-25% for Sherburne County systems and 25%-35% for Wright County systems in the areas riparian to these waters. The SSTS specific to each water body are described in more detail in lake characterizations below.

Shoreland septic system phosphorus contributions are accounted for and allocated under the watershed LA as the actual contributions are implicitly accounted for in the monitoring data used to calculate watershed loading. However, the total septic load to each lake can be calculated by multiplying the number of SSTS around the lakes assuming four persons per home and a TP load of 4.2 pounds (lb) of phosphorus per system per year. The TP septic load to the lakes can then be determined by multiplying the total septic system load by an assumed failure rate. For example, for Briggs Lake there are 177 SSTS on the lake. Based on the assumptions the range of potential septic loads to the lake could be calculated as follows:

(177 systems)*(4.2 TP/year per system)*(10% failure rate) = 74 lb/year (Septic Load to Lake)
(177 systems)*(4.2 TP/year per system)*(25% failure rate) = 123 lb/year (Septic Load to Lake)

4.2.3 Loading from Upstream Lakes

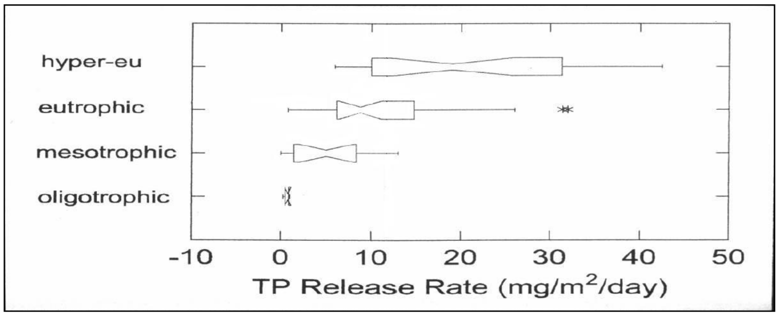
For the lakes included in this TMDL that are linked, average growing season lake water quality data for the upstream lake was used to characterize watershed export. In these cases, the upstream lake functioned as the boundary condition.

Nutrient and water budgets for lakes with approved TMDLs within a lake watershed included in this TMDL were included in the nutrient budget but existing phosphorus allocations within the approved TMDL watershed will remain unchanged. The only lake this applies to is Lake Orono; Big Elk Lake is located upstream and has a TMDL which was approved in 2012.

4.2.4 Internal Loading

To estimate internal loading, an anoxic factor, which estimates the period where anoxic conditions exist over the lake bottom sediments was estimated from the DO profile data, where available, or from literature using the anoxic factor approach (Nurnberg 2004). The anoxic factor is expressed in days but is normalized over the area of the lake. Under this approach, a release rate was then estimated based on monitoring. The selected release rates are a range based on previous lake studies (Nurnberg 1997). The anoxic factor is then used, along with a sediment release rate, to estimate the TP load from the sediments.

Table 4.2 - Sediment phosphorus release rates by eutrophic conditions (Nurnberg 2007)



4.2.5 Atmospheric 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 to Minnesota Watersheds" (Barr Engineering, 2004), and are based on annual precipitation. The values used for dry (less than 25 inches), average, and wet precipitation years (less than 38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km2-year or 0.22, 0.24, and 0.26 lb/acre-years respectively.

4.2.6 Groundwater

Existing data was used to calculate the groundwater component of the water balance for the lakes. A range of groundwater inflow to each of the lakes was calculated using regional values for hydraulic conductivity for the Anoka Sand Plain, hydraulic gradient from the regional hydrogeological atlas and Darcy's Law. Resulting phosphorus loads were then calculated based on inflow using the statewide median phosphorus concentration for surficial glacial aquifers of 56 µg/L (MPCA, 1999). Each response model was calibrated within the range of conditions as calculated above.

Using the described model inputs, BATHTUB provided the following predictions:

Table 4.3 - Calibrated model prediction table

Watershed	Average Observed Lake Conditions (µg/L)	Average Predicted Lake Conditions (µg/L)	Estimated annual Phosphorus Load (lb)
Donovan Lake	129	127	352
Julia Lake	62	60	376
Briggs Lake	75	72	3,032
Rush Lake	106	104	2,765
Birch Lake	41	39	267
Upper & Lower Orono Lake	115	115	98,605
Fish Lake	48	48	717
Mink Lake	132	133	2,125
Somers Lake	81	87	1,025
Silver Lake	79	82	3,134
Indian Lake	47	48	315
Locke Lake	68	65	4,199

4.2.7 Source assessment summaries

A geographic information system (GIS) search of sources that should be considered upon implementation, including land use, is listed in Table 4.4 and Table 4.5. Permitted sources falling within the watershed are specifically listed under section 3.1. *Wasteload Allocations.*

Table 4.4 - Nonpoint sources to be considered in the TMDL watersheds.

Watershed	Number of MPCA Registered Feedlots	Primary Livestock Type	Animal Units	SSTS[1]	Permitted Sources in Watershed
Donovan Lake	--	--	--	--	Yes
Julia Lake	--	--	--	116	No
Briggs Lake	3	Bovine	950.0	177	No
Rush Lake	1	Birds	150.0	90	No
Birch Lake	--	--	--	31	Yes
Watershed	**Number of MPCA Registered Feedlots**	**Primary Livestock Type**	**Animal Units**	**SSTS[1]**	**Permitted Sources in Watershed**
Upper and Lower Orono Lake	72[2]	Bovine	11,200.2	76	Yes
Fish Lake	2	Bovine	163.0	94	No
Mink Lake	6	Bovine	672.5	24	No
Somers Lake	--	--	--	5	No
Silver Lake	18[3]	Bovine	1,536.9	28	No
Indian Lake	2	Bovine	284.5	77	No
Locke Lake	6[4]	Bovine	358.6	242	No

1 Based on County Records, lots with SSTS in shore land area. Conversations with local government units (LGU) document an estimated 10-35% failure rate.

2 Does not include livestock in the Big Elk Lake Watershed (boundary condition).

3 Excluding those already listed in Mink and Somers Lake watershed.

4 Excluding those already listed in Silver, Mink, and Somers Lake watersheds.

Table 4.5 – National Land Cover Database (NLCD) 2006 Land use in the impaired lakes watersheds (acres).

Impaired Watershed	Hay/Pasture	Cultivated Cropland	Forest	Developed	Wetland	Natural Areas[2]	Open Water
Donovan Lake	17%	38%	8%	14%	20%	0%	3%
Birch Lake	4%	0%	65%	2%	28%	0%	3%
Julia Lake	9%	3%	69%	15%	4%	0%	1%
Briggs Lake[1]	13%	26%	36%	11%	12%	0%	2%
Rush Lake[1]	12%	24%	35%	11%	11%	0%	6%
Upper & Lower Orono Lake[1]	18%	27%	25%	10%	17%	0%	2%
Fish Lake	29%	11%	37%	11%	7%	0%	6%
Mink Lake	9%	58%	10%	16%	7%	0%	1%
Somers Lake[1]	7%	51%	9%	14%	6%	0%	12%
Indian Lake	4%	49%	32%	14%	0%	0%	0%
Silver Lake[1]	10%	37%	21%	10%	10%	0%	12%
Locke Lake[1]	11%	33%	24%	10%	11%	0%	11%

1 includes upstream lakes

2 includes barren and shrublands

Table 4.6 - TMDL Lake morphology

Lake Name	Lake DNR ID	Lakeshed Area (acres)	Lake Surface Area (acres)	% Littoral	Max Depth (feet)	Mean Depth (feet)	Volume (ac-ft.)
Donovan Lake (Main Bay)	05-0004-02	1,026	54	100%	5	4	90
Julia Lake	71-0145	725	152	89%	15	8	1,203
Briggs Lake	71-0146	8,619	404	54%	25	13	5,211
Rush Lake	71-0147	8,892	160	100%	10	5	984
Birch Lake	71-0057	726	154	77%	18	10	1,577
Orono Lake	71-0013-01 & 02	388,129	300	94%	18	5	1,500
Fish Lake	86-0183	4,421	96	56%	38	13	4,421
Mink Lake	86-0229	2,320	298	86%	30	6	1,700
Somers Lake	86-0230	2,528	147	100%	15	10	1,477
Silver Lake	86-0140	18,921	83	31%	42	17	1,378
Indian Lake	86-0223	445	135	41%	31	17	2,285
Locke Lake	86-0168	24,624	133	31%	49	18	3,026

4.3 Donovan Lake

4.3.1 Watershed and Lake Characterization

Donovan Lake represents the only natural, deep marsh/shallow lake in Benton County, Minnesota. The average TP and chlorophyll-*a* values for Donovan Lake exceed the water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the MR-SC Lakes Assessment Report (2012b). Refer to Table 4.6 for lake morphology records.

The watershed is small with an area of 1,026 acres and a watershed to lake area ratio of 19:1. To this point, the majority of the watershed land use is composed of agricultural related practices including corn and soybean crop rotations and pasture land (Table 4.5). Residential development began to encroach on the west side of the watershed in 2003; however, due to a slow in the economy, these areas remain relatively vacant.

The Benton County Comprehensive Plan (2005) indicates that the shoreline around the lake has a number of moderate-quality natural communities which help to buffer the lake from surrounding areas. Additionally, St. Cloud's Stormwater drainage maps indicate that a majority of the runoff from the new developments is treated prior to discharge into the lake.

Assessment of 2011 aerial photos revealed a ditched inlet on the North West bay of the lake which originates at an agricultural field. Through the use of aerial imagery we determined there is no buffer between the cropland and the ditch.
A development on the west side has been constructed since the land use classification used in Table 4.6 was completed. Stormwater drainage maps obtained from the City of St. Cloud indicate that stormwater from the developed area is routed into infiltration ponds rather than the lake. The stormwater map can be found in Appendix A.

4.3.2 Total Phosphorus TMDL Allocation

The lake response model was calibrated with four years of in-lake water quality data collected from 2003-2006. The baseline for this lake TMDL is 2006. Calibrated models determined the current phosphorus load is 352 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Donovan Lake is 143 lb/year. The TMDL is listed in Table 4.7 at the end of this section.

4.3.3 Impairment Summary

- In-lake phosphorus and chlorophyll-*a* concentrations violated the TMDL shallow lake goals during all years sampled.

- While the watershed is small, land use runoff has the potential to influence in-lake health.

- No fish surveys have been conducted since the 1950's. Notes from those surveys indicated that fisheries could not be supported due to low water and loss of oxygen during winter.

- The last aquatic plant survey was done in 1951, while native species were noted as present; there has likely been a change in populations since that time.

- Between 2003 and 2006 approximately 275 acres of agricultural land on the west side of the lake was rezoned into Residential Planned Unit Development; due to a slow in the economy, the area remains relatively vacant.

- Internal nutrient recycling may contribute to reduced water quality; however there is little data available to support contributions.

- Permitted Sources are assigned a categorical WLA: St. Cloud MS4 (MS400052, Benton County MS4 (MS440067); Minden Township MS4 (MS400147); MNDOT Outstate District MS4 (non-traditional) (MS400180).

4.4 Briggs Lake Chain (Julia, Briggs and Rush Lakes)

4.4.1 Lake and Watershed Characterization

Julia, Briggs and Rush Lakes are connected by channels and Big Elk Lake is located nearby. Big Elk Lake receives flow from both Elk River and Lily Creek. Julia, Briggs, and Rush Lakes are drained by Lily Creek. All four lakes together are commonly referred to as the Briggs Chain of Lakes and are characterized together due to their interconnectedness. Big Elk Lake is not addressed in this TMDL as a TMDL was completed and approved for the lake in June 2012. In order for Big Elk Lake to meets its TMDL goal, the Briggs Chain of lakes must meet state water quality standards for phosphorus, chlorophyll-*a* and Secchi depth.

The lake shore property around these and many lakes in Sherburne County, Minnesota tend to be densely populated. Much of the development occurred prior to the adoption of shore land ordinances. Subsequently, many lots are as small as 50 feet in width and most natural vegetation has been removed from the shorelines and replaced with turf grass. All homes riparian to the lakes are served by SSTS. Based on records obtained by Sherburne County, there are 396 residential units with SSTS and 55 have no records filed with the County. The Elk River Watershed Multiple TMDLs (MPCA 2012f) indicates there may be anywhere from a 10%-25% failing rate of SSTS in the watershed.

Julia Lake

Julia Lake, a small shallow lake, is the first lake in the Briggs Chain of Lakes. The average TP and chlorophyll-*a* values for the lake hover near the water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (2012b). Refer to Table 4.6 for lake morphology records.

A minor tributary, Julia Creek, flows in from the northeast and the watershed specific to Julia Lake is small with an area of 725 acres and a watershed to lake area ratio of 5:1. Land use is dominated by forested areas (Table 4.5). Cropland and developed land make up the remaining land use in the watershed.

Briggs Lake

Briggs Lake, the only deep lake in the system, is the second lake in the chain. The average TP and chlorophyll-*a* values for the lake are well above the water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (2012b). Refer to Table 4.6 for lake morphology records.

In addition to inflow from Julia Lake, the primary tributary is Briggs Creek, which enters on the north end of the lake. Briggs Creek drains a fairly extensive area and originates in Benton County. The Elk River periodically overflows into Briggs Lake via the bayou on the south west corner of the lake. The watershed is moderately sized with an area of 8,619 acres and a watershed to lake area ratio of 21:1. Watershed land use is dominated by cultivated cropland consisting primarily of corn and soybean rotations followed by forest and pastured areas (Table 4.5).

Rush lake

Rush Lake, a small shallow lake, is the third lake in the chain. The average TP and chlorophyll-*a* values for the lake are well above the water quality standard for shallow lakes in the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (2012b). Refer to Table 4.6 for lake morphology records.

Rush lake is connected to Briggs Lake on the west side. The watershed is moderately sized with an area of 8,892 acres and a watershed to lake area ratio or 56:1. The portion of the watershed directly draining to the lake (excluding Briggs and Julia Lake) is small and land use is dominated by forest and equal amounts of cropland, pasture/hay land, and developed areas (Table 4.5). Therefore, water quality in Rush Lake depends largely on upstream water quality in Briggs Lake.

Significant efforts have been made by the Briggs Lake Chain Association, Sherburne SWCD, Sherburne County, and the DNR to identify pollutant sources and restore the Lake Chain over the years. All of these works were considered in development of the TMDL.

4.4.2 Total phosphorus TMDL Allocation

The Briggs Lake Chain response models were calibrated using data collected via the Briggs Chain Mass Balance (Sherburne SWCD, 2008) as these are the years with the most extensive data (2006 and 2007). Average calibrated models determined the current cumulative phosphorus load is 6,173 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Julia Lake is 376 lb/year, Briggs Lake is 1,349 lb/year and Rush Lake is 1,436 lb/year The TMDL is listed in Table 4.9, Table 4.11, and Table 4.13 at the end of this section.

4.4.3 Impairment Summary

Julia Lake

- All data indicates that the quality of Julia Lake needs to be protected.
- Over the last 10 years, in-lake summer phosphorus and chlorophyll-*a* have hovered near (even below) the State standard for shallow lakes. Water Clarity, on the other hand, has decreased.
- Previous water quality studies, as well as work conducted by the Briggs Lake Chain Association, have provided a substantial dataset with which to identify sources contributing to water quality degradation; still, local knowledge and input are fundamental.
- The lake has a small, forest-dominated watershed which can provide excellent stormwater filtration.
- 2009 DNR fisheries surveys indicate that rough fish, including carp are common in the lake chain.
- While Phosphorus may be within the state established guidelines, it is clear that algae blooms still occur. Low water clarity may be caused by excessive algae growth in absence of native aquatic plants.
- Julia and Rush Lakes received “whole-lake” treatment for curly-leaf pondweed (CLP) from 2006-2009 and all three lakes continue to receive partial treatment. Notes from 2009 DNR aquatic plant surveys indicated that biomass was reduced and native species appeared to be on the rise.
- Stream nutrient samples taken in 2006 and 2007 on Julia Creek indicated very good quality of water.
- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 49-122 lb/year.

Briggs Lake

- Over the last 10 years, in-lake summer phosphorus and chlorophyll-*a* have varied greatly, however all years data have exceeded the deep lake goals.

- Previous water quality studies, as well as work conducted by the Briggs Lake Chain Association, have provided a substantial dataset with which to identify sources contributing to water quality degradation; still, local knowledge and input are fundamental.

- Past monitoring (Sherburne SWCD 2008) indicates that under certain conditions, the Elk River overflows into Briggs Lake via the bayou on the south west side of the lake. No data exists to indicate the specific conditions under which this occurs.

- Stream nutrient samples taken in 2006 and 2007 on Briggs Creek indicated TP values within ecoregion reference conditions for the NCHF.

- In 2009, DNR fisheries surveys indicate that rough fish, including carp are common in the lake chain.

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 74-186 lb/year.

Rush Lake

- In-lake summer phosphorus, chlorophyll-*a* and Secchi disk depth have exceeded the standard for shallow lakes nearly all years sampled. Interestingly, there was a period of time (early 1990's) that water quality seemed to be improving.

- Previous water quality studies, as well as work conducted by the Briggs Lake Chain Association, have provided a substantial dataset with which to identify sources contributing to water quality degradation; still, local knowledge and input are fundamental.

- Upstream lakes (Briggs & Julia) influence the quality of water in Rush Lake.

- Based on available information, internal nutrient recycling has a major impact on the quality of water in Rush Lake.

- In 2009, DNR fisheries surveys indicate that rough fish, including carp are common in the lake chain.

- Julia and Rush Lakes received "whole-lake" treatment for CLP from 2006-2009 and all three lakes continue to receive partial treatment. Notes from 2009 DNR aquatic plant surveys indicated that biomass was reduced and native species appeared to be on the rise.

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 38-95 lb/year.

4.5 Birch Lake

4.5.1 Lake and Watershed Characterization

Birch Lake is a deep lake located in Big Lake Township in Sherburne County, Minnesota. The average TP and chlorophyll-*a* values for the lake hover just above the water quality standard for deep lakes within the ecoregion. A detailed description of water quality can be found in the MR-SC Lakes Assessment Report (2012b). Refer to Table 4.6 for lake morphology records.

The watershed is small with an area of 727 acres and a watershed to lake area ratio of 5:1. Forest and wetland land uses make up over three quarters of the total watershed area (Table 4.5). Small pockets of residential development interrupt forested areas, particularly along the lake shore. All homes riparian to the lake are served by SSTS. Based on a GIS search, there are 31 residential units directly surrounding the lake. Past studies cited in the Elk River Watershed Multiple TMDLs (MPCA 2012f) indicate there may be anywhere from a 10%-25% failing rate of SSTS in the watershed.

The primary inlet enters on the northeast corner of the lake from Mud Lake, a small seasonally flooded, drained wetland. Much of the watershed area flowing to Mud Lake is within the Sand Dunes State Forest.

Due to a high percentage of littoral area (78%) heavy emergent and submergent macrophytes grow over much of the basin. In addition to the presence of native vegetation, CLP is reported to be growing in isolated areas around the lake. Additionally, the lake is reported by the DNR to be susceptible to winterkill and the lake association operates and maintains aeration equipment as needed over the ice-on season.

In addition to this TMDL study, a Subwatershed Watershed Assessment was completed in 2013 (Sherburne SWCD, 2013). The assessment provides recommendations for cost effectively improving treatment of stormwater from rural residential neighborhoods surrounding the lake before it is discharged into the lake.

4.5.2 Total phosphorus TMDL Allocation

The lake response model was calibrated with three years of in-lake water quality data collected between 2001 and 2011. The baseline for this lake TMDL is 2010. Calibrated models determined the current phosphorus load is 267 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Birch Lake is 267 lb/year, equal to the current phosphorus budget.
Note that the average 10-year phosphorus concentration is very close to the goal and the lake response model predicts lake water quality to be at or below the water quality goal. Still, a MOS was applied to ensure the lake meets water quality standards and WLA and LA were set based on the LC of the lake. This approach will ensure the lake is protected from further degradation. The TMDL is listed in Table 4.15 at the end of this section.

4.5.3 Impairment Summary

- All data indicates that the quality of Birch Lake needs to be protected from degradation.

- In-lake summer phosphorus, Chlorophyll-*a* and Secchi Depth data all linger close to deep lake goals. In 2011, all listed parameters were within acceptable levels.

- The lake has a small, forest-dominated watershed which provides filtration prior to water entering the lake.

- Mud Lake flows in from the east. No flow or phosphorus data has been collected there; this wetland comes in from what appears to be a relatively un-impacted watershed.

- Historical (1999) reports indicate that heavy emergent and submergent vegetation, excellent fish and wildlife habitat; there are no known current vegetation surveys.

- Reports indicate that Birch Lake is susceptible to winterkill; after the last occurrence in 1997, aeration equipment was installed.

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 13-33 lb/year.

4.6 Upper and Lower Orono Lake

4.6.1 Lake and Watershed Characterization

Orono Lake (Upper and Lower) is a moderately sized shallow lake located in the City of Elk River, in Sherburne County, Minnesota. The average TP and chlorophyll-*a* values for Upper and Lower Lake Orono do not meet the water quality standards for shallow lakes in the ecoregion. A detailed description of water quality can be found in the MR-SC Lakes Assessment Report (MPCA 2012b). Refer to Table 4.6 for lake morphology records.

Lake Orono is situated 1.1 miles above the confluence of the Elk River with the Mississippi River and was created when the Elk River Dam was constructed in 1915. The entire Elk River Watershed drains through the lake. As such, the Elk River is the dominant factor in the lake's water quality. In addition to inflow from the Elk River, there is minor inflow on the north side of Upper Orono Lake draining a residential area. The extensively sized watershed has an area of 333,129 acres and a watershed to lake area ratio of 1,294:1. Land use in the northern portions of the watershed is primarily agricultural and feedlot density is high (Table 4.54). The southern portion of the watershed is mainly comprised of irrigated agriculture and residential developments. Most of the homes surrounding the lake are on the city sewer system; however, there are 71 homes with SSTS remaining on the north side of the lake on Island View Drive and 5 along 186th Avenue Northwest on the south-west.

Because Lake Orono was created by installing a dam on the Elk River, the lake is still functioning like a portion of the river with the local floodplain inundated. Lake Orono is in essence an active riverine channel/flowage lake. This means that the location and shape of sediments in Lake Orono will continue to change as the system seeks equilibrium, even if the sediment volume remains the same or changes only slightly. Aggradation is more likely to impede navigation and lake access in the upper portion of the lake with scour in the lower portion. The lake was drawn down in 1999 to allow dredging of accumulated sediment in selected areas. Lake users currently express the need for another dredging operation due to sediment accumulation in the upstream portions of the lake.

Due to the aggradation of the upper portions of the lake, dense vegetation grows over much of the area and has been reported to impede navigation for some residents. The CLP has been surveyed and reported by the DNR as rare to moderate in some locations. Most CLP was found along the east shore in the north basin growing in 4-4.6 feet of water.

4.6.2 Total phosphorus TMDL Allocation

The boundary conditions for the lake TMDL were set at Big Elk Lake (71-0148) because a TMDL was completed and approved for that lake in 2012, all allocations set in the approved TMDL will still hold true. That is to say, the Lake Orono TMDL is established by assuming Big Elk Lake meets its TMDL. Additionally, upper and lower Orono water quality samples were averaged and used as input into the lake response model as it was determined that there are not significant differences in the TP, chlorophyll-*a* or Secchi disk levels in the upper vs. lower portions of the lake.

The lake response model was calibrated with five years of in-lake water quality data collected between 2002 and 2011. The baseline for this lake is 2009. Calibrated models determined the current phosphorus load is 98,605 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Upper and Lower Orono Lake is 50,815 lb/year. The TMDL is listed in Table 4.17 at the end of this section.

4.6.3 Impairment Summary

- In-lake phosphorus concentrations exceeded the TMDL goals during all years sampled.

- Current water quality is not surprising considering Lake Orono's very small volume and size relative to the size of the watershed; in-lake water health is dominated by the Elk River. Like Big Elk Lake, the water quality in the lake is closer to river water quality than lake basin water quality.

- A vegetation survey conducted by the DNR in June 2012 found the diversity of native plant species to be low overall; however, there were more native plants present than initially thought. Both native plants (frequency 1%-49%) and CLP (frequency 33%) were present in higher quantities north of Highway 10; boaters have voiced trouble with navigation in this area.

- Internal recycling of nutrients may contribute to reduced water quality; however the upstream drainage area seems to have the largest impact on water quality.

- A fish survey conducted in 2008 indicated the presence of rough fish including both black bullhead and common carp.
- Big Elk Lake has an approved TMDL (2012); source reductions in that watershed remain as allocated

in that TMDL.

- Zimmerman and Becker WWTF- due to the large size of the watershed, the impact of the current discharge limits are minimal compared to other sources. However, discharge limits are recommended to be set at MPCA's WQBEL (August 2012).

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 32-80 lb/year.

4.7 Fish Lake

4.7.1 Lake and Watershed Characterization

Fish Lake is a deep lake located approximately three miles southeast of Clearwater, in Wright County, Minnesota. The average TP and chlorophyll-*a* values for the lake are above the water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (2012b). Refer to Table 4.6 for lake morphology records.

There are three inflow tributaries into the lake including Fish Creek which enters the lake from the south and two smaller perennial ditched tributaries; one entering from the northwest and the other from the southeast. The outlet exits on the northeast corner of the basin and flows into the Mississippi River. The watershed is moderately sized with an area of 4,421 acres and a watershed to lake area ratio of 46:1. Agricultural uses, composed of equal amounts of cropland and pasture land, dominate the land use in the watershed (Table 4.5). Forested and open spaces also make up a sizable area of the watershed (25%). All homes riparian to the lakes are served by SSTS. Based on records obtained by Wright SWCD, there are 94 residential units with SSTS surrounding the lake, failure rates were estimated to range from 30%-35%.

During high water the Mississippi River backflows into the lake causing fluctuations in lake water level. This connection likely has an impact on the quality of water in the lake. Wright SWCD will be placing a continuous level logger at the outlet of Fish Lake in 2013 which will aid in understanding the effect of the Mississippi River on Fish Lake. The connection to the Mississippi river allows fish and other aquatic species to enter the lake. Zebra mussels and Eurasian water milfoil have been confirmed by the DNR. Aquatic plants were noted to be abundant by the DNR during their last survey in 2004.

4.7.2 Total phosphorus TMDL Allocation

The lake response model was calibrated with 10 years of in-lake water quality data collected between 2002 and 2011. The Elk River USGS long term flow station was used to calculate watershed runoff and loading as the lake characteristics of the watershed and lake were determined to more closely represent that of lakes in the Elk River watershed north of the Mississippi River. Monitoring data collected by Wright SWCD was used as reference for water quality conditions in the two ditched tributaries.

Calibrated models determined the current phosphorus load is 717 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Fish Lake is 561 lb/year The TMDL is listed in Table 4.19 at the end of this section.

4.7.3 Impairment Summary

- In-lake phosphorus, chlorophyll-*a* and Secchi disk depth have varied throughout the years, however they typically hang at or near the State standard.

- Fish Lake is connected to Mississippi River by a short stream; high water on the river often causes the level of Fish Lake to rise.

- 2009 and 2010 tributary monitoring data indicated that the highest concentrations of phosphorus flow in from Fish Creek and the north-west ditched inlet. Watershed load reductions should be targeted towards this drainage area. Very low phosphorus concentrations were observed in the south east ditched inlet.

- Inflow from Fish Creek, a tributary from Sheldon Lake and the primary inlet to Fish Lake, has a major influence on water quality of Fish Lake.

- Most recent DNR fisheries report indicated low levels of rough fish including carp.

- The 1992 Lake Assessment Report indicated that copper sulfate was applied for several years to control algae and that a long-term solution was being sought.

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 99-138 lb/year.

4.8 Mink and Somers Lakes

4.8.1 Lake and Watershed Characterization

Mink and Somers Lakes are connected lakes located near Maple Lake in Wright County, Minnesota. Both Lakes are shallow, turbid, and experience water level fluctuations. Historical surveys indicated that while Mink and Somers Lakes are classified as separate basins, water levels typically fluctuate as one lake. Due to their connectedness, the lakes are characterized together.

Homes riparian to both lakes are served by individual SSTS. Based on records obtained by Wright SWCD, there are 24 residential units with SSTS surrounding Mink Lake and 5 on Somers Lake, failure rates were estimated to range from 30%-35%.

Mink Lake

Mink Lake is the first lake in the chain and is located near the headwaters of Silver Creek which originates as a series of channelized headwater tributaries in the south west area of the MR-SC watershed. The average TP and chlorophyll-*a* values for Mink Lake do not meet the water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (2012b). Refer to Table 4.6 for lake morphology records.

While there are no major inflows, there are two ditched perennial streams which flow into the lake on the east and west sides. Mink Lake flows directly into Somers Lake. The watershed is small with an area of 2,320 acres and a watershed to lake area ratio of 8:1. Land use is dominated by cultivated cropland consisting primarily of corn and soybeans rotations. Pasture and hay land also cover significant areas (Table 4.5).

Somers Lake

Mink Lake is the only inflow to Somers Lake. The average TP and chlorophyll-*a* values for the lake are above the water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (2012b). Refer to Table 4.6 for lake morphology records.

Records infer that Mink Lake acts as a settling basin for Somers Lake. The watershed is relatively small with an area of 2,528 acres and a watershed to lake area ratio of 17:1. The watershed area, not first flowing into Mink Lake, is 208 acres composed chiefly of cultivated cropland followed by pasture and hay lands (Table 4.5).

The DNR records note that the lakes tend to winterkill and fishing is often boom or bust. The lakes were reclaimed with Rotenone in 1994, and the DNR implemented special fishing regulations after that.

4.8.2 Total phosphorus TMDL Allocation

The lake response models were calibrated with ten years of in-lake water quality data collected between 2001 and 2011. Calibrated models determined the current cumulative phosphorus load is 3,150 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Mink Lake is 649 lb/year, and Somers Lake is 597 lb/year. The TMDL for these lakes are listed in Table 4.21 and Table 4.23 at the end of this section.

4.8.3 Impairment Summary

Mink Lake

- In-lake phosphorus and chlorophyll-*a* concentrations exceeded the TMDL shallow lake goals during all years sampled.
- While water clarity seems to have remained the same over the last ten years, TP and chlorophyll-*a* declined after 2007. It is unclear if this trend will continue.
- While watershed runoff is a major contributor, in-lake nutrient goals will not be met if internal nutrients sources are not addressed.
- Mink Lake acts as a settling basin for Somers Lake.
- Point-intercept surveys conducted in July 2009, indicated 88% frequency of CLP in both Mink and Somers Lakes. Filamentous algae blooms were also frequently observed.
- Based on previous studies, non-compliant septic systems have been noted as a potential contributor

of nutrients to the lakes.

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 25-35 lb/year.

Somers Lake

- While in-lake TP exceeded State goals for both lakes, Somers Lake typically has lower concentrations than Mink Lake; the same trend appears with chlorophyll-*a* and Secchi depth.

- Based on available data, it appears that Mink Lake acts as a settling basin for Somers Lake.

- While land use runoff is a major contributor, in-lake nutrient goals will not be met if internal nutrients sources are not addressed.

- Aquatic plant surveys conducted in July 2009 indicated a high frequency of CLP in both Mink and Somers Lakes. Filamentous algae blooms were frequently observed.

- Mink and Somers Lakes are classified as separate basins but water levels are equal as they fluctuate as one lake.

- Both lakes were treated with Rotenone (complete fish kill) in 1994. Pre-treatment population estimates showed carp populations ranged from 400-800 lb/acre. A 2011 fisheries survey noted no reproduction has occurred since that time.

- Based on historical surveys and local information, leaking septic systems have been noted as a potential contributor of nutrients to the lakes.

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 5-7 lb/year.

4.9 Silver Lake

4.9.1 Lake and Watershed Characterization

Silver Lake is a deep flow-through lake located near Maple Lake in Wright County, Minnesota. The average TP and chlorophyll-*a* values for Silver Lake do not meet water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (MPCA 2012b). Refer to Table 4.6 for lake morphology records.

Silver Creek and Sandy Creek are the two inflows to the lake. Silver Creek is the primary inflow and plays a large role in determining the water quality and fish community of the lake particularly when the water levels are high. Sandy Creek flows in through the north via Sandy Lake and has excellent water quality.

The Silver Lake watershed is hefty with a total area of 18,921 acres and a watershed to lake area ratio of 228:1. Approximately half of the total area of the watershed is composed of cultivated cropland and pastured and hay land areas (Table 4.5). Open space and forested areas make up another quarter of the watershed area. Homes riparian to the lake are served by SSTS. Based on records obtained by Wright SWCD, there are 28 residential units with SSTS surrounding the lake, failure rates were estimated to range from 30%-35%.

The DNR records indicate that Eurasian water milfoil was recently discovered in the lake and has become a major component of the submerged plant community.

4.9.2 Total phosphorus TMDL Allocation

The lake response model was calibrated with four years of in-lake water quality data collected between 2002 and 2007. Calibrated models determined the current cumulative phosphorus load is 3,134 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Silver Lake is 1,361 lb/year The TMDL is listed in Table 4.25 at the end of this section.

4.9.3 Impairment Summary

- In-lake phosphorus exceeded the State standard during all years monitored; water clarity and chlorophyll-*a* exceeded standards with the exception of 2002.

- Silver Creek flows through the lake and plays a large role in determining the water quality of Silver Lake.

- Water moving into the lake through the north via Sandy Creek is very low in nutrients.

- Internal recycling of nutrients may contribute to reduced water quality, particularly during low flow; however, the drainage area seems to have the largest impact on water quality.

- Eurasian water milfoil was confirmed present by the DNR in 2012; CLP was identified to be present but rare.

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 29-41 lb/year.

4.10 Indian Lake

4.10.1 Lake and Watershed Characterization

Indian Lake is located near the City of Annandale in northwest Wright County, Minnesota. Indian Lake is a deep, seepage lake, meaning there are no inlets or outlets flowing into or out of the lake. The average TP and chlorophyll-*a* values for Indian Lake are slightly above the water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (MPCA 2012b). Refer to Table 4.6 for lake morphology records.

The watershed is small with an area of 445 acres and a watershed to lake area ratio of 3:1. The watershed is primarily composed of agricultural land use consisting of cultivated crops predominantly composed of corn and soybean rotations as well as pastured and hay land (Table 4.5). All homes riparian to the lakes are served by SSTS. Based on records obtained by Wright SWCD, there are 77 residential units with SSTS surrounding the lake, failure rates were estimated to range from 30%-35%.

The CLF has been reported by the DNR to grow to nuisance levels in the spring in most of the near shore areas. Eurasian water milfoil was discovered on the lake in 2003 during the vegetation survey.

4.10.2 Total phosphorus TMDL Allocation

The lake response model was calibrated with seven years of in-lake water quality data collected between 2002 and 2008. Calibrated models determined the current cumulative phosphorus load is 3,134 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

Calibrated models estimate that the existing average year phosphorus load is of 315 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Indian Lake is 231 lb/year. The TMDL is listed in Table 4.27 at the end of this section.

4.10.3 Impairment Summary

- In-lake phosphorus, chlorophyll-*a* and Secchi disk depth have varied through the years, however they typically hang at or near the State Standard.

- The following characteristics seem to protect the quality of water in Silver Lake: very small watershed, relatively high percentage of deep waters.

- Two small ditched inlets flow into the south east corner of the lake; no water quality monitoring has been gathered.

- The most recent aquatic plant survey was done in 2003, Eurasian water milfoil was confirmed present at that time; additionally, CLP was identified as growing to nuisance levels in the spring in most of the near shore areas.

- Internal nutrient recycling during lake mixing events likely has a major influence on lake water quality.

- Local knowledge identified that an aerator along with algaecide was used to reduce internal loads in 2006 and 2007. This may explain the increased quality of water since that time.

- Decreased water quality occurred in and after 2004, since that time, water quality has improved, this may just be a cyclical occurrence.

- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 81-113 lb/year.

4.11 Locke Lake

4.11.1 Lake and Watershed Characterization

Locke Lake is a deep lake located southeast of the City of Hasty in northern Wright County, Minnesota. The average TP and chlorophyll-*a* values for Locke Lake are above the water quality standard for lakes within the ecoregion. A detailed description of water quality can be found in the Lakes Assessment Report (2012b). Refer to Table 4.6 on for lake morphology records.

Locke Lake is situated at the lower end of a large watershed with an area of 24,624 acres and a watershed to lake area ratio of 185:1. The large watershed drains the entire Silver Creek Watershed which is dominated by agricultural land use including cultivated cropland (primarily corn and soybean rotation) and pasture/hay land (Table 4.5). Homes riparian to the lake are served by SSTS. Based on records obtained by Wright SWCD, there are 242 residential units with SSTS, failure rates were estimated to range from 30%-35%.

Silver Lake watershed makes up approximately 60% of the watershed area; thus, the quality of water in Silver Lake has a large influence on the lake. Locke Lake discharges into Silver Creek just prior to its confluence with the Mississippi River. A fish barrier (dam) is located downstream of the lake outlet which disables migration of species from the Mississippi River.

4.11.2 Total phosphorus TMDL Allocation

The lake response model was calibrated with 10 years of in-lake water quality data collected between 2002 and 2011. The current phosphorus load to Locke Lake is 4,199 lb/year from a mix of watershed and internal load sources. A current phosphorus budget can be found in Appendix A.

The phosphorus LC of Locke Lake is 2,368 lb/year. The TMDL is listed in Table 4.29 at the end of this section.

4.11.3 Impairment Summary

- In-lake phosphorus, chlorophyll-*a* and Secchi disk depth have varied through the years, however they have exceeded the State standard for nearly all years monitored.

- Current water quality is not surprising considering Locke Lake's small volume and size relative to the size of the watershed.

- Silver Lake Watershed makes up approximately 60% of the watershed; thus, the quality of water in Silver Lake has an influence on Locke Lake. Models estimate that if Silver Lake meets its water quality goals, Locke Lake will be 95% closer to its goal.

- Eurasian water milfoil was confirmed by the DNR in 2011.

- 2008 DNR aquatic plant surveys note that CLP was found growing on one quarter of an acre.
- 2008 DNR fisheries survey noted that black bullheads were numerous. Carp were also present.
- Internal recycling of nutrients may contribute to reduced water quality; however the upstream drainage area seems to have the largest impact on water quality.
- The range of potential phosphorus loading from SSTS, based on the calculations described in section 4.2.2, is 254-356 lb/year.

4.12 Total Phosphorus TMDL Allocations for MR-SC Watershed Lakes.

Table 4.7 - Donovan Lake TMDL allocations

Total Phosphorus	**TMDL lb/day**	**TMDL lb/year**
Loading Capacity	**0.392**	**143.28**
Margin of Safety	0.039	14.33
Wasteload Allocation*		
Construction Stormwater	0.002	0.76
“Straight Pipe” Septic Systems	0.000	0.00
MS4 Communities Benton County St. Cloud Minden Twp. MN DOT, non-traditional	0.033	12.16
Load Allocation		
Watershed	0.173	63.08
Internal	0.079	28.91
Atmospheric + Groundwater	0.066	24.04

Table 4.8 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	240.89	76.00	68%
Upstream Lakes	N/A	N/A	N/A
Atmospheric+ Groundwater	24.04	24.04	0%
Internal	86.72	28.91	67%
MOS (10%)	NA	14.33	NA
Total	351.65	143.28	63%

Table 4.9 - Julia Lake TMDL allocations and percent reductions

Total Phosphorus	TMDL lb/day	TMDL lb/year
Loading Capacity	**1.03**	**376.46**
Margin of Safety	0.103	37.65
Wasteload Allocation*		
Construction Stormwater	0.002	0.59
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	0.161	58.73
Internal	0.580	211.82
Atmospheric + Groundwater	0.185	67.67

Table 4.10 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	96.97	59.32	39%[1]
Upstream Lakes			
Atmospheric+ Groundwater	67.67	67.67	0%
Internal	211.82	211.82	0%
MOS	NA	37.65	NA
Total	376.46	376.46	0%[2]

[1] watershed reduction is needed due to MOS. A reduction in watershed phosphorus will ensure that water quality will be protected.

[2] In-lake water quality data suggests that these lakes are very close to the existing water quality standards. Lake water quality standards are within a standard deviation of the most recent 10-year mean TP concentrations. Load reductions for these lakes will represent only a MOS necessary to guarantee they achieve the standard

Table 4.11 - Briggs Lake TMDL allocations and percent reductions

Total Phosphorus	TMDL lb/day	TMDL lb/year
Loading Capacity	**3.693**	**1,348.85**
Margin of Safety	0.369	134.90
Wasteload Allocation*		
Construction Stormwater	0.020	7.39
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	2.004	732.03
Upstream Lake (Julia Lake)	0.227	82.82
Internal	0.728	265.91
Atmospheric + Groundwater	0.344	125.80

Table 4.12 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	1,134.57	739.42	35%
Upstream Lakes	82.82	82.82	0%
Atmospheric+ Groundwater	125.80	125.80	0%
Internal	1,688.34	265.91	84%
MOS		134.90	
Total	3,031.53	1,348.85	56%

Table 4.13 - Rush Lake TMDL allocations and percent reductions

Total Phosphorus	**TMDL lb/day**	**TMDL lb/year**
Loading Capacity	**3.931**	**1,435.86**
Margin of Safety	0.393	14359
Wasteload Allocation*		
Construction Stormwater	0.001	0.43
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	0.116	42.41
Upstream Lake (Briggs Lake)	1.636	597.54
Internal	1.570	573.49
Atmospheric + Groundwater	0.215	78.41

Table 4.14 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	133.87	42.84	68%
Upstream Lakes	1,263.30	597.54	53%
Atmospheric+ Groundwater	78.41	78.41	0%
Internal	1,289.87	573.49	56%
MOS	NA	143.59	NA
Total	2,765.40	1,435.86	48%

Table 4.15 - Birch Lake TMDL allocations and percent reductions

Total Phosphorus	**TMDL lb/day**	**TMDL lb/year**
Loading Capacity	**0.731**	**266.96**
Margin of Safety	0.073	26.70
Wasteload Allocation*		
Construction Stormwater	0.004	1.48
MS4 Communities Big Lake Township	0.007	2.39
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	0.394	143.91
Internal	0.075	27.41
Atmospheric + Groundwater	0.178	65.08

Table 4.16 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	174.48	147.51	15%[1]
Upstream Lakes	NA	NA	NA
Atmospheric+ Groundwater	65.08	65.08	0%
Internal	27.41	27.41	0%
MOS		26.70	NA
Total	266.67	266.67	0%[2]

[1] watershed reduction is needed due to MOS. A reduction in watershed phosphorus will ensure that water quality will be protected.

2 In-lake water quality data suggests that these lakes are very close to the existing water quality standards. Lake water quality standards are within a standard deviation of the most recent 10-year mean TP concentrations. Load reductions for these lakes will represent only a MOS necessary to guarantee they achieve the standard.

Table 4.17 - Upper & Lower Orono Lake TMDL allocations and percent reductions

Total Phosphorus	**TMDL lb/day**	**TMDL lb/year**
Loading Capacity	**139.123**	**50,814.83**
Margin of Safety	13.912	5,081.50
Wasteload Allocation*		
Zimmerman WWTP[1]	2.529	923.74
Becker WWTP[1]	5.450	1990.77
Aspen Hills WWTP[1]	0.163	59.52
Construction Stormwater	0.641	234.05
“Straight Pipe” Septic Systems	0.000	0.00
MS4 Communities City of Elk River City of Big Lake Town of Big Lake	1.282	468.11
CAFOs	0.000	0.00
Load Allocation		
Watershed	62.158	22,703.26
Upstream Lakes (Big Elk Lake)	51.310	18,740.85
Internal	1.262	460.99
Atmospheric + Groundwater	0.416	152.03

1 WLA was set the same as the WQBEL as determined by the MPCA

Table 4.18 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	48,249.56	23,405.42	51%
Upstream Lakes	44,270.97	18,740.85	58%
Atmospheric+ Groundwater	152.03	152.03	0%
Internal	3,841.62	460.99	88%
MOS (10%)		5,081.50	NA
Total	98,525.67	50,814.83	48%

Table 4.19 - Fish Lake TMDL allocations and percent reductions

Total Phosphorus	TMDL lb/day	TMDL lb/year
Loading Capacity	**1.536**	**560.86**
Margin of Safety	0.154	56.09
Wasteload Allocation*		
Construction Stormwater	0.013	4.68
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	1.270	463.73
Internal	0.041	15.03
Atmospheric + Groundwater	0.058	21.33

Table 4.20 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	678.61	468.42	31%
Upstream Lakes			
Atmospheric+ Groundwater	21.33	21.33	0%
Internal	16.70	15.03	10%
MOS (10%)		56.09	NA
Total	716.64	560.86	22%

Table 4.21 - Mink Lake TMDL allocations and percent reductions

Total Phosphorus	TMDL lb/day	TMDL lb/year
Loading Capacity	**1.777**	**649.07**
Margin of Safety	0.178	64.91
Wasteload Allocation*		
Construction Stormwater	0.005	1.93
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	0.522	190.68
Internal	0.877	320.34
Atmospheric + Groundwater	0.195	71.22

Table 4.22 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	719.30	192.60	73%
Upstream Lakes			
Atmospheric+ Groundwater	71.22	71.22	0%
Internal	1,334.76	320.34	76%
MOS (10%)		64.91	
Total	2,125.27	649.07	69%

Table 4.23 - Somers Lake TMDL allocations and percent reductions

Total Phosphorus	TMDL lb/day	TMDL lb/year
Loading Capacity	**1.635**	**597.36**
Margin of Safety	0.164	59.74
Wasteload Allocation*		
Construction Stormwater	0.001	0.23
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	0.063	22.86
Upstream Lakes (Mink Lake)	0.547	199.83
Internal	0.765	279.51
Atmospheric + Groundwater	0.096	35.20

Table 4.24 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	64.49	23.09	64%
Upstream Lakes	400.46	199.83	50%
Atmospheric + Groundwater	35.20	35.20	0%
Internal	524.60	279.51	47%
MOS (10%)		59.74	
Total	1,024.75	597.36	42%

Table 4.25 - Silver Lake TMDL allocations and percent reductions

Total Phosphorus	TMDL lb/day	TMDL lb/year
Loading Capacity	**3.727**	**1,361.35**
Margin of Safety	0.373	136.14
Wasteload Allocation*		
Construction Stormwater	0.024	8.76
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	2.375	867.59
Upstream Lakes (Mink & Somers Lakes)	0.820	299.44
Internal	0.085	31.05
Atmospheric + Groundwater	0.050	18.37

Table 4.26 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	2,686.18	876.36	67%
Upstream Lakes	367.41	299.44	19%
Atmospheric+ Groundwater	18.37	18.37	0%
Internal	62.09	31.05	50%
MOS (10%)		136.14	
Total	3,134.06	1,361.35	57%

Table 4.27 - Indian Lake TMDL allocations and percent reductions

Total Phosphorus	TMDL lb/day	TMDL lb/year
Loading Capacity	**0.633**	**231.07**
Margin of Safety	0.063	23.11
Wasteload Allocation*		
Construction Stormwater	0.002	0.57
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	0.154	56.32
Internal	0.332	121.17
Atmospheric + Groundwater	0.082	29.91

Table 4.28 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	99.99	56.89	43%
Upstream Lakes			
Atmospheric+ Groundwater	29.91	29.91	0%
Internal	184.99	121.17	35%
MOS (10%)		23.11	
Total	314.90	231.07	27%

Table 4.29 - Locke Lake TMDL allocations and percent reductions

Total Phosphorus	TMDL lb/day	TMDL lb/year
Loading Capacity	**6.485**	**2,368.50**
Margin of Safety	0.648	236.85
Wasteload Allocation*		
Construction Stormwater	0.017	6.26
"Straight Pipe" Septic Systems	0.000	0.00
Load Allocation		
Watershed	1.698	620.22
Upstream Lakes (Silver Lake)	3.476	1,269.61
Internal	0.564	206.01
Atmospheric + Groundwater	0.081	29.55

Table 4.30 Partitioned current and TMDL phosphorus expressed as yearly loads

	Existing Phosphorus lb/year	TMDL Phosphorus lb/year	% Reduction
Watershed Load	955.12	626.48	34%
Upstream Lakes	3,008.56	1,269.61	58%
Atmospheric+ Groundwater	29.55	29.55	0%
Internal	206.01	206.01	0%
MOS (10%)		236.85	
Total	4,199.23	2,368.50	44%

5 DISSOLVED OXYGEN- RICE CREEK, BATTLE BROOK, CLEARWATER RIVER

The DO concentrations in streams are driven by a combination of natural and anthropogenic factors. Natural background characteristics of a watershed, such as topography, hydrology, climate, and biological productivity can influence the DO regime of a waterbody. Agricultural and urban land uses, impoundments (dams), and point-source discharges are just some of the anthropogenic factors that can cause unnaturally low, or widely fluctuating DO concentrations.

The following sections summarize the approach used to analyze, model and set the DO TMDLs. Wenck completed technical memorandums which cover the processes in much greater detail. The memorandums can be found in Appendix's C through F.

5.1 Modeling Approach

The model chosen to characterize the existing condition and identify the pollutant of concern resulting in low DO was the River and Stream Water Quality Model QUAL2K (Version 2.11). QUAL2K is a windows version of the EPA's QUAL2E model and is approved by the EPA for setting DO TMDLs in rivers. It is a one-dimensional, steady state model which represents the stream as a well-mixed channel and is intended to be applied to steady-state flow conditions. State variables in the QUAL2K model include DO, CBOD, nitrogen series and phosphorous. Model processes include CBOD decay, nitrification, algae photosynthesis/respiration, and SOD. Model inputs include flow rates and concentrations from non-point sources, headwater inflows, and tributaries.

Oxygen sources and sinks for the streams, such as SOD, were quantified through modeling in-stream water quality using the EPA's QUAL2K (Version 2.11). The QUAL2K model was selected to:

- Quantify the SOD contribution in downstream wetlands
- Determine the steady state assimilative capacity of Battle Brook, Rice Creek, and Clearwater River during low flow condition to determine necessary load reductions.

Models were developed using available data as well as literature values for water quality, hydrologic and hydraulic data to quantify these sources. For a complete discussion of the methods, model input parameters and assumptions used to build, calibrate and validate these models refer to the technical memorandums in Appendix's C through F.

5.2 Oxygen Deficit Terms

Carbonaceous biochemical oxygen demand (CBOD) represents the oxygen equivalent (amount of oxygen that microorganisms require to breakdown and convert organic carbon to CO_2) of the carbonaceous organic matter in a sample.

A second source of oxygen depletion is nitrogenous biochemical oxygen demand (NBOD). A wide variety of micro-organisms rapidly transform organic nitrogen (ON) to ammonia nitrogen (NH_3-N). Bacteria then transform NH_3-N to nitrate though an oxygen consuming process called nitrification.

Finally, SOD is the aerobic decay of organic materials in stream bed sediments and in peat soils in wetlands. There are two sources of SOD; model-predicted and additional SOD prescribed by the modeler. Prescribed SOD was necessary in model reaches to adequately calibrate the model to observed data. Prescribed SOD represents additional SOD generated by contact with riparian wetlands when flushing rates are low.

5.3 Critical Conditions and Seasonal Variation

Seasonal variation was addressed by using the critical period in terms of flow regime and temperature with the assumption that if the LAs necessary to maintain the DO concentration at the critical flow regime (which occurs rarely) can be achieved, DO concentrations will be maintained above state standards at all other seasons/flow regimes as well. For DO impairments, the critical period usually occurs during low flow (7Q10). This was the case for both Rice Creek and Battle Brook. For Clearwater River however, violation of DO standards were observed in high flow conditions. High flow impairment is likely due to increased SOD as flow spreads out over riparian wetland floodplain. As such, the high flow was set as the critical condition for the DO impairment.

5.4 Total Maximum Daily Load Calculations

5.4.1 Existing Loads

The existing loads to each of the streams under the modeled critical flow conditions were determined and are calculated in terms of C-BOD, N-BOD, and SOD in Table 5.1. Table 5.1 does not list any wasteloads as no NPDES wastewater discharges or MS4s are located in the watersheds of these reaches nor were they modeled in the DO-violation scenarios.

Table 5.1 - Existing daily oxygen demand loads during critical flow conditions

Stream	Loads	CBOD (lb/day)	NBOD (lb/day)	SOD (lb/day)
Battle Brook	Headwater Watershed	4	20	--
	Diffuse & Tributary	9	115	--
	SOD	--	--	105
	Total	**13**	**135**	**105**
Rice Creek	Headwater Watershed	626	1,290	--
	Diffuse & Tributary	79	419	--
	SOD	--	--	847
	Total	**705**	**1,709**	**847**
Clearwater River	Headwater Watershed	37,571	13,557	--
	Diffuse & Tributary	87	0	--
	SOD	--	--	721
	Total	**37,658**	**13,557**	**721**

5.4.2 Source assessment summary

An assessment of sources of oxygen demand in the watershed is summarized separately in each section below. In general, oxygen demanding sources in the watersheds include wetland SOD and watershed sources including runoff from crop farming, feedlots, pastured livestock, rural residential, and failing septic systems.

Table 5.2 - NLCD 2006 land use percent in the impaired stream watersheds.

Impaired Watershed	Hay/Pasture	Cultivated Cropland	Forest	Developed	Wetland	Natural Areas[1]	Open Water	Watershed Size (acres)
Rice Creek	19%	38%	17%	11%	14%	0%	1%	29,169
Battle Brook	15%	23%	23%	11%	26%	0%	3%	25,749
Clearwater River	14%	39%	20%	12%	8%	0%	8%	111,897

1 includes barren and shrublands.

Table 5.3 - MPCA registered feedlots in the impaired stream watersheds.

Impaired Watershed	Number Facilities	Animal Units	Animal Type (ascending order)
Rice Creek	19	3,621.4	Bovine, Birds, Goat/sheep
Battle Brook	9	1,150.9	Bovine, Birds, Pigs
Clearwater River	152	16,435.63	Bovine, Birds, Pig, Goat/ Sheep, Horse, Deer/Elk

Other land use inventories including the MR-SC Stressor Identification Report and the Elk River Watershed TMDLs (MPCA 2012d and 2012f) indicate that there are several small unregistered pasturing operations within the watershed area. Because these operations are not permitted, there are no consistent records of animals units or locations.

Loading Capacity: QUAL2K

For DO TMDLs, the LC is the maximum allowable oxygen demand (CBOD+NBOD+SOD) the stream can withstand and still meet water quality standards. To determine this number, SOD rates and pollutant loading from headwaters and tributary/diffuse sources were reduced until model-predicted minimum daily DO in each reach remained above the 5.0 mg/L standard.

The linkage of the impairment to the source, as well as the load and WLAs are based on thorough evaluation of water quality data, hydrologic and hydraulic data collected by the MPCA and the Sherburne SWCD and Clearwater River Watershed District. The models were calibrated to synoptic survey data as described in technical memos submitted to the MPCA by Wenck (Appendix's C-F).

5.5 Rice Creek

5.5.1 Watershed and Stream Characterization

The Rice Creek watershed covers 29,169 acres, composed of cropland, primarily corn and soybean rotations (38%); pastured (20%); Forest (17%); Wetland (14%), developed (11%) and open water (1%) areas. For more detailed information on the characteristics of the Rice Creek Watershed, refer to the MR-SC Watershed Monitoring and Assessment Report (MPCA, 2012a).

The impaired reach of Rice Creek extends from the outlet of Rice Lake (71-014200) to Rice Creek's confluence with the Elk River representing 7.3 river miles. The headwaters of Rice Creek, Stony Brook, originate north of the city of Foley and flows southerly into Rice Lake. Rice Lake is 96 acre lake and has a maximum depth of four feet. The bottom substrate is comprised of mainly muck with an area of sand that follows the old creek channel where Stony Brook runs through the lake. An aquatic plant survey was completed in 2012 to assess the lakes potential contributions to the DO impairment. During that survey CLP was identified to be the only plant in the lake and that it covers over 72 acres of the lake. Many of the tributaries flowing into both Rice Creek and Stony Brook have been channelized and often drain agricultural lands.

Interestingly, this reach of Rice Creek was assessed for fish and invertebrate communities during the IWM in 2009 and it was determined that the stream was meeting criteria set for each community. Hence, in this reach of Rice Creek, low DO is not a stressor to fish or invertebrate communities. This may be because there are sufficient refuge areas within the connected ecosystem.

5.5.2 Model configuration and Calibration

The model includes one main stem reach extending from the outlet of Rice Lake to Rice Creek's confluence with the Elk River. This stretch of the creek, explicitly modeled, represents approximately 7.3 river miles and was subdivided into five reaches. The starts of each main stem reach correlate with a change in stream morphometry, or tributary inflow point. Rice Lake represents the upstream boundary for this section of Rice Creek as the lake served as the headwaters for this model.

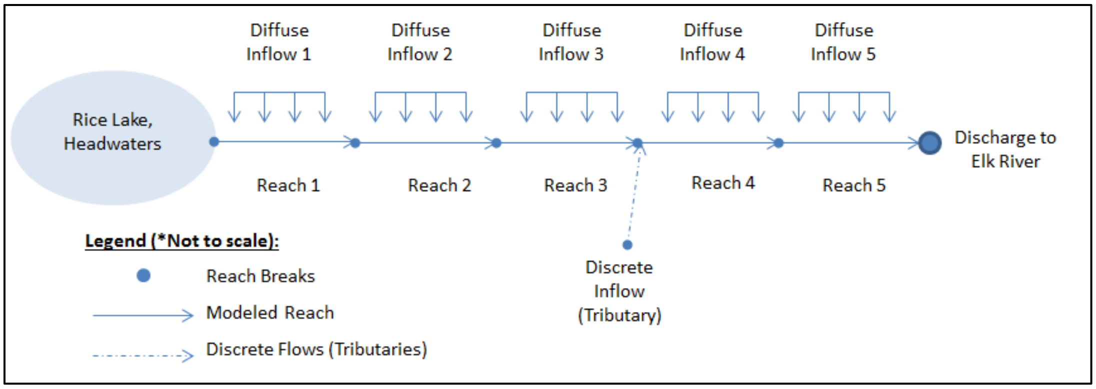


Figure 6-1 - Rice Creek Model Schematic Diagram

The Rice Creek model was developed using water quality, hydrologic and hydraulic data collected by the MPCA and the Elk River Watershed Association (ERWA). The model was calibrated to limited synoptic survey data which included:

- Continuous DO data measurements at two locations in the impaired reach between July 22, and August 10, 2011.
- Longitudinal DO data measured four times at four locations in Rice Creek between June 28, and July 22, 2011.

The model was calibrated to data collected on the main stem of Rice Creek between July 22, 2011, and August 10, 2011, along with grab samples collected on September 12, 2012. The model simulated the flow on July 28, 2011, where synoptic data and flow measurements were available.

The DO concentrations fall below the standard of 5 mg/L daily minimum in the reach between Rice Lake and its confluence with the Elk River. Data shows that DO declines sharply in Reach 4 where the creek widens and flows through a wetland with several backwater areas. This points to SOD and morphometry/topography as the primary driver of the impairment in Reach 4.

Rice Creek assimilative capacity can be found in Table 5.4 at the end of this section.

5.5.3 TMDL Allocation

Reaching the DO standard in Rice Creek will require both load reductions from watershed and instream sources as well as an improvement in headwater conditions. The assimilative capacity was determined to be a simultaneous 80% reduction of watershed loads and SOD load along with improvement to the headwater water quality such that it meets state Nutrient standards. The TMDL for Rice Creek is listed in Table 5.5 at the end of this section.

5.5.4 Impairment Summary/ Sources and Current Contributions

Primary sources of impairment:

- Channelization/ditches in the upper watershed: The 2012 Watershed Assessment report points out that many of the tributaries flowing into Rice Creek have been channelized and often drain from agricultural lands.
- Wetland SOD: There is an undersized culvert located on Rice Creek below Co. Rd. 16 on a private drive and a large beaver dam is also often present upstream of the Co. Rd. 16 bridge. The culvert backs up water and expanded the wetland system upstream. Also causes an over-widened stream channel, slows travel time and velocity and aeration drops drastically.

- Riparian land use runoff: any land use within the riparian zone of this system has the potential to contribute nutrients into the stream. The stressor ID report indicates that excessive nutrients are causing increased plant and algal growth within all assessed waterbodies. Primary land use in this watershed is cropland and pastureland.

- Rice Lake: Algal decomposition resulting from high densities of CLP in the lake. More data collection on Rice Lake is required.

- NBOD: Nitrogen was identified as a critical component during a TMDL technical meeting (via watershed runoff).

Other key points identified during a technical planning meeting and historic reports:

- Modeling points to Rice Lake as a primary source of oxygen demand from in-lake algal blooms caused by late season CLP weed senescence. Additional data on Rice Lake water quality and nutrient sources are necessary to achieve load reductions in the lake.

- Rice Creek is an artificially channelized stream through wetland complex along the entire reach; the topography limits re-aeration.

- Field staff identified a beaver dam on Rice Creek at CR 16. Removal of the beaver dam may decrease main stem stream contact with wetland sediments, and therefore, SOD.

5.6 Battle Brook

5.6.1 Watershed and Stream Characterization

The Battle Brook watershed covers 25,749 acres, composed of wetlands (26%), equal parts cropland, primarily corn and soybean rotations, (23%) and forest (23%), pasture (15%), developed lands (11%) and a very small percent of open water (3%). For more detailed information on the characteristics of the Battle Brook Watershed, refer to the MR-SC Watershed Monitoring and Assessment Report and Stressor Identification Report (MPCA 2012a and 2012d).

This reach of Battle Brook extends from CR 42 to Elk Lake (71-055) representing 5.98 river miles. The entire length of Battle Brook originates near the south border of Benton and Mille Lacs County. The headwaters of Battle Brook originate as a channelized stream, draining agricultural lands. From the headwaters the stream flows east through a large wetland complex and then past Rice Lake (48-0010) in Mille Lacs county. From Rice Lake, Battle Brook begins to flow south-east where it empties into Elk Lake and ultimately empties into the St. Francis River approximately one mile downstream of Elk Lake. There is a water level control structure located at the outlet of Elk Lake.

A conversation with Craig Wills, DNR Area Hydrologist, indicated that Battle Brook historically originated from Rice Lake in Mille Lacs County. At some point a drainage ditch was constructed at Rice Lake to divert water into the Rum River. It was reported that the diversion was implemented to provide drainage for agricultural land which has since been abandoned. Air photos show a ditched channel connecting Rice Lake to the Rum River; however, it was not clear whether the connection created to the Rum River had existed previously. The drainage ditch is present in the 1939 air photo. The resulting change in hydrology to Battle Brook resulting from this ditch is not clear.

A stressor ID was completed for this reach of the Battle Brook in conjunction with the WRAPS process (MPCA 2012d). Battle Brook is the only biological impairment to be addressed during the 2009 WRAPS cycle.

5.6.2 Model configuration and Calibration

This model includes one main stem extending from CR 42 to Elk Lake. This stretch of the brook, explicitly modeled, represents 5.98 river miles and was subdivided into three reaches. The starts of each main stem reach correlate with a change in stream morphometry or tributary inflow point. The wetland northwest and upstream of CR 42 represents the upstream boundary for this section of Battle Brook and served as the headwaters for this model.

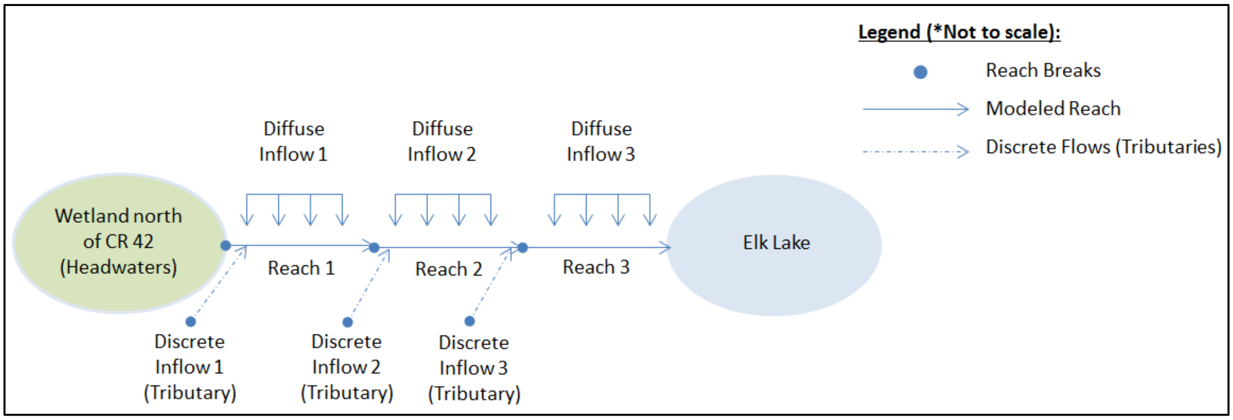


Figure 6-2 - Battle Brook Model Schematic Diagram

The Battle Brook model was developed using water quality, hydrologic and hydraulic data collected by the MPCA and the ERWA. The model was calibrated to limited synoptic survey data which included

- Continuous DO data measurements at 2 locations in the impaired reach during July 9-16, 2012
- Longitudinal DO data measured 2 times at 3 locations in Battle Brook on July 9 & July 16, 2012

The model was calibrated to data collected on the main stem of Battle Brook between July 9, 2012, and July 16, 2012, along with grab samples collected on July 9, 2012. The model simulated the flow on July 9, 2012 where synoptic data and flow measurements were available.

DO concentrations fell below the 5 mg/L daily minimum in the reach between CR 42 and Elk Lake. Data shows that DO declines sharply in reaches two and three where the brook flows through a wetland. This points to SOD as the primary driver of the impairment in reach two and three.

Battle Brook assimilative capacity can be found in Table 5.4 at the end of this section.

5.6.3 TMDL Allocation

Reaching the DO standard in this section of Battle Brook will require both load reduction from headwater, direct watershed, and in stream sources as well as morphometric modification or aeration. Modeled scenarios show that 80% reductions in both watershed and SOD load alone are not sufficient to achieve DO concentrations above the daily minimum of 5.0 mg/L at the critical location. The TMDL for Battle Brook is listed in Table 5.5 at the end of this section.

5.6.4 Impairment Summary/ Sources and Current Contributions

<u>Primary sources of Impairment</u>:

- Hydrology:
  - The dam located at Elk Lake causes water to back up from the lake and allows for the settling of fine organic material on the stream bed. Bacterial decomposition of this organic material strips DO from the water column. The Stressor ID report indicated that the dam

    located at the outlet of Elk Lake is 2.5 feet higher than the road culvert invert at CR 9. The backwater created by this low culvert setting is causing a slope change in Battle Brook. This slope change is causing the riparian wetland to be saturated at all times and probably contributing to the high rate of DO flux. The large wetland complexes appear to be affecting the SOD and BOD in this lower section of Battle Brook. The high daily DO flux is in part being caused by the amount of wetland soils that are intermittently being exposed to wet and dry conditions.

  - The existing ditch between Rice Lake and the Rum River Watershed may have reduced flows in Battle Brook.

- Wetland SOD: Noted as a wetland dominated system with a low gradient.

- Riparian land use runoff: any land use within the riparian zone of this system has the potential to contribute nutrients into the stream. The Stressor ID Report indicates that Excessive nutrients are causing increased plant and algal growth within all assessed waterbodies. Majority of riparian habitat is agricultural (row crop) with a sedge meadow buffer. The Stressor ID Report also indicates that there are likely several smaller unregistered pasturing operations.

- Stakeholders indicated during a TMDL technical meeting that local agricultural practices support NBOD as a major source of oxygen demand.

Other key points identified during a technical planning meeting and historic reports:

- Majority of riparian habitat is agricultural with a sedge meadow buffer.

- High *E. coli* levels in this reach (two stations) would indicate that there are anthropogenic sources.

- An email from the DNR (2002) to Sherburne SWCD regarding invasive plant species in Elk Lake indicated that a secondary benefit of increasing the flow in Battle Brook could be decreased Eurasian water milfoil and CLP.

5.7 Clearwater River

5.7.1 Watershed and Stream Characterization

The watershed draining directly to the reach of the Clearwater River watershed addressed by this TMDL covers 111,897 acres composed of cropland (39%), primarily corn and soybean rotations, woodland (20%), pasture (14%), developed land (12%), and equal parts wetlands and open water (8%). For more detailed information on the characteristics of the Clearwater River Watershed, refer to the MR-SC Watershed Monitoring and Assessment Report and Stressor Identification Report (MPCA 2012a and 2012d).

The Clearwater River system originates in Clear Lake and is joined by a series of channelized tributaries flowing south from Watkins. From there the Clearwater River flows east through Meeker County, then north along the border of Wright and Stearns Counties through a series of large, high quality recreational lakes and ultimately empties into the Mississippi River.

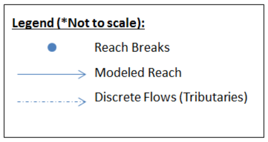
The reach of the Clearwater River included in this TMDL is located at the north (downstream) most section of the system extending from Grass Lake to the Mississippi River. From the outlet of Grass Lake the river flows northeast and through the west side of Wiegand Lake (86-0242) and then continues north to the confluence with the Mississippi River. The outlet of Grass Lake is a low head concrete dam, which adds oxygen to the already well-oxygenated lake outflow. Wiegand Lake is a small, shallow 43 acre lake.

The downstream section of the impaired reach flows into the Mississippi River over a dam located at CR75 just northwest of the City of Clearwater. The dam directs flow with very high velocity and has a drop structure, further oxygenating the Clearwater River flow prior to its confluence with the Mississippi.

A stressor ID study was completed for this reach of the Clearwater River in conjunction with the WRAPS process (MPCA, 2012d).

5.7.2 Model configuration and Calibration

This main stem of the Clearwater River is modeled between Grass Lake and the Mississippi River. This stretch of the river, explicitly modeled, represents 17.8 river miles. For analysis purposes, this reach was broken into an upstream and downstream model with Wiegand Lake serving as the downstream boundary for the upstream model and the headwaters for the downstream model. Each model was then broken into three reaches which align with changes in stream morphometry or a water quality sampling point.



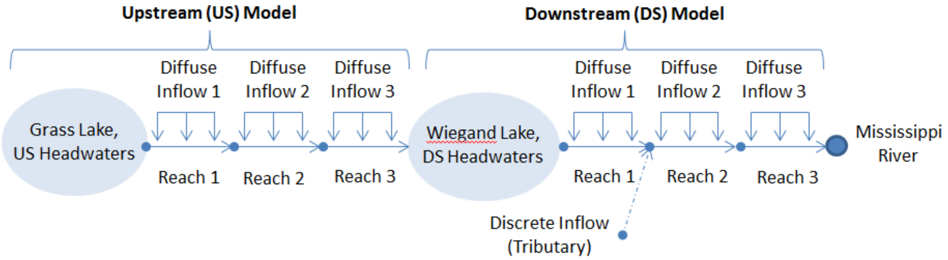


Figure 6-3 - Clearwater River Watershed Model Schematic Diagram

The Clearwater River model was developed using water quality, hydrologic and hydraulic data collected by the MPCA and the Clearwater River Watershed District (CRWD) which included:

- Continuous DO data measurements at 3 locations in the impaired reach between July 3, 2007, and September 4, 2007

- Longitudinal DO data measured 4 times at 3 locations (12 total measurements) in Clearwater River between June 29, 2011, and August 30, 2011.

The model calibration is discussed in the attached memo (Appendix F). The model simulated the flow on July 22, 2011, where synoptic data and high flow conditions were observed.

DO concentrations fell below the 5 mg/L daily minimum in the reach between Clearwater Lake and the Mississippi River during high flow conditions. The calibrated model shows DO throughout the system is most sensitive to the breakdown of organic carbon (CBOD) and organic nitrogen (organic-N hydrolysis), as well as prescribed SOD settings in Reach 1.

Clearwater River assimilative capacity can be found in Table 5.4 at the end of this section.

5.7.3 TMDL Allocation

Reaching the DO standard in this section of Clearwater River will require a simultaneous improvement in the headwater DO during the critical conditions, 80% reduction of watershed loads and a 10% reduction of SOD load.

The TMDL for Clearwater River is listed in Table 5.5 at the end of this section.

5.7.4 Impairment Summary/ Sources and Current Contributions

Primary sources of Impairment:

- Hydrology: the river short-circuits Wiegand Lake, especially in critical condition high flows, instead of mixing well; thus depleted DO from upstream is moving straight though the lake.
- SOD:
  - System is wetland dominated with a low gradient.
  - Upstream of Wiegand Lake channel is wide and flat.
  - Wetlands downstream of Wiegand Lake are typically dry
- Riparian land use runoff: any land use within the riparian zone of this system has the potential to contribute nutrients into the stream. The stressor id report also indicates that rangeland and pasture are common landscape features throughout the Clearwater River watershed and that it is common to place pastures along streams to give animal's free access to water.
- NBOD: Nitrogen was identified as a critical component during a TMDL technical meeting (via watershed runoff)

Other key points identified during a technical planning meeting and historic reports:

- The CRWD worked with the MPCA in 2007 to collect water quality data support setting a TMDL. Data collected at that time indicated the stream was meeting state water quality standards for DO. The MPCA directed additional water quality sampling in 2011 to determine if the reach was impaired. The MPCA conducted fish and macro invertebrate sampling on an extremely hot day which water temperature was less than 25 degrees Celsius which showed impaired biota. The 2011 DO data, collected before 9 am, was below the state standard of 5 mg/L. Water temperature and flows were unusually high during the sampling.

- Technical staff reviewed DO and water quality data to determine the impact of wet vs dry years on DO concentrations. Staff concluded that the impairment listing was likely valid and the result high flows with corresponding high residence times, when high water levels were high, inundating riparian low lands for long periods.

5.8 TMDL Allowable Loads for Rice Creek, Battle Brook, and Clearwater River

Table 5.4 summarizes the LC along with the percent reduction needed to meet or exceed the 5 mg/L daily minimum state standard DO concentration for each of the streams. Table 5.5 summarizes the TMDL allowable loads broken down by major source category. In many of the scenarios, large watershed reductions alone do not fully mitigate the DO impairment. Therefore, to achieve the TMDL, simultaneous improvements to headwater conditions and reductions in watershed loads and wetland SOD are required to provide an implicit MOS.

Table 5.4 - TMDL allowable loads and percent reductions needed for the modeled streams

Stream	Allocation	CBOD, lb/day (%-reduction)	NBOD, lb/day (%-reduction)	SOD, lb/day (%-reduction)
Battle Brook (AUID 07010203-535)[1]	Wasteload Allocation[3]	0.1 (80%)	1 (80%)	0 (N/A)
	Load Allocation	2.5 (80%)	40 (80%)	21 (80%)
Rice Creek (AUID 07010203-512)[2]	Wasteload Allocation	2 (80%)	5 (80%)	0 (N/A)
	Load Allocation	139 (80%)	337 (80%)	169 (80%)
Clearwater River (AUID 07010203-511)[2]	Wasteload Allocation	113 (80%)	41 (80%)	0 (N/A)
	Load Allocation	7,419 (80%)	2,670 (80%)	649 (10%)

1 In addition to these allowable loads, changes in channel morphometry are necessary.
2 In addition to these allowable loads, changes in headwater conditions are necessary.
3 NPDES Construction WLAs were are assigned e 1.5% of the total WLA

Table 5.5 - Assimilative capacity (includes MOS) for Rice Creek, Battle Brook, and Clearwater River

Stream	Allocation	Load	CBOD (lb/day)	NBOD (lb/day)	SOD (lb/day)
Battle Brook	**Wasteload Allocation (WLA)**	NPDES Construction[1]	0.1	1	--
		Other	--	--	--
		WLA Total	*0.1*	*1*	*0*
	Load Allocation (LA)	Headwater Watershed	0.7	4	--
		Tributary Watershed	1.8	35.9	--
		SOD	--	--	21.1
		LA Total	*2.5*	*39.9*	*21.1*
	MOS		**Implicit**		
	TMDL		**2.6**	**40.9**	**21.1**
Rice Creek	**Wasteload Allocation (WLA)**	NPDES Construction	2	5	
		Other	--	--	--
		WLA Total	2	5	0
	Load Allocation (LA)	Headwater Watershed	124	255	--
		Tributary Watershed	15	82	--
		SOD	--	--	169
		LA Total	139	337	169
	MOS		**Implicit**		
	TMDL		**141**	**342**	**169**
Clearwater River	**Wasteload Allocation (WLA)**	NPDES Construction	113	41	--
		Other	--	--	--
		WLA Total	113	41	--
	Load Allocation (LA)	Headwater Watershed	7,404	2,670	--
		Tributary Watershed	14	0	--
		SOD	--	--	649
		LA Total	7,418	2,670	649
	MOS		**Implicit**		
	TMDL		**7,531**	**2,711**	**649**

[1] NPDES Construction Wasteloads are assigned 1.5% of the total WLA

6 TURBIDITY- RICE CREEK

Turbidity is a measure of the cloudiness or haziness of water caused by suspended and dissolved substances in the water column. Turbidity can be caused by increased suspended soil or sediment particles, phytoplankton growth, and dissolved substances in the water column. Excess turbidity can degrade aesthetic qualities of water bodies, increase the cost of treatment for drinking water or food processing uses, and harm aquatic life. Adverse ecological impacts caused by excessive turbidity include hampering the ability of aquatic organisms to visually locate food, negative effects on gill function, and smothering of spawning beds and benthic organism habitat.

6.1 Rice Creek Characterization

The Rice Creek watershed covers 29,169 acres, composed of cropland, primarily corn and soybean rotations (38%); pastured (20%); Forest (17%); Wetland (14%), developed (11%) and open water (1%) areas. There are currently no permitted MS4 communities within the watershed discharging to Rice Creek. For more detailed information on the characteristics of the Rice Creek Watershed, refer to the MR-SC Watershed Monitoring and Assessment Report (MPCA 2012a).

This reach of Rice Creek extends from the outlet of Rice Lake (71-014200) to Rice Creek's confluence with the Elk River representing 7.3 river miles. The headwaters of Rice Creek, called Stony Brook, originate north of the city of Foley and flows southerly into Rice Lake. Rice Lake is a 96 acre lake and has a maximum depth of four feet. The bottom substrate is comprised of mainly muck with an area of sand that follows the old creek channel where Stony Brook runs through the lake. An aquatic plant survey was completed in 2012 to assess the lakes potential contributions to the DO impairment. During that survey CLP was identified to be the only plant in the lake and that it covers over 72 acres of the lake. Many of the tributaries flowing into both Rice Creek and Stony Brook have been channelized and often drain agricultural lands.

6.2 Degree of Impairment

Table 6.1 - Turbidity related water quality exceedances for Rice Creek

Parameter	Years Monitored	Violation Threshold	Measurements	Exceedances	Percent Exceedances
Turbidity	2004-2007	> 25 NTU	63	3	5%
TSS	2000-2012	> 30 mg/L	106	17	16%
		> 63 mg/L		4	4%
Transparency	1998-2012	< 20 cm	400	71	18%

During a technical planning meeting staff discussed the reliability of the data used to list Rice Creek as impaired for turbidity. The 2009 field data collection sheets indicted that the water clarity was typically high but that there was significant amounts of suspended detrital material. Visual observations by SWCD and the MPCA staff indicated that a beaver dam located upstream of the sampling point may have contributed to material suspension. Additionally, technical staff hypothesized that a portion of the turbidity exceedances may be the result of algal blooms in Rice Lake (the headwaters of the impaired reach of Rice Creek). An aquatic plant survey was completed by the MPCA and SWCD staff to assess potential impacts in Rice Creek. Additional data collection to assess water quality in Rice Lake is recommended to address this impairment. Finally, biological surveys completed in conjunction with the WRAPS found that the stream was supporting several sensitive taxa and the index of biological integrity (IBI) was meeting minimum criteria for healthy aquatic wildlife (MPCA 2012a).

6.3 Selection of the Turbidity Surrogate

Data analysis to select turbidity surrogates was conducted in accordance with the Turbidity TMDL Protocols and Submittal Requirements (MPCA 2007b). A regression analysis was completed and is described in further detail in the Rice Creek Turbidity Memo located in Appendix C. The analysis indicated that the turbidity standard of 25 nephelometric turbidity unity (NTU) corresponds to a surrogate TSS concentration of 63 mg/L for this data set. For TSS, a measurement of more than 30 mg/L indicates a violation of the turbidity standard in the CRN Region (MPCA 2011). If sufficient turbidity measurements exist, only turbidity measurements are used to determine impairment. For this analysis, all three parameters (turbidity, TSS and transparency) were evaluated to investigate trends and take full advantage of the dataset. In the end, the CRN water quality target of 30 mg/L represented a more conservative standard than the turbidity surrogate. The assimilative capacity was set using the CRN water quality target of 30 mg/L instead of the TSS surrogate concentration value 63 mg/L.

6.4 Allocation Approach

Assimilative capacities for Rice Creek were quantified by developing a load duration curve (Cleland 2002). Necessary load reductions to meet state standards are determined by comparing the stream's assimilative capacity to existing loads.

The flow duration curve was developed using historic data collected from one flow monitoring station located at the county state aid highway CSAH-16 Bridge on Rice Creek (S001-523). Flow zones were determined for very high (0-10%), high (10%-40%), mid (40%-60%), low (60%-90%) and dry (90%-100%) flow conditions. The mid-range flow value for each flow regime was then multiplied by the CRN to calculate the LC.

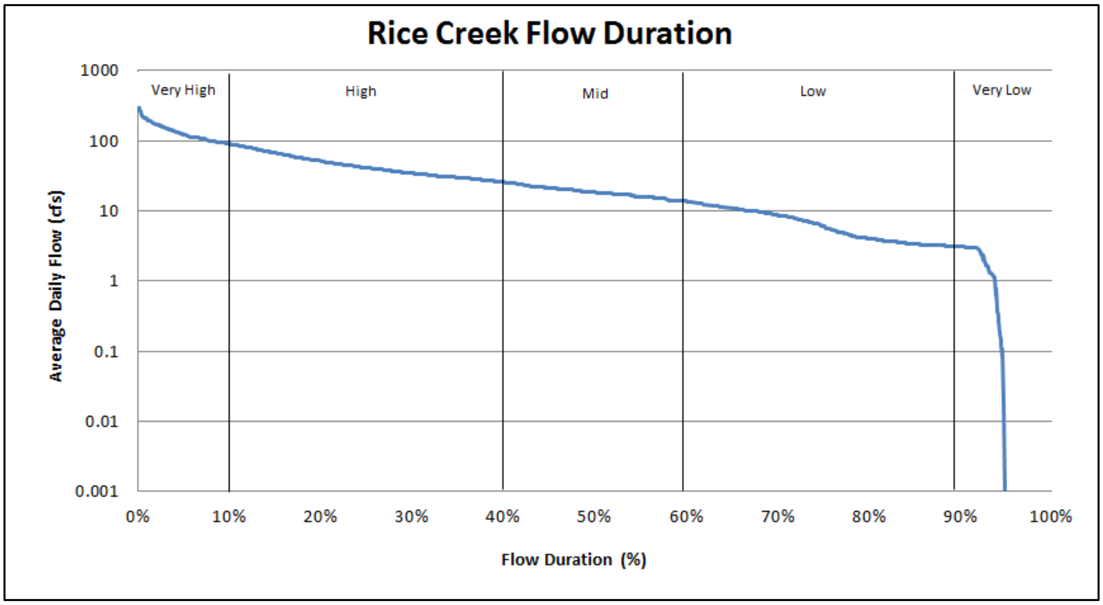


Figure 7-1 - Flow duration curve for Rice Creek

To develop a load duration curve, all average daily flow values were multiplied by the CRN Threshold (30 mg/L), and then converted to a daily load to create "continuous" load duration curves (Figure 6.2). The resulting line represents the assimilative capacity of the stream for each daily flow. Both the CRN and the TSS surrogate (63 mg/L) are compared to observed daily loads in the figure below.

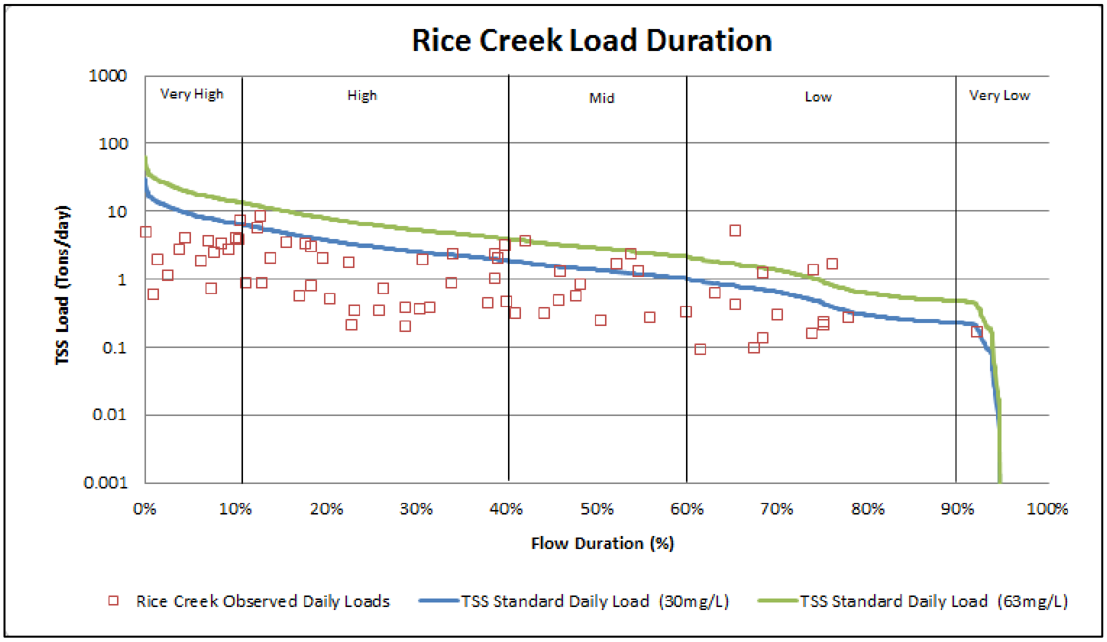


Figure 7-2 - TSS Load duration curve and necessary TSS reductions

The necessary reductions to meet the CRN threshold standard can be calculated using the median values for each flow regime and 90th percentile values from the monitored TSS data. The 90th percentile value in each regime is the reading that is only exceeded by 10% of the data points and the median value is the target LC for each flow regime. The data is plotted with the 90th percentile and median values to determine load reductions as shown in Figure 6.2.

For a complete discussion of the methods and assumptions used to build the load duration curves, see the Rice Creek DO Technical Memorandum in Appendix B.

6.5 Critical Conditions and Seasonal Variation

The load duration curve method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specific period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve-the accounts for seasonal variation and all critical conditions. In the TMDL equation tables of this report (Table 6.6.2) only five points on the entire LC curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by EPA.

6.6 Total Maximum Daily Load Calculations

Wasteload load, LA and MOS for the Rice Creek turbidity impairment are shown in Table 6.6.2. No permitted sources are within the reach, any new permitted point source dischargers would meet WLAs as long as discharged concentrations remain below the established standard, 30 mg/L. The table also presents the LAs as the percentages of the total allowable load in each flow category.

Table 6.6.2 - Rice Creek TSS total daily loading capacities and allocations

Rice Creek (AUID 07010203-512)		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		TSS Load (tons/day)				
Wasteload Allocation	Construction Stormwater	0.14	0.05	0.02	0.01	0.00
Load Allocation	Nonpoint source and in-stream	8.97	3.00	1.34	0.43	0.17
MOS		**Implicit**				
Total Daily Loading Capacity		**9.11**	**3.05**	**1.36**	**0.44**	**0.17**
Value expressed as percentage of total daily loading capacity						
Total Daily Loading Capacity		100%	100%	100%	100%	100%
Wasteload Allocation	Construction Stormwater	1.5%	1.5%	1.5%	1.5%	1.5%
Load Allocation	Nonpoint source and channel	98.5%	98.5%	98.5%	98.5%	98.5%

6.6.1 Impairment summary/sources and current contributions

In-stream Sources and Allocation:

- A quantitative streambank assessment for Rice Creek has not been performed. However, visual observations at monitoring locations along Rice Creek coupled with the results of the streambank assessments for other streams within the Elk River Watershed showed that bank erosion was minimal. The results of those streambank assessments are shown in the ERWA TMDL Phase II Report (MPCA 2012f).

- No chlorophyll-*a* data was available for Rice Lake. However, the results of an Aquatic Plan inventory for Rice Lake (from June 6, 2012) showed that CLP is prevalent in the lake and that the density of aquatic plants growing to the surface has increased in the past couple years. At the time of the inventory the lake was hypertrophic, dominated by CLP and has limited ecological value.

Watershed Sources and Allocation: Knowledge of local practices and available data indicate that the dominant source of impairment is agricultural runoff.

7 MONITORING

Monitoring is essential to track trends and progress towards goals, to evaluate the efficiency of selected BMPs and determine if course corrections (adaptive management) are needed to meet stated endpoints. Going forward, a baseline monitoring program is recommended to track the progress towards goals. This means monitoring is limited to measuring the impaired waters themselves to track their progress; additional monitoring to fill data gaps is limited and priority is given to high value receiving waters. Regular evaluation of monitoring data and reporting is recommended to document the process of adaptive management. Reporting should include not only water quality data evaluation, but discussion of BMPs implemented and annual recommendations for upcoming projects and programs.

Excessive Nutrients: Monthly surface TP and chlorophyll-*a* samples along with Secchi depth readings. In many cases volunteers are already collecting this information.

DO: Clearwater River: Track flow and DO concentrations weekly or monthly in one location within the impaired reach.

Rice Creek: Track flow turbidity and DO concentrations weekly or monthly in one location within the impaired reach (CR 16).

Battle Brook: Track flow and DO concentrations weekly or monthly in one location within the impaired reach.

Turbidity: Continue monitoring flow, transparency and DO at CR 16 in Rice Creek.

Regardless of the monitoring recommended in this TMDL, IWM associated with the MPCA WRAPS will occur in the MR-SC Watershed on a 10-year schedule. The monitoring and assessment work for this watershed will be repeated beginning 2019 or 2020. Long term load monitoring at watershed outlets is in place and additional long term intermediate scale load monitoring is planned to begin in 2014 with efforts lead by the DNR.

8 IMPLEMENTATION

The monitoring, assessment and stressor ID work performed in the MR-SC Watershed have identified the practices and geographic areas that should receive priority for implementation. The complete implementation table can be found in the MPCA WRAPS for the MR-SC Watershed (MPCA 2014). The focus of load reduction will be on reducing nonpoint watershed loads to impaired receiving waters. Areas for implementation will focus first on impaired lakes, focusing on the most achievable goals first. Addressing the impaired lakes will provide some improvement for area streams. Once impaired lakes are addressed in full, the additional work to target impaired streams will then be re-assessed.

Necessary repairs to leaking and straight pipe SSTSs (where identified) are recommended to reduce nutrient loading into the lakes. State law prohibits discharge from septic systems. To this point, there has been no specific work done to target and address straight pipe septic systems in the watershed.

8.1 General Implementation Strategies

Below is a summary of restoration strategies focused on decreasing pollutants causing impairments in Rice Creek, Battle Brook, and Clearwater River as described in the MR-SC Watershed Biotic Stressor Identification Report (MPCA, 2012d). Restoration strategies were also identified as priority actions through the TMDL development process. Strategies are further detailed during the WRAPS implementation planning process and included in the WRAP report. Additionally, agencies responsible for water management in each area should identify specific actions to address the impairments.

- **Nutrient Management:** Excess TP is a concern throughout the MR-SC watershed. Stormwater runoff from both urban and agricultural sources is supplying an abundance of phosphorus to area streams. Fertilizer management plans, manure management, and urban Stormwater drainage plans should focus on reducing the amount of nutrients that are washing into the area streams. Programs to reduce agricultural fertilizer and manure application rates are the highest priority and should be focused on using only the amounts needed to plant production.

- **Riparian Buffer Zones:** Many riparian areas within the watershed lack sufficient buffers. Maintaining perennial vegetative cover can stabilize the stream banks, reduce erosion, and prevent transport of nutrients to receiving waters. Riparian woody vegetation needs to be managed however to prevent shading the understory and increasing erosion. A healthy riparian corridor will help increase biodiversity of both terrestrial and aquatic species. The first priority should be simply establishing the minimum buffer in which perennial vegetation must be maintained. The highest priority areas should be those where livestock has direct access to the stream, or lands are cultivated right up to the edge of the stream. Lower priority can be given to eliminating invasive species within the buffer. Reed canary grass, a common buffer plant, is shallow rooted and tends to out compete native grasses. It provide little value in terrestrial habitat - however, it does meet the basic water quality need to provide perennial vegetative cover and therefore do provide water quality benefit. Efforts to establish buffers in high priority areas are the highest priority; efforts to expand buffers to other areas are secondary. Efforts to convert invasive species dominated buffers to more diverse native plant communities that do not shade out understory are the last priority.

- **Restoration of channelized stream reaches** was also identified by stakeholders as a possible implementation strategy. Several reaches of the MR-SC tributaries have been channelized to provide drainage for agriculture. Impairments in some of the reaches can be traced to channel morphometry (i.e. low slopes or over widened channels). In some cases, implementation activities can be supported by returning channelized stream reaches to a pattern, dimension, and profile similar to stable reference reaches in the area. If public sentiment and ditch management policy is such that these ditches must remain straightened and channelized, then a two-stage ditch design is a possible compromise that could improve stream habitat, water quality, and sediment transport. These activities are low priority overall. If they are implemented, impaired waters that will benefit from this strategy should be given the priority for implementation of this strategy. Load reductions in the watershed to be gained by nutrient and riparian area management are the highest priority.

Below is a listing of individual restoration strategies which were identified by local units of government and Wenck. Additional concepts and reach/lake specific implementation goals can be found in the Mississippi River (St. Cloud) WRAPS.

8.2 Individual Lakes Recommendations

8.2.1 Donovan Lake

- Completion of modern aquatic plant and fisheries surveys would help identify current biological health of this shallow lake.

- A shallow lake like Donovan is more sensitive to changes in the biological community within. Shallow Lakes typically reside in two states: Clear water dominated by rooted plants, or algae dominated turbid waters without much aquatic vegetation. Management strategies for shallow lakes can include: surface drawdowns, shoreline stabilizations, management of rough fish communities, and boating education and guidelines to minimize water quality degradations.**

- The shallowness of Donovan Lake makes it is susceptible to increased eutrophication with increases in phosphorus loading. Developmental pressure may have an impact on water quality; every effort should be made to minimize TP loading to the lake. For example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.
- According to data reviewed from the DNR and GIS, the lake has no inlets and no outlets; Field observations may be worthwhile.

** Local resource professionals have indicated that having a healthy biological community is more applicable than a numerical water quality goal.

8.2.2 Birch Lake

- Completion of modern aquatic plant and fisheries surveys would help identify current biological health. Presence of non-native species can negatively impact water quality.

- If present, care should be taken to maintain a healthy aquatic plant community.

- The shallowness of Birch Lake makes it is susceptible to increased eutrophication with increases in phosphorus loading. Developmental pressure may have an impact on water quality; every effort should be made to minimize TP loading to the lake. For example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- Flow and TP data should be collected at the Mud Lake Inlet to help determine the impact it has on Birch Lake.

- Continued in-lake monitoring program to monitor trends.

8.2.3 Briggs Lake Chain

8.2.3.1 Julia Lake

- The shallowness of Julia Lake makes it is susceptible to increased eutrophication with increases in phosphorus loading. Developmental pressure may have an impact on water quality; every effort should be made to minimize TP loading to the lake. For example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- High priority should be placed on protecting high concentration of forested land in the watershed.

- Lake goals should include establishment and/or maintenance of native aquatic plant community.

- The results of this work should be used to provide support to work currently underway by the Briggs Lake Chain Association including placement of stormwater reduction practices in key areas.

- Steps should be taken to educate lakeshore property owners on the cumulative impacts of residential development on water quality.

- Septic systems out of compliance with County/state codes and those that are imminent public health threats should be brought into compliance.

- Efforts should be pursued to continue with nutrient management strategies until water clarity is within guidelines.

- Continue in-lake monitoring program along with collection of current water quality data on Julia Creek to verify health.

- A shallow lake like Julia is sensitive to changes in the biological community within. Shallow Lakes typically reside in two states: Clear water dominated by rooted plants, or algae dominated turbid waters without much aquatic vegetation. Management strategies for shallow lakes can include: surface drawdowns, shoreline stabilizations, management of rough fish communities, and boating education and guidelines to minimize water quality degradations.

8.2.3.2 Briggs

- In-depth investigation into the actual Elk River Contributions via the Bayou (intensive flow and nutrient sampling program).

- Quantification of sediment release rates (internal nutrient recycling) would help in prioritization of cleanup strategies. Methods to reduce said source may include: management of rough fish communities, boating education/guidelines, alum treatments, or other innovative reduction strategies. Internal treatment should be considered after watershed sources have been exhausted.

- Ensure minimal water quality impacts from developments around the lake; for example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- The results of this work should be used to provide support to work currently underway by the Briggs Lake Chain Association (see bullet above).

- Steps should be taken to educate lakeshore property owners on the cumulative impacts of residential development on water quality.

- Septic systems out of compliance with County/state codes and those that are imminent public health threats should be brought into compliance.

- Continue regular in-lake monitoring program.

8.2.3.3 Rush

- The shallowness of Rush Lake makes it is susceptible to increased eutrophication with increases in phosphorus loading. Developmental pressure may have an impact on water quality; every effort should be made to minimize TP loading to the lake. For example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- High priority should be placed on reducing the impacts from lakes upstream.

- Quantification of sediment release rates (internal nutrient recycling) would help in prioritization of cleanup strategies. Methods to reduce said source may include: management of rough fish communities, boating education/guidelines, alum treatments, or other innovative reduction strategies. Internal treatment should be considered after watershed sources have been exhausted.

- Lake goals should include establishment and/or maintenance of native aquatic plant community.

- The results of this work should be used to provide support to work currently underway by the Briggs Lake Chain Association including placement of stormwater reduction practices in key areas.

- Steps should be taken to educate lakeshore property owners on the cumulative impacts of residential development on water quality.

- Septic systems out of compliance with County/state codes and those that are imminent public health threats should be brought into compliance.

- Continue in-lake monitoring program to assess trends and response to changes in the watershed.

- A shallow lake like Rush Lake is sensitive to changes in the biological community within. Shallow Lakes typically reside in two states: Clear water dominated by rooted plants, or algae dominated turbid waters without much aquatic vegetation. This fact should be considered by lake users during management planning.

8.2.4 Upper & Lower Orono Lake

- Based on available data, it is likely that very large reductions in the amount of TP entering the lake will be necessary to provide measurable and perceptible improvements in the water quality of the lake.

- A shallow lake like Orono is more sensitive to changes in the biological community within them. Shallow Lakes typically reside in two states: Clear water dominated by rooted plants, or algae dominated turbid waters without much aquatic vegetation. Management strategies for shallow lakes can include: surface drawdowns, shoreline stabilizations, management of rough fish communities, and boating education and guidelines to minimize water quality degradations.**

- Activities recommended by the TMDL Implementation Plan for the Big Elk Lake TMDL will improve water quality in Orono Lake.

- As recommended in the January 2011, Lake Orono Sedimentation Study, a first recommendation is to develop a lake management plan of Lake Orono. Develop a set of goals based on the desired use by the residents for the lake; discuss the attainability of that use, and develop a course of action to implement the goals. Developing a lake management plan is helpful because it helps lake residents to set realistic expectations and achievable goals. It identifies specific action stems to reach the goals and associated costs.

** Local resource professionals have indicated that having a healthy biological community is more applicable than a numerical water quality goal.

8.2.5 Fish Lake

- A detailed examination of the Mississippi River backflow (flow and nutrients) is necessary to determine its impacts on Fish Lake.

- Efforts to reduce nutrient inflow from Fish Creek (annually) as well as the northwest inlet (seasonally) should be employed.

- Restoring or improving wetlands in the watershed may be beneficial for reducing the amount of nutrients which reach Fish Lake.

- Ensure minimal water quality impacts from rural developments around the lake; for example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- Methods to manage exotic aquatic plant species and enhance native plant species should be employed.

- Continuation of regular In-lake monitoring program will aid in identifying trends and lake response to nutrient reduction.

8.2.6 Mink and Somers Lakes

- Shallow lakes like Mink and Somers are more sensitive to changes in the biological community within. Shallow Lakes typically reside in two states: Clear water dominated by rooted plants, or algae dominated turbid waters without much aquatic vegetation. Management strategies for shallow lakes can include: surface drawdowns, shoreline stabilizations, management of rough fish communities, and boating education and guidelines to minimize water quality degradations.**

- The shallowness of the lakes makes them susceptible to increased eutrophication with increases in phosphorus loading; every effort should be made to minimize TP loading to the lake. For example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- Quantification of sediment release rates (internal nutrient recycling) would help in prioritization of cleanup strategies. Methods to reduce said source may include: management of rough fish communities, boating education/guidelines, alum treatments, or other innovative reduction strategies. Internal treatment should be considered after watershed sources have been exhausted.

- Steps should be taken to educate lakeshore property owners on the cumulative impacts of residential development on water quality.
- Septic systems out of compliance with County/state codes and those that are imminent public health threats should be brought into compliance.
- Restoring or improving wetlands in the watershed may also be beneficial for reducing the amount of nutrients or sediments which reach Mink and Somers Lake.

- Continued in-lake monitoring is recommended and will track trends/progress over time.

  ** Local resource professionals have indicated that having a healthy biological community is more applicable than a numerical water quality goal.

8.2.7 Silver Lake

- If numerical goals are to be met for Silver Lake, nutrient loads from the Silver Creek watershed must be greatly reduced.

- The excellent quality of water in Sandy Creek should be protected.

- Methods to manage exotic aquatic plant species and enhance native plant species should be employed.

- Ensure minimal water quality impacts of rural developments around the lake; for example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- Monitoring flow and nutrients in both inlets will aid in identifying current nutrient levels as well as to establish a baseline for future conditions.

- Establishment of a regular In-lake monitoring program will aid in tracking trends.

8.2.8 Indian Lake

- Methods to manage exotic aquatic plant species and enhance native plant species should be considered.

- Quantification of sediment release rates (internal nutrient recycling) would help in prioritization of cleanup strategies. Methods to reduce said source may include: management of rough fish communities, boating education/guidelines, alum treatments, or other innovative reduction strategies. Internal treatment should be considered after watershed sources have been exhausted.

- Ensure minimal water quality impacts of rural developments around the lake; for example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- Monitoring flow and nutrients in both ditched inlets will aid in identifying approximate contributions levels as well as to establish a baseline for future conditions.

- Establishment of a regular In-lake monitoring program will aid in tracking trends.

8.2.9 Locke Lake

- Should Silver Lake meet numerical water quality standards, measurable improvements may be indicated in Locke Lake; consider prioritizing efforts on improvements per Silver Lake recommended activities.

- Restoring or improving wetlands in the watershed may be beneficial for reducing the amount of nutrients which reach Locke Lake.

- Ensure minimal water quality impacts from developments around the lake; for example, no untreated stormwater should be directed into the lake, the amount of impervious surfaces in developed areas should be kept to a minimum, natural buffers of vegetation should be maintained between lawns and the lakeshore.

- Methods to manage exotic aquatic plant species and enhance native plant species should be considered.

- Monitoring flow and nutrients directly upstream of Locke Lake would provide concrete status on the contributions from the large watershed.

- Establishment of a regular In-lake monitoring program will aid in tracking trends.

Streams Considerations (DO, Turbidity)

DO: Oxygen demand sources in the watershed to the listed reaches include wetland SOD, and anthropogenic (watershed runoff) sources such as agriculture and associated land practices including feedlots, pasturing, and crop farming, and rural residential and urban runoff and septic systems.

8.3 Rice Creek

The primary recommended strategy is to manage for nutrient runoff from the large watershed.

- Watershed runoff reduction: Wenck staff recommended a watershed wide programmatic approach. (i.e. cover crops, nutrient management).

- Perched Culvert (downstream Cr 16) replacement; if the culvert at the private drive is replaced there would likely be a reduction in TP and SOD.

8.4 Battle Brook

The primary recommended strategy is to manage for nutrient runoff from the large watershed.

- Watershed runoff reduction: Wenck staff recommended a watershed wide programmatic approach. (i.e. cover crops, nutrient management).
- Headwater Improvements: Investigate feasibility of restoring original flow channel from Rice Lake.
- Culvert Replacement: Replace and properly size culvert at CR 9.
- Channel Morphology Restoration: Investigate re-shaping channel (two-stage ditch) to reconnect the flood plain.

8.5 Clearwater River

The primary recommended strategy is to manage for nutrient runoff from the large watershed.

- Watershed runoff reduction: Wenck staff recommended a watershed wide programmatic approach. (i.e. cover crops, nutrient management).
- Investigate improvement to Channel Morphology: Stream restoration to modify upstream Wiegand Lake by digging low flow channel.
- Wiegand Lake forced mixing: Force water into lake during high flows
- Investigate grass lake dam modification to improve aeration.
- Streambank improvements to increase shading.

8.6 Rice Creek (Turbidity)

As discussed earlier, streambank assessments show minimal bank erosion, it is assumed that most of the sediment enters the stream from field runoff. The primary nonpoint sources of sediment in Rice Creek are conveyed from the landscape.

- Follow Strategies for the Rice Creek DO impairment.
- Continue monitoring transparency and DO at CR 16.

8.7 Construction Sites and SWPPPs

Attaining the construction stormwater loads described in the MR-SC Watershed TMDLs is the responsibility of construction site managers. Local municipal MS4 permittees are responsible for overseeing construction stormwater loads which impact water quality in the waters covered by the MR-SC Watershed TMDLs. The MS4 communities within the watershed are required to have a construction stormwater ordinance at least as stringent as the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). In the final TMDL document MPCA explained that if a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit (MNR100001) and properly selects, installs and maintains all BMPs required under MNR1000001 and applicable local construction stormwater ordinances, 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. BMPs and other stormwater control measures which act to limit the discharge of the pollutant of concern (phosphorus) are defined in MNR100001.

The NPDES program requires construction and industrial sites to create SWPPPs which summarize how stormwater pollutant discharges will be minimized from construction and industrial sites. Under the MPCA's Stormwater General Permit (MNR100001) and applicable local construction stormwater ordinances, managers of sites under construction or industrial stormwater permits must review the adequacy of local SWPPPs to ensure that each plan complies with the applicable requirements in the State permits and local ordinances. As noted above, MPCA has explained that meeting the terms of the applicable permits will be consistent with the WLAs set in the MR-SC Watershed TMDLS. In the event that the SWPPP does not meet the WLA, the SWPPP will need to be modified. This applies to sites under permits for MNR100001, MNR050000 and MNG490000.

8.8 Adaptive Management

Adaptive management is an iterative implementation process that makes progress toward achieving water quality goals while using any new data and information to reduce uncertainty and adjust implementation activities. It is an ongoing process of evaluating and adjusting the strategies and activities that will be developed to implement the TMDL. The implementation of practicable controls should take place even while additional data collection and analysis are conducted to guide future implementation actions. Adaptive management does not include changes to water quality standards or LC. Any changes to water quality standards or LC must be preceded by appropriate administrative processes; including public notice and an opportunity for public review and comment.

The list of implementation elements included in this section focuses on adaptive management. As nutrient, sediment DO and other stressors are better understood, management activates both to reduce the pollutants of concern 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 lakes and stream reaches.

8.9 Reasonable Assurance

Several Federal, State and Local agencies have been and continue to work toward the goal of reducing pollutant loads in the MR-SC Watershed. Strong partnerships formed during the WRAPS process such as those between counties, SWCD's, Natural Resource Conservation Service (NRCS), DNR, Watershed Districts, National Park Service and U.S. Fish and Wildlife Service have and will continue to lead to watershed wide implementation of conservation practices. Civic Engagement efforts initiated during the WRAPS will strengthen the relationship between the MR-SC peoples and the agencies which provide technical assistance and incentives to attain water quality improvements.

Minnesota voters have approved an amendment to increase the state sales tax to fund water quality improvements. Subsequently, several state agencies have come together to focus on high level planning in order to best utilize these funds. The interagency Minnesota Water Quality Framework as applied to Minnesota's 81 major watersheds clearly illustrates the cycle of assessment, watershed planning and implementation activities and inform an adaptive management approach to restoration and protection.

The majority of pollutant reductions in the study areas will rely on voluntary adoption of conservation practices by an engaged citizenry. Through the MR-SC Watershed project, the Civic Engagement Committee was tasked with involving watershed citizens to devise protection and restoration strategies for water quality. Goals of civic engagement activities are to leverage opportunities within the watershed assessment and management process to promote active public participation, and craft protection and restoration strategies with input from watershed residents, businesses and organizations.

Figure 9-1 - Minnesota Water Quality Framework

All agencies involved in the process have and continue to pursue the implementation of BMPs in the watershed through the use of funds including those administered by the Minnesota Board of Water and Soil Resources (BWSR), CWL, Federal 319 program, and the Environmental Quality Incentives Program (EQIP).

Watershed technical staff maintains contact with landowners interested in installing water quality improvement projects in the watershed and keep them regularly updated on funding as it becomes available. Over the long term, active participation will help build and sustain local civic infrastructure and leadership for watershed stewardship initiatives.

8.10 Cost Estimate

As part of all TMDLs a cost estimate for implementing the necessary actions to restore the impaired waters included is required. Based on a review of the impairments, and the scale at which restoration needs to happen in the watershed, it is estimated that a dollar range of 8-13 million might be necessary. However, this is an estimate and many aspects can cause the costs to rise and fall as implementation takes place across the MR-SC Watershed.

8.11 Public Participation

As part of the strategy to achieve implementation of the necessary allocations, the MR-SC Civic Engagement Committee, composed of staff from Sherburne, Benton and Wright SWCDs, CRWD, DNR, MPCA and the NPS, held public gatherings on October 13, 2011, March 7, 2013, and April 24, 2014. The purpose of the meetings was to inform the watershed citizens and stakeholders about the TMDL process, and draft results of the MR-SC TMDLS and WRAPS. The MR-SC Watershed TMDL was available for public comment October 13, 2014, through November 12, 2014. Additional watershed events, following the completion of this document, will be held to update residents and to seed additional input of implementation efforts and planning. In addition to the watershed events, the MR-SC CE committee has posted information pertaining to the TMDLs on the ERWA website, presented at board of managers meetings, local water plan advisory committee meetings, lake association meetings and the MR-SC Facebook page. A full description of civic engagement activities associated with the TMDL process can be found in the MR-SC WRAPS (MPCA 2014).

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APPENDIX A - LAKE SUPPORTING DOCUMENTS

Donovan Lake

Supporting Information

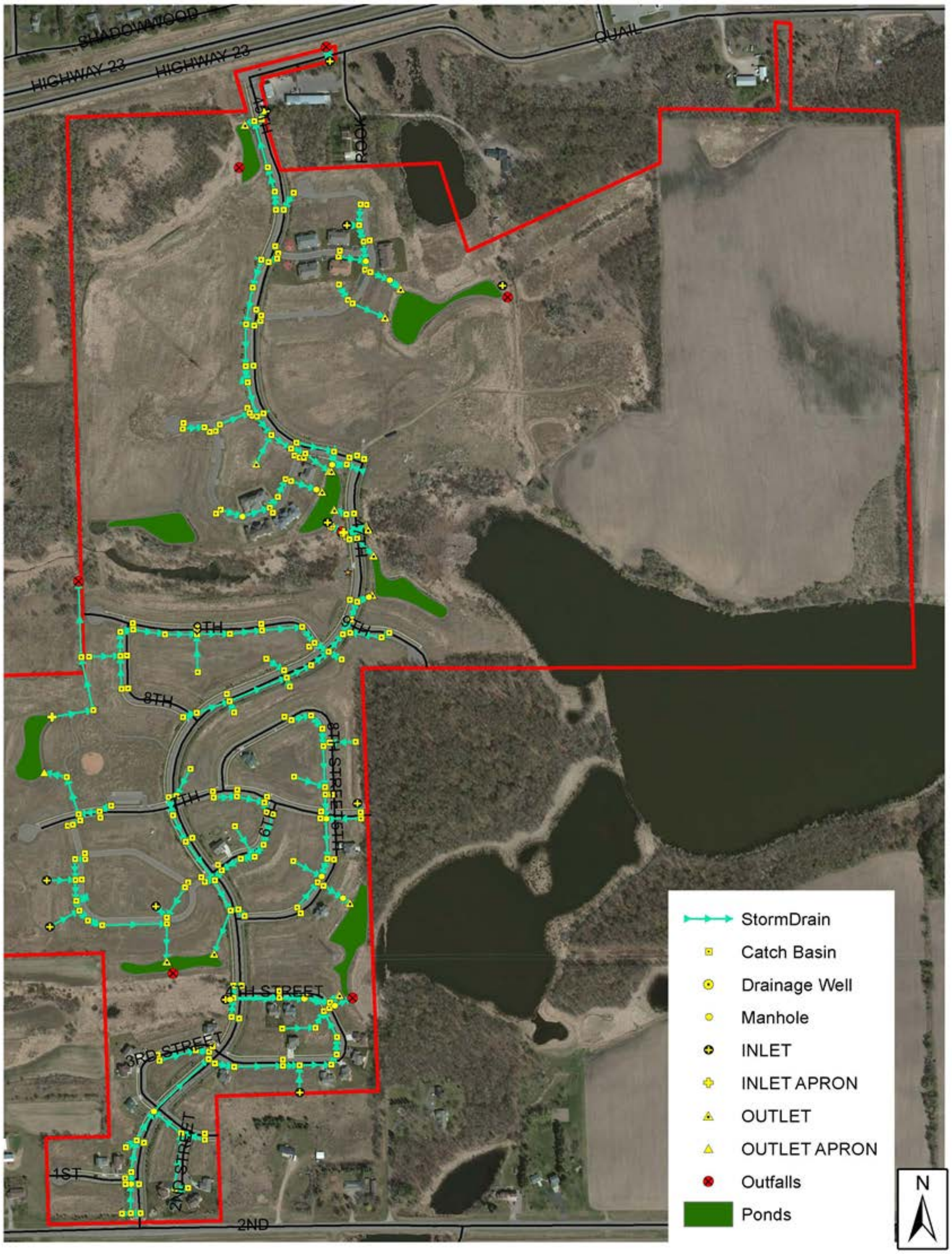
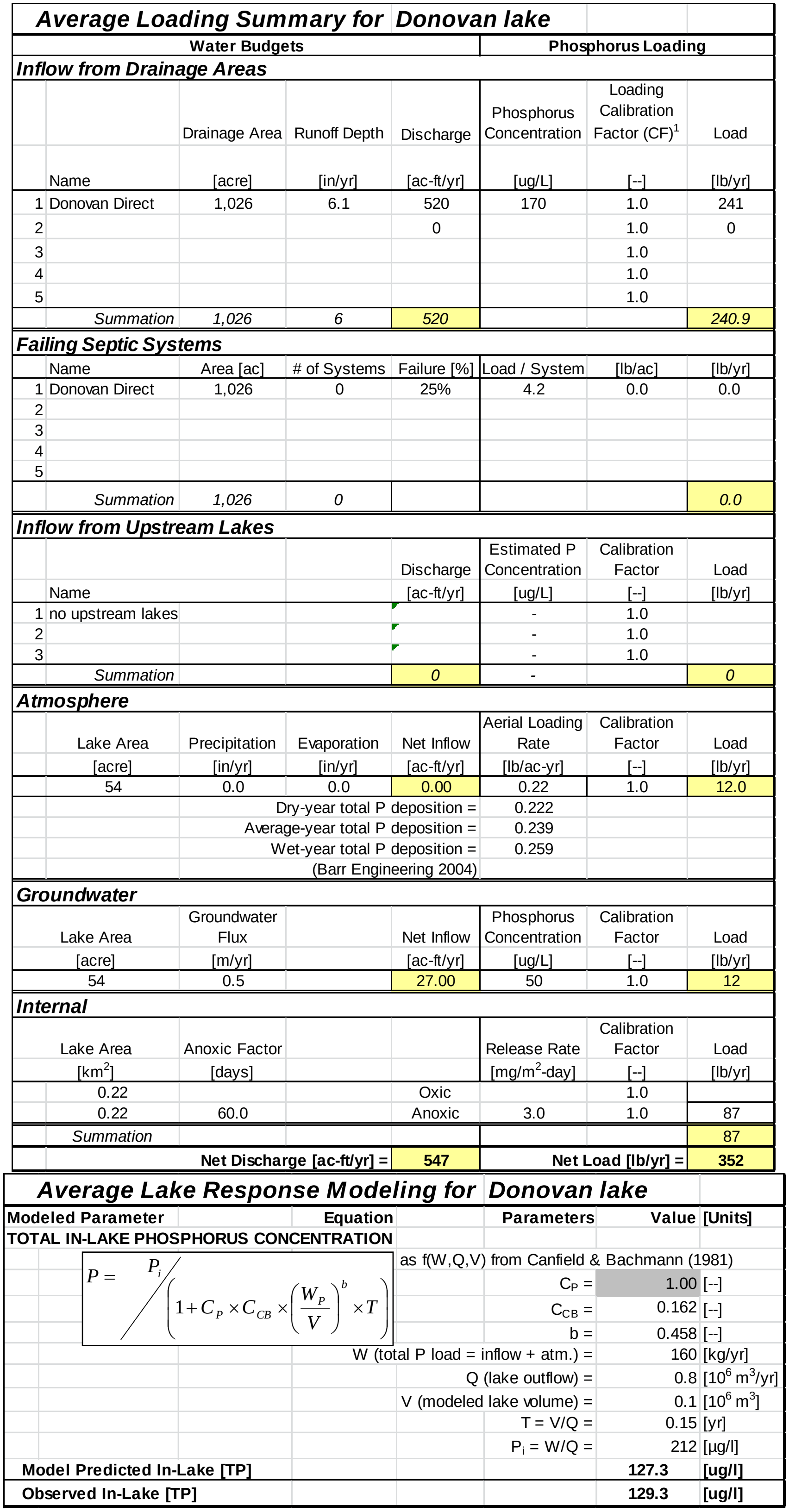


Figure 0.1 Stormwater drainage maps for Donovan Lake

Donovan Lake Average conditions BATHTUB Lake Response Model



Average Loading Summary for Donovan lake

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Donovan Direct	1,026	6.1	520	170	1.0	241
2				0		1.0	0
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,026*	*6*	*520*			*240.9*

Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Donovan Direct	1,026	0	25%	4.2	0.0	0.0
2							
3							
4							
5							
	Summation	*1,026*	*0*				*0.0*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	no upstream lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere						
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
54	0.0	0.0	0.00	0.22	1.0	12.0
	Dry-year total P deposition =			0.222		
	Average-year total P deposition =			0.239		
	Wet-year total P deposition =			0.259		
	(Barr Engineering 2004)					

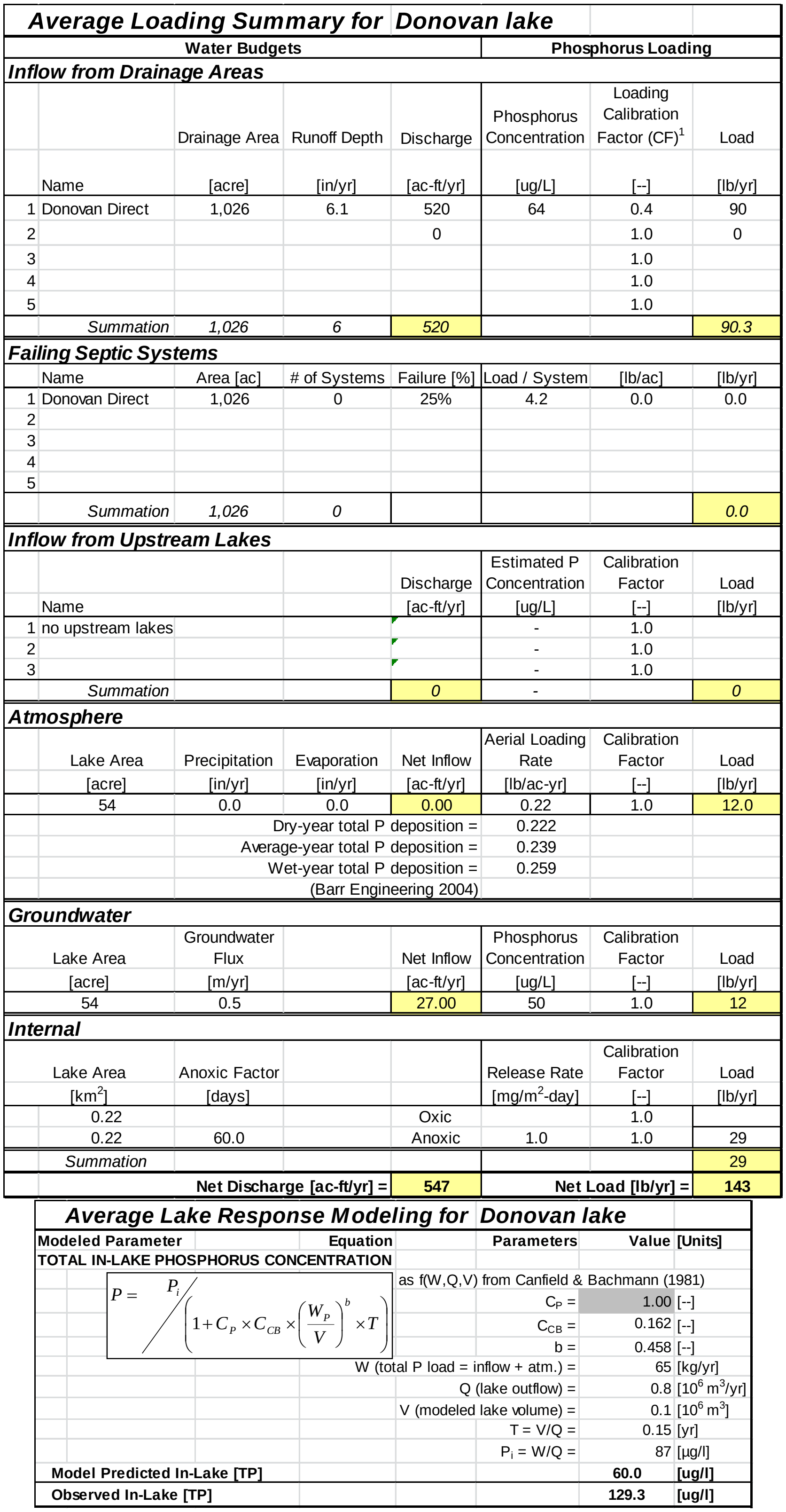
Groundwater						
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
54	0.5		27.00	50	1.0	12

Internal						
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
0.22			Oxic		1.0	
0.22	60.0		Anoxic	3.0	1.0	87
Summation						87
		Net Discharge [ac-ft/yr] =	**547**		**Net Load [lb/yr] =**	**352**

Average Lake Response Modeling for Donovan lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	160	[kg/yr]
		Q (lake outflow) =	0.8	[10^6 m^3/yr]
		V (modeled lake volume) =	0.1	[10^6 m^3]
		T = V/Q =	0.15	[yr]
		P_i = W/Q =	212	[µg/l]
Model Predicted In-Lake [TP]			**127.3**	**[ug/l]**
Observed In-Lake [TP]			**129.3**	**[ug/l]**

Donovan Lake TMDL Conditions BATHTUB Lake Response Model



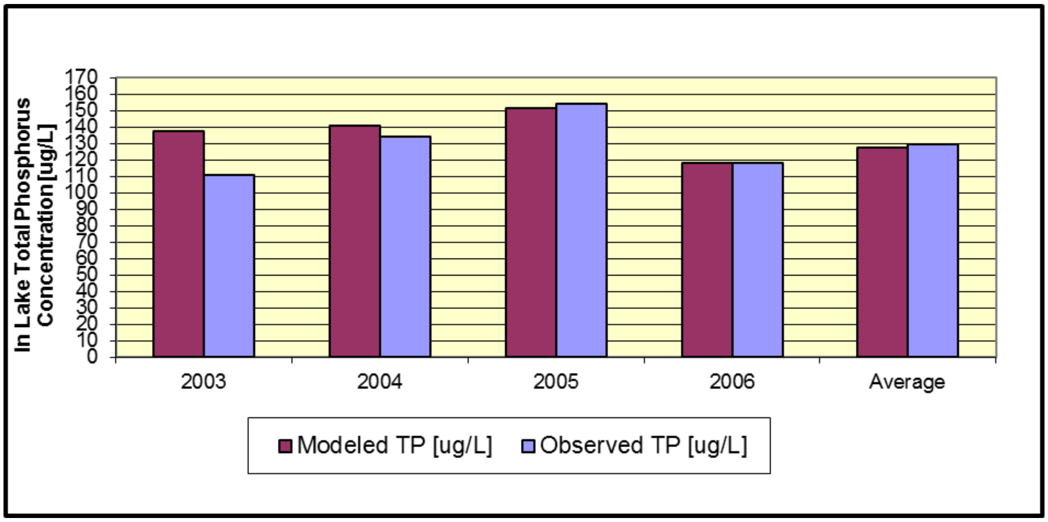
Average Loading Summary for Donovan lake

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	Donovan Direct	1,026	6.1	520	64	0.4	90
2				0		1.0	0
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,026*	*6*	*520*			*90.3*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Donovan Direct	1,026	0	25%	4.2	0.0	0.0
2							
3							
4							
5							
	Summation	*1,026*	*0*				*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	no upstream lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	54	0.0	0.0	0.00	0.22	1.0	12.0
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	54	0.5		27.00	50	1.0	12
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.22			Oxic		1.0	
	0.22	60.0		Anoxic	1.0	1.0	29
	Summation						29
			Net Discharge [ac-ft/yr] =	**547**		**Net Load [lb/yr] =**	**143**

Average Lake Response Modeling for Donovan lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	65	[kg/yr]
		Q (lake outflow) =	0.8	[10^6 m^3/yr]
		V (modeled lake volume) =	0.1	[10^6 m^3]
		T = V/Q =	0.15	[yr]
		P_i = W/Q =	87	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**129.3**	**[ug/l]**

Donovan Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2003
2004
2005
2006
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Julia Lake

Supporting Information

Julia Lake Average conditions BATHTUB Lake Response Model

Average Loading Summary for Julia Lake 71-0145

	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	Julia Lake Direct	176	5.2	76	250	1.0	52
2	Julia Creek Subwa	549	5.9	269	61.4	1.0	45
3						1.0	
4				0		1.0	
5						1.0	
	Summation	*725*	*11*	*346*			97.0
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Julia Lake Direct	176	0	15%	4.2	0.0	0.0
2	Julia Creek Subwa	549		15%	4.2		
3							
4							
5							
	Summation	*725*	*0*				*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	no upstream lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	152	0.0	0.0	0.00	0.22	1.0	33.8
				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]
	152	0.5		76.00	50	1.0	34
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.62			Oxic		1.0	
	0.62	45.9		Anoxic	3.4	1.0	212
	Summation						212
			Net Discharge [ac-ft/yr] =	**422**		**Net Load [lb/yr] =**	**376**

Average Lake Response Modeling for Julia Lake 71-0145

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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	171	[kg/yr]
		Q (lake outflow) =	0.7	[10^6 m^3/yr]
		V (modeled lake volume) =	1.5	[10^6 m^3]
		T = V/Q =	2.02	[yr]
		P_i = W/Q =	233	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**61.8**	**[ug/l]**

Julia Lake TMDL Conditions BATHTUB Lake Response Model

Average Loading Summary for Julia Lake 71-0145

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	Julia Lake Direct	176	5.2	76	250	1.0	52
2	Julia Creek Subwa	549	5.9	269	61.4	1.0	45
3						1.0	
4						1.0	
5						1.0	
	Summation	*725*	*11*	*346*			*97.0*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Julia Lake Direct	176		15%	4.2	0.0	0.0
2	Julia Creek Subwa	549		15%	4.2		
3							
4							
5							
	Summation	*725*	*0*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	no upstream lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
152	0.0	0.0	0.00	0.22	1.0	33.8
		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]
152	0.5		76.00	50	1.0	34

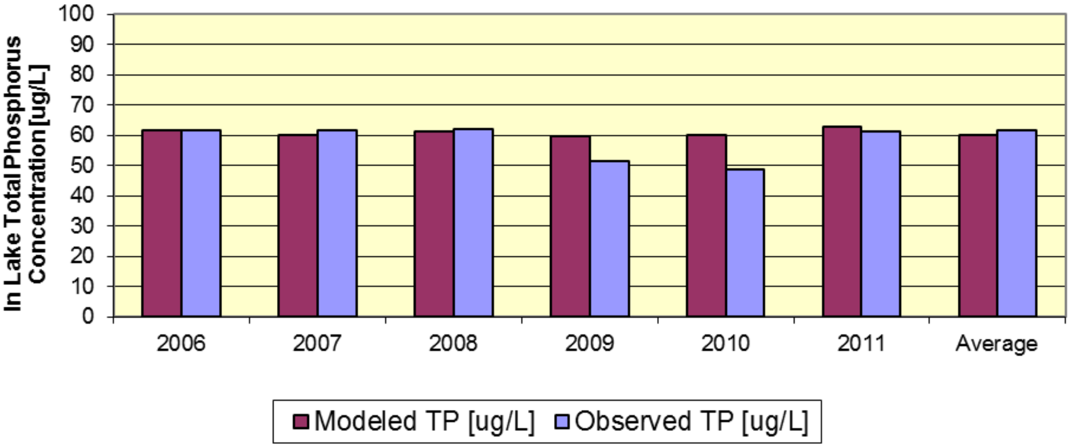
Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.62			Oxic		1.0	
0.62	45.9		Anoxic	3.4	1.0	212
Summation						212
		Net Discharge [ac-ft/yr] =	**422**	**Net Load [lb/yr] =**		**376**

Average Lake Response Modeling for Julia Lake 71-0145

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	171	[kg/yr]
		Q (lake outflow) =	0.7	[10^6 m^3/yr]
		V (modeled lake volume) =	1.5	[10^6 m^3]
		T = V/Q =	2.02	[yr]
		P_i = W/Q =	233	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**61.8**	**[ug/l]**

Julia Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
100
90
80
70
60
50
40
30
20
10
0
2006
2007
2008
2009
2010
2011
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Briggs Lake

Supporting Information

Briggs Lake Average conditions BATHTUB Lake Response Model

Average Loading Summary for Briggs Lake 71-146

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	Briggs Direct	1,116	5.0	469	300	1.0	383
2	Briggs Creek	6,778	5.5	3,122	51.2	1.0	435
3	ER Briggs Bayou (	4,886	3.0	1,212	96.2	1.0	317
4				0		1.0	0
5						1.0	
	Summation	*12,780*	*14*	*4,802*			*1,134.6*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Briggs Direct	1,116		15%	4.2		
2	Briggs Creek				4.2		
3	ER Briggs Bayou Overflow				4.2		
4							
5							
	Summation	*1,116*	*0*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Julia lake			527	57.8	1.0	83
2					-	1.0	
3					-	1.0	
	Summation			*527*	*57.8*		*83*

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]
	404	0.0	0.0	0.00	0.22	1.0	89.8
				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]
	404	0.2		80.80	50	1.0	36

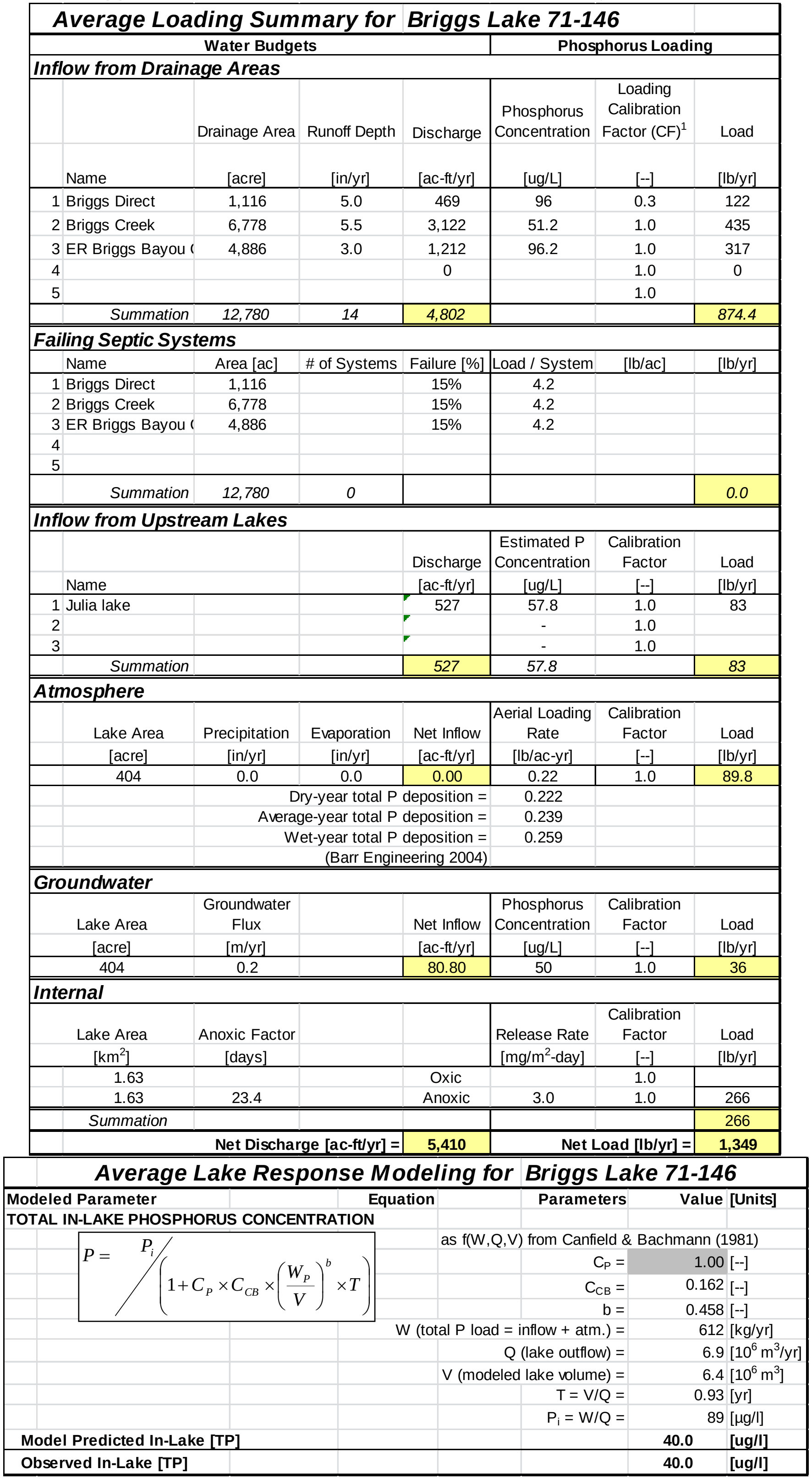
Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.63			Oxic		1.0	
	1.63	23.4		Anoxic	20.0	1.0	1,688
	Summation						1,688
		Net Discharge [ac-ft/yr] =		**5,410**	**Net Load [lb/yr] =**		**3,032**

Average Lake Response Modeling for Briggs Lake 71-146

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,375	[kg/yr]
		Q (lake outflow) =	6.9	[10^6 m^3/yr]
		V (modeled lake volume) =	6.4	[10^6 m^3]
		T = V/Q =	0.93	[yr]
		P_i = W/Q =	199	[µg/l]
Model Predicted In-Lake [TP]			**72.1**	**[ug/l]**
Observed In-Lake [TP]			**75.0**	**[ug/l]**

Briggs Lake TMDL Conditions BATHTUB Lake Response Model



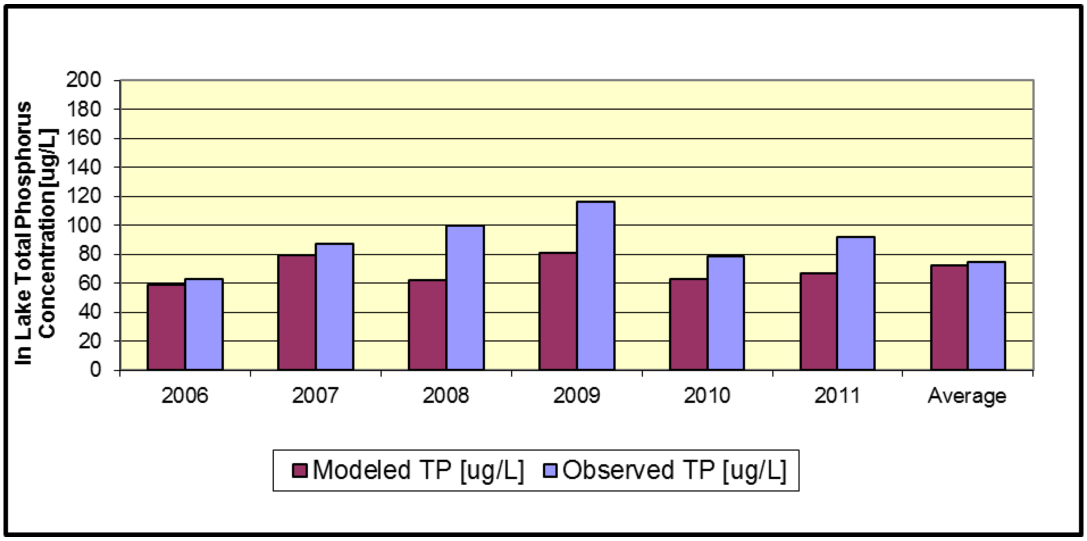
Average Loading Summary for Briggs Lake 71-146

	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)^{1}	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Briggs Direct	1,116	5.0	469	96	0.3	122
2	Briggs Creek	6,778	5.5	3,122	51.2	1.0	435
3	ER Briggs Bayou (	4,886	3.0	1,212	96.2	1.0	317
4				0		1.0	0
5						1.0	
	Summation	*12,780*	*14*	*4,802*			*874.4*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Briggs Direct	1,116		15%	4.2		
2	Briggs Creek	6,778		15%	4.2		
3	ER Briggs Bayou (	4,886		15%	4.2		
4							
5							
	Summation	*12,780*	*0*				*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Julia lake			527	57.8	1.0	83
2					-	1.0	
3					-	1.0	
	Summation			*527*	*57.8*		*83*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	404	0.0	0.0	0.00	0.22	1.0	89.8
		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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	404	0.2		80.80	50	1.0	36
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^{2}]	[days]			[mg/m^{2}-day]	[--]	[lb/yr]
	1.63			Oxic		1.0	
	1.63	23.4		Anoxic	3.0	1.0	266
	Summation						266
			Net Discharge [ac-ft/yr] =	**5,410**		**Net Load [lb/yr] =**	**1,349**

Average Lake Response Modeling for Briggs Lake 71-146

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	612	[kg/yr]
		Q (lake outflow) =	6.9	[10^6 m^3/yr]
		V (modeled lake volume) =	6.4	[10^6 m^3]
		T = V/Q =	0.93	[yr]
		P_i = W/Q =	89	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

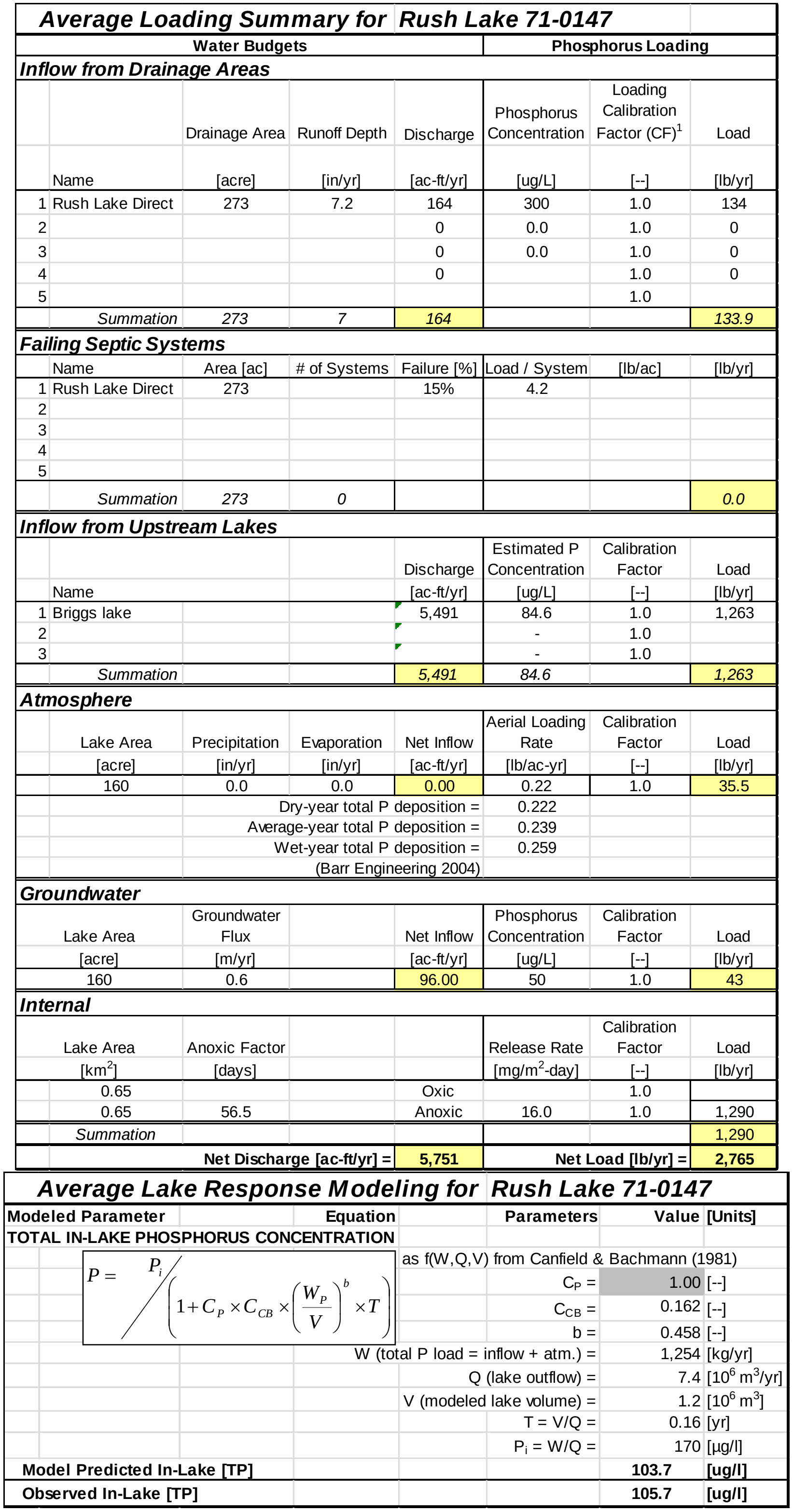
Briggs Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2006
2007
2008
2009
2010
2011
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Rush Lake

Supporting Information

Rush Lake Average conditions BATHTUB Lake Response Model



Average Loading Summary for Rush Lake 71-0147

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	Rush Lake Direct	273	7.2	164	300	1.0	134
2				0	0.0	1.0	0
3				0	0.0	1.0	0
4				0		1.0	0
5						1.0	
	Summation	*273*	*7*	*164*			*133.9*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Rush Lake Direct	273		15%	4.2		
2							
3							
4							
5							
	Summation	*273*	*0*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Briggs lake			5,491	84.6	1.0	1,263
2					-	1.0	
3					-	1.0	
	Summation			*5,491*	*84.6*		*1,263*

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]
160	0.0	0.0	0.00	0.22	1.0	35.5
	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]
160	0.6		96.00	50	1.0	43

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.65			Oxic		1.0	
0.65	56.5		Anoxic	16.0	1.0	1,290
Summation						1,290
		Net Discharge [ac-ft/yr] =	**5,751**		**Net Load [lb/yr] =**	**2,765**

Average Lake Response Modeling for Rush Lake 71-0147

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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,254	[kg/yr]
		Q (lake outflow) =	7.4	[10^6 m^3/yr]
		V (modeled lake volume) =	1.2	[10^6 m^3]
		T = V/Q =	0.16	[yr]
		P_i = W/Q =	170	[μg/l]
Model Predicted In-Lake [TP]			**103.7**	**[ug/l]**
Observed In-Lake [TP]			**105.7**	**[ug/l]**

Rush Lake TMDL Conditions BATHTUB Lake Response Model

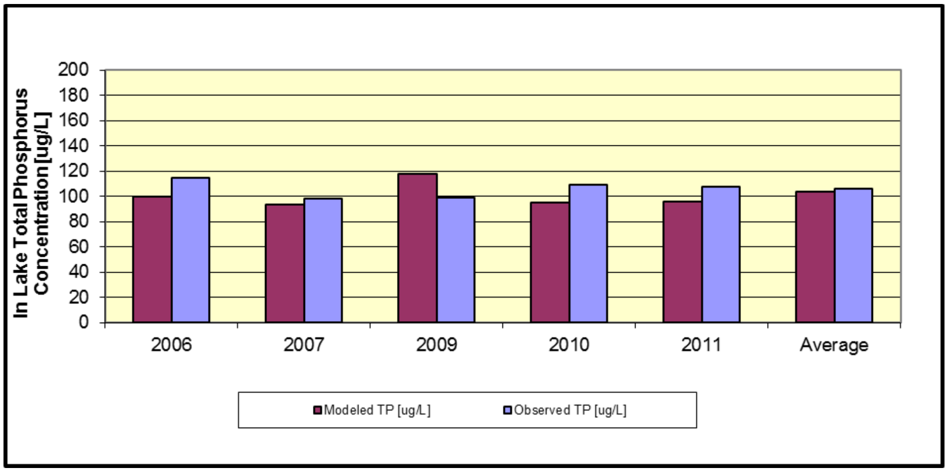
Average Loading Summary for Rush Lake 71-0147

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Rush Lake Direct	273	7.2	164	96	0.3	43
2				0	0.0	1.0	0
3				0	0.0	1.0	0
4				0		1.0	0
5						1.0	
	Summation	*273*	*7*	*164*			*42.8*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Rush Lake Direct	273		15%	4.2		
2							
3							
4							
5							
	Summation	*273*	*0*				*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Briggs lake		0	5,491	40.0	0.5	598
2					-	1.0	
3					-	1.0	
	Summation			*5,491*	*40.0*		*598*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	160	0.0	0.0	0.00	0.22	1.0	35.5
		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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	160	0.6		96.00	50	1.0	43
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.65			Oxic		1.0	
	0.65	56.5		Anoxic	16.0	1.0	717
	Summation						717
			Net Discharge [ac-ft/yr] =	**5,751**		**Net Load [lb/yr] =**	**1,436**

Average Lake Response Modeling for Rush Lake 71-0147

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	651	[kg/yr]
		Q (lake outflow) =	7.4	[10^6 m^3/yr]
		V (modeled lake volume) =	1.2	[10^6 m^3]
		T = V/Q =	0.16	[yr]
		P_i = W/Q =	88	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Rush Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2006
2007
2009
2010
2011
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Upper & Lower Orono Lake

Supporting Information

Upper & Lower Orono Lake Average conditions BATHTUB Lake Response Model

Average Loading Summary for Orono Lake 71-013-01 &02

	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	Direct	5,643	8.9	4,196	250	1.0	2,852
2	Orono Ditched inle	3,617	8.9	2,689	249.9	1.0	1,828
3	Elk River	357,760	5.1	151,190	91.7	1.0	37,698
4	Tibbits Brook	24,205	8.1	16,359	131.9	1.0	5,871
5						1.0	
	Summation	*391,225*	*31*	*174,435*			*48,249.6*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Aspen Hills WWTP			10	912	1.0	25
2	Zimmerman WWTP			322	600.8	1.0	526
3	Becker WWTP			883	607.7	1.0	1,460
4							
5							
	Summation			*1,215*			*2,011.5*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Direct	5,643		15%	4.2		
2	Orono Ditched inle	3,617		15%	4.2		
3	Elk River	357,760		15%	4.2		
4	Tibbits Brook	24,205		15%	4.2		
5							
	Summation	*391,225*	*0*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Big Elk Lake			113,963	142.3	1.0	44,124
2	Birch Lake			1,310	41.3	1.0	147
3					-	1.0	
	Summation			*115,273*	*91.8*		*44,271*

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]
	300	31.5	31.5	0.00	0.24	1.0	71.7
				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]
	300	0.6		180.00	50	1.0	80

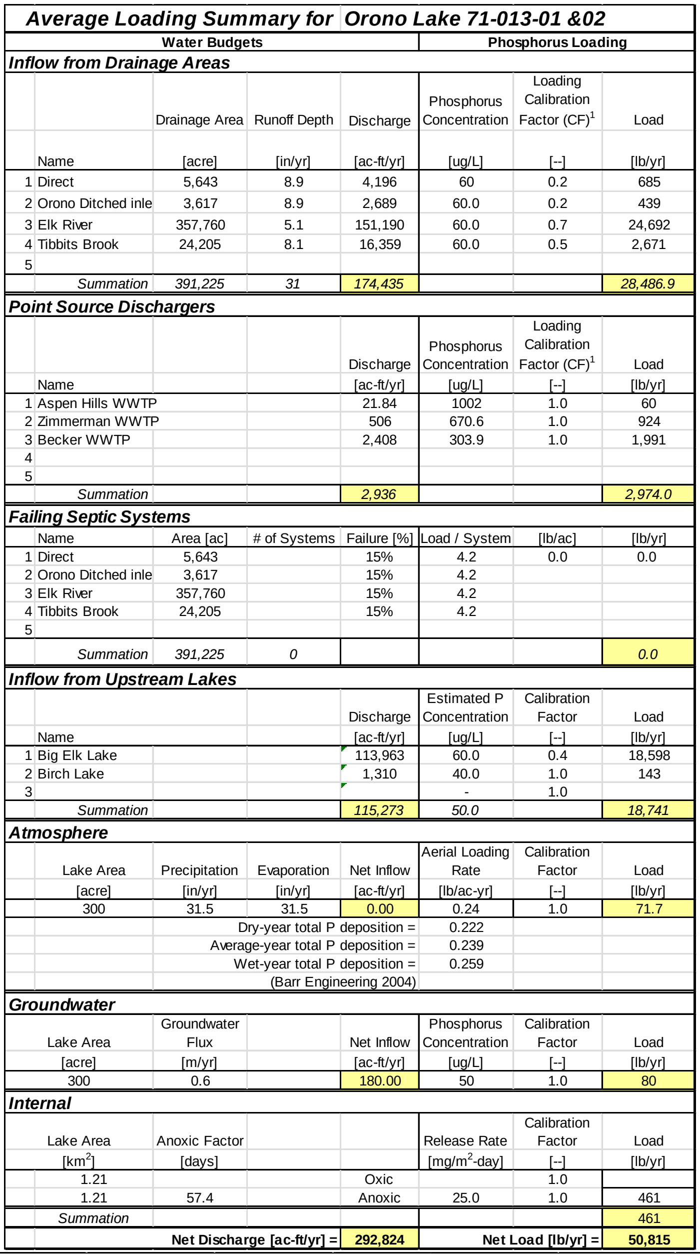
Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.21			Oxic		1.0	
	1.21	57.4		Anoxic	25.0	1.0	3,842
	Summation						3,842
			Net Discharge [ac-ft/yr] =	**291,103**		**Net Load [lb/yr] =**	**98,526**

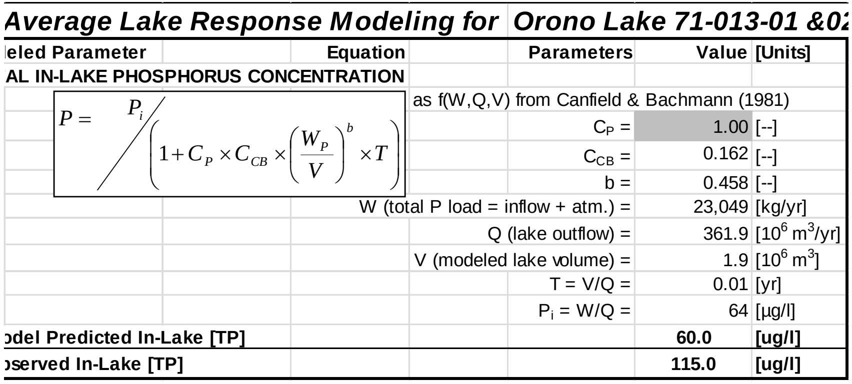
Average Lake Response Modeling for Orono Lake 71-013-01 &0

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	44,690	[kg/yr]
		Q (lake outflow) =	359.7	[10^6 m^3/yr]
		V (modeled lake volume) =	1.9	[10^6 m^3]
		T = V/Q =	0.01	[yr]
		P_i = W/Q =	124	[µg/l]
Model Predicted In-Lake [TP]			**114.5**	**[ug/l]**
Observed In-Lake [TP]			**115.0**	**[ug/l]**

Upper & Lower Orono Lake TMDL Conditions BATHTUB Lake Response Model

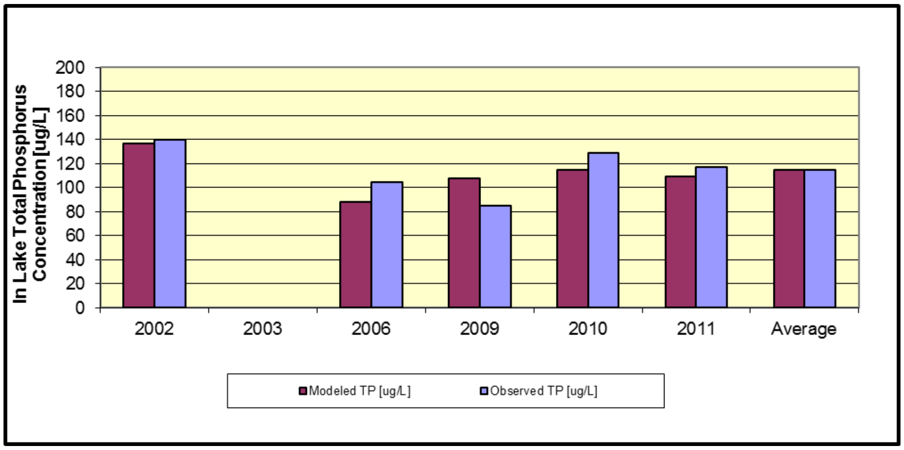


Average Loading Summary for	*Orono Lake 71-013-01 &02*						
Water Budgets					**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct	5,643	8.9	4,196	60	0.2	685
2	Orono Ditched inle	3,617	8.9	2,689	60.0	0.2	439
3	Elk River	357,760	5.1	151,190	60.0	0.7	24,692
4	Tibbits Brook	24,205	8.1	16,359	60.0	0.5	2,671
5							
	Summation	*391,225*	*31*	*174,435*			*28,486.9*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Aspen Hills WWTP			21.84	1002	1.0	60
2	Zimmerman WWTP			506	670.6	1.0	924
3	Becker WWTP			2,408	303.9	1.0	1,991
4							
5							
	Summation			*2,936*			*2,974.0*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Direct	5,643		15%	4.2	0.0	0.0
2	Orono Ditched inle	3,617		15%	4.2		
3	Elk River	357,760		15%	4.2		
4	Tibbits Brook	24,205		15%	4.2		
5							
	Summation	*391,225*	*0*				*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Big Elk Lake			113,963	60.0	0.4	18,598
2	Birch Lake			1,310	40.0	1.0	143
3					-	1.0	
	Summation			*115,273*	*50.0*		*18,741*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	300	31.5	31.5	0.00	0.24	1.0	71.7
				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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	300	0.6		180.00	50	1.0	80
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.21			Oxic		1.0	
	1.21	57.4		Anoxic	25.0	1.0	461
	Summation						461
			Net Discharge [ac-ft/yr] =	**292,824**		**Net Load [lb/yr] =**	**50,815**



Average Lake Response Modeling for				*Orono Lake 71-013-01 &02*		
eled Parameter		**Equation**		**Parameters**	**Value**	**[Units]**
AL IN-LAKE PHOSPHORUS CONCENTRATION						
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$			as f(W,Q,V) from Canfield & Bachmann (1981)			
				C_P =	1.00	[--]
				C_{CB} =	0.162	[--]
				b =	0.458	[--]
				W (total P load = inflow + atm.) =	23,049	[kg/yr]
				Q (lake outflow) =	361.9	[10^6 m^3/yr]
				V (modeled lake volume) =	1.9	[10^6 m^3]
				T = V/Q =	0.01	[yr]
				P_i = W/Q =	64	[µg/l]
odel Predicted In-Lake [TP]					**60.0**	**[ug/l]**
served In-Lake [TP]					**115.0**	**[ug/l]**

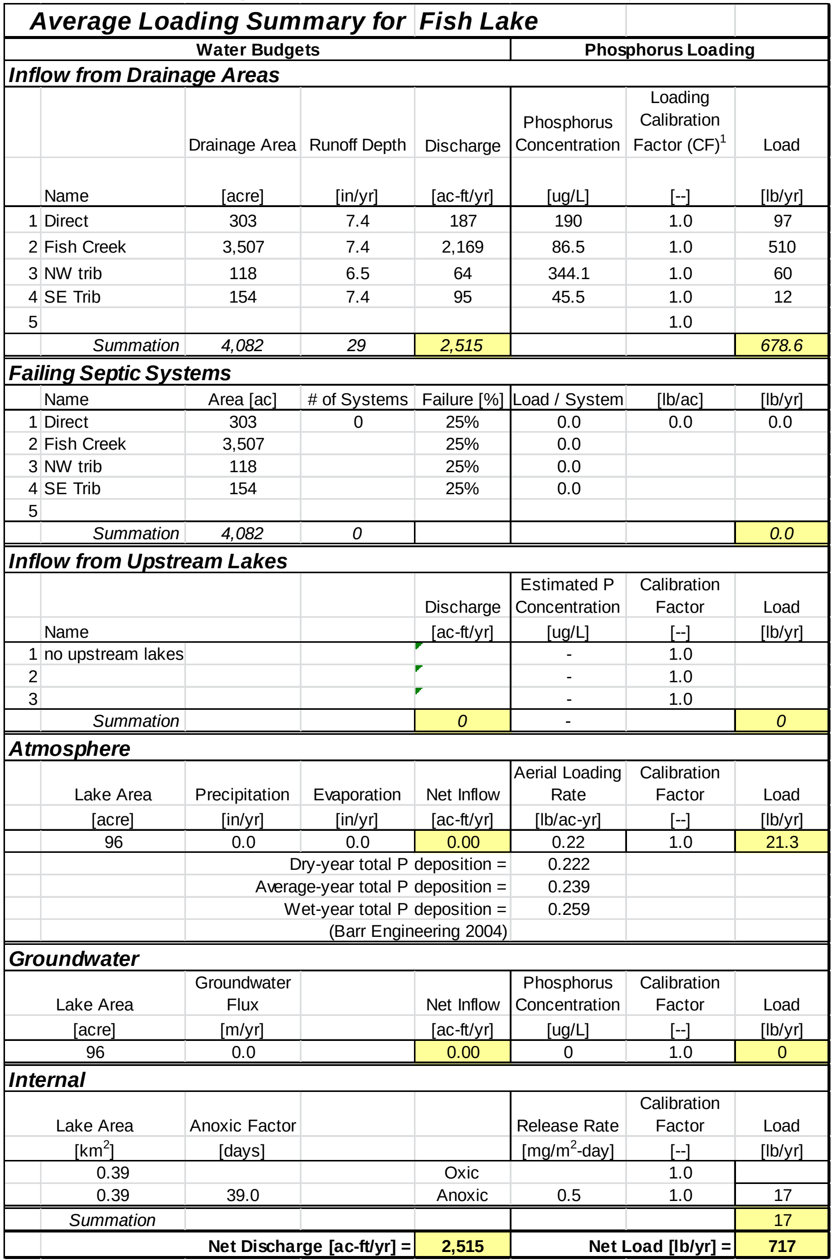
Upper & Lower Orono Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2002
2003
2006
2009
2010
2011
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Fish Lake

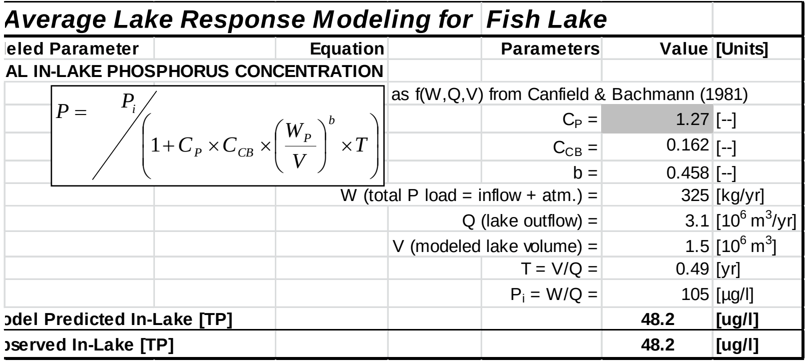
Supporting Information

Fish Lake Average conditions BATHTUB Lake Response Model



Average Loading Summary for Fish Lake

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct	303	7.4	187	190	1.0	97
2	Fish Creek	3,507	7.4	2,169	86.5	1.0	510
3	NW trib	118	6.5	64	344.1	1.0	60
4	SE Trib	154	7.4	95	45.5	1.0	12
5						1.0	
	Summation	*4,082*	*29*	*2,515*			*678.6*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Direct	303	0	25%	0.0	0.0	0.0
2	Fish Creek	3,507		25%	0.0		
3	NW trib	118		25%	0.0		
4	SE Trib	154		25%	0.0		
5							
	Summation	*4,082*	*0*				*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	no upstream lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	96	0.0	0.0	0.00	0.22	1.0	21.3
				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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	96	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.39			Oxic		1.0	
	0.39	39.0		Anoxic	0.5	1.0	17
	Summation						17
			Net Discharge [ac-ft/yr] =	**2,515**		**Net Load [lb/yr] =**	**717**



Average Lake Response Modeling for Fish Lake

eled Parameter	Equation	Parameters	Value	[Units]
AL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.27	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	325	[kg/yr]
		Q (lake outflow) =	3.1	[10^6 m^3/yr]
		V (modeled lake volume) =	1.5	[10^6 m^3]
		T = V/Q =	0.49	[yr]
		P_i = W/Q =	105	[µg/l]
odel Predicted In-Lake [TP]			**48.2**	**[ug/l]**
served In-Lake [TP]			**48.2**	**[ug/l]**

Fish Lake TMDL Conditions BATHTUB Lake Response 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	Direct	303	7.4	187	78	0.4	40
2	Fish Creek	3,507	7.4	2,169	77.8	0.9	459
3	NW trib	118	6.5	64	77.8	0.2	14
4	SE Trib	154	7.4	95	45.5	1.0	12
5						1.0	
	Summation	*4,082*	*29*	*2,515*			*524.5*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Direct	303		25%	0.0		
2	Fish Creek	3,507		25%	0.0		
3	NW trib	118		25%	0.0		
4	SE Trib	154		25%	0.0		
5							
	Summation	*4,082*	*0*				*0.0*

Inflow from Upstream Lakes

	Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	no upstream lakes		-	1.0	
2			-	1.0	
3			-	1.0	
	Summation	*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
96	0.0	0.0	0.00	0.22	1.0	21.3

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]
96	0.0	0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]		Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.39		Oxic		1.0	
0.39	39.0	Anoxic	0.5	1.0	15
Summation					15

Net Discharge [ac-ft/yr] = 2,515 | **Net Load [lb/yr] = 561**

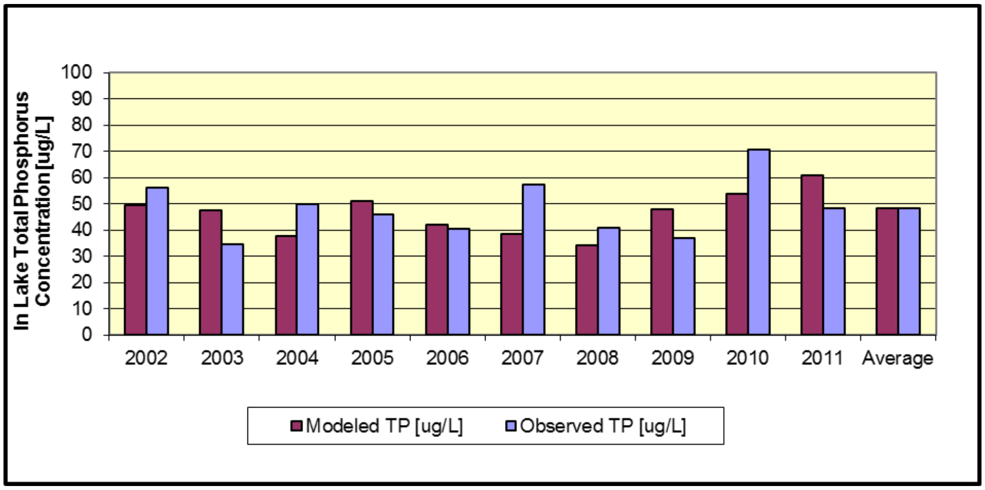
Average Lake Response Modeling for Fish Lake

TOTAL IN-LAKE PHOSPHORUS CONCENTRATION

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

Modeled Parameter	Equation	Parameters	Value	[Units]
		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.27	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	254	[kg/yr]
		Q (lake outflow) =	3.1	[10^6 m^3/yr]
		V (modeled lake volume) =	1.5	[10^6 m^3]
		T = V/Q =	0.49	[yr]
		P_i = W/Q =	82	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**48.2**	**[ug/l]**

Fish Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
100
90
80
70
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Mink Lake

Supporting Information

Mink Lake Average conditions BATHTUB Lake Response Model

Average Loading Summary for Mink

Water Budgets				**Phosphorus Loading**			
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Mink Direct Water:	2,320	6.8	1,322	200	1.0	719
2				0	0.0		0
3				0	0.0		0
4				0	0.0		0
5						1.0	
	Summation	*2,320*	*7*	*1,322*			*719.3*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Mink Direct Water:	2,320		25%	4.2		
2							
3							
4							
5							
	Summation	*2,320*	*0*				*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	298	32.3	32.3	0.00	0.24	1.0	71.2
		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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	298	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.21			Oxic		1.0	
	1.21	60.3		Anoxic	10.0	1.0	1,335
	Summation						1,335
		Net Discharge [ac-ft/yr] =		**1,322**	**Net Load [lb/yr] =**		**2,125**

Average Lake Response Modeling for Mink

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
		as f(W,Q,V) from Canfield & Bachmann (1981)		
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	964	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	2.1	[10^6 m^3]
		T = V/Q =	1.29	[yr]
		P_i = W/Q =	591	[µg/l]
Model Predicted In-Lake [TP]			**132.7**	**[ug/l]**
Observed In-Lake [TP]			**132.1**	**[ug/l]**

Mink Lake TMDL Conditions BATHTUB Lake Response Model

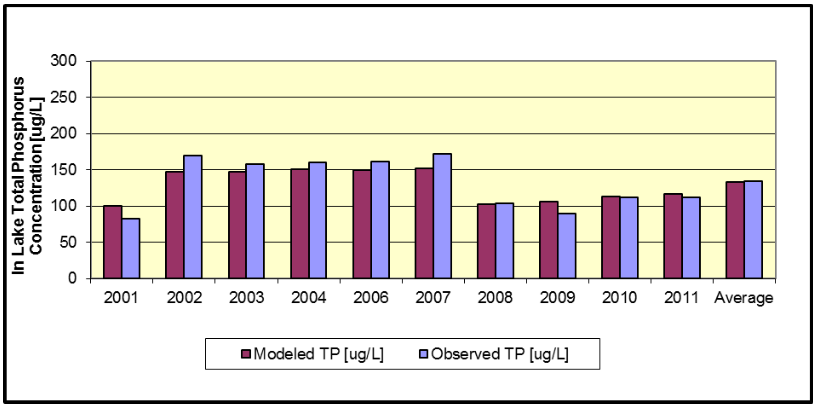
Average Loading Summary for Mink

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	Mink Direct Water	2,320	6.8	1,322	72	0.4	258
2				0	0.0		0
3				0	0.0		0
4				0	0.0		0
5							
	Summation	*2,320*	*7*	*1,322*			*257.5*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Mink Direct Water	2,320	24	25%	4.2		
2							
3							
4							
5							
	Summation	*2,320*	*24*				*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	298	32.3	32.3	0.00	0.24	1.0	71.2
				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]
	298	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.21			Oxic		1.0	
	1.21	60.3		Anoxic	2.0	1.0	320
	Summation						320
			Net Discharge [ac-ft/yr] =	**1,322**		Net Load [lb/yr] =	**649**

Average Lake Response Modeling for Mink

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	294	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	2.1	[10^6 m^3]
		T = V/Q =	1.29	[yr]
		P_i = W/Q =	180	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**132.1**	**[ug/l]**

Mink Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
300
250
200
150
100
50
0
2001
2002
2003
2004
2006
2007
2008
2009
2010
2011
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Somers Lake

Supporting Information

Somers Lake Average conditions BATHTUB Lake Response Model

Average Loading Summary for Somers

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	Somers Direct	208	6.8	119	200	1.0	64
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5						1.0	
	Summation	*208*	*7*	*119*			*64.5*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Somers Direct	208		35%	4.2		
2							
3							
4							
5							
	Summation	*208*	*0*				*0.0*

Inflow from Upstream Lakes

	Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Mink	1,190	123.7	1.0	400
2			-	1.0	
3			-	1.0	
	Summation	*1,190*	*123.7*		*400*

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]
147	31.7	31.7	0.00	0.24	1.0	35.2

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]
147	0.0	0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]		Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.60		Oxic		1.0	
0.60	53.2	Anoxic	7.5	1.0	525
Summation					525

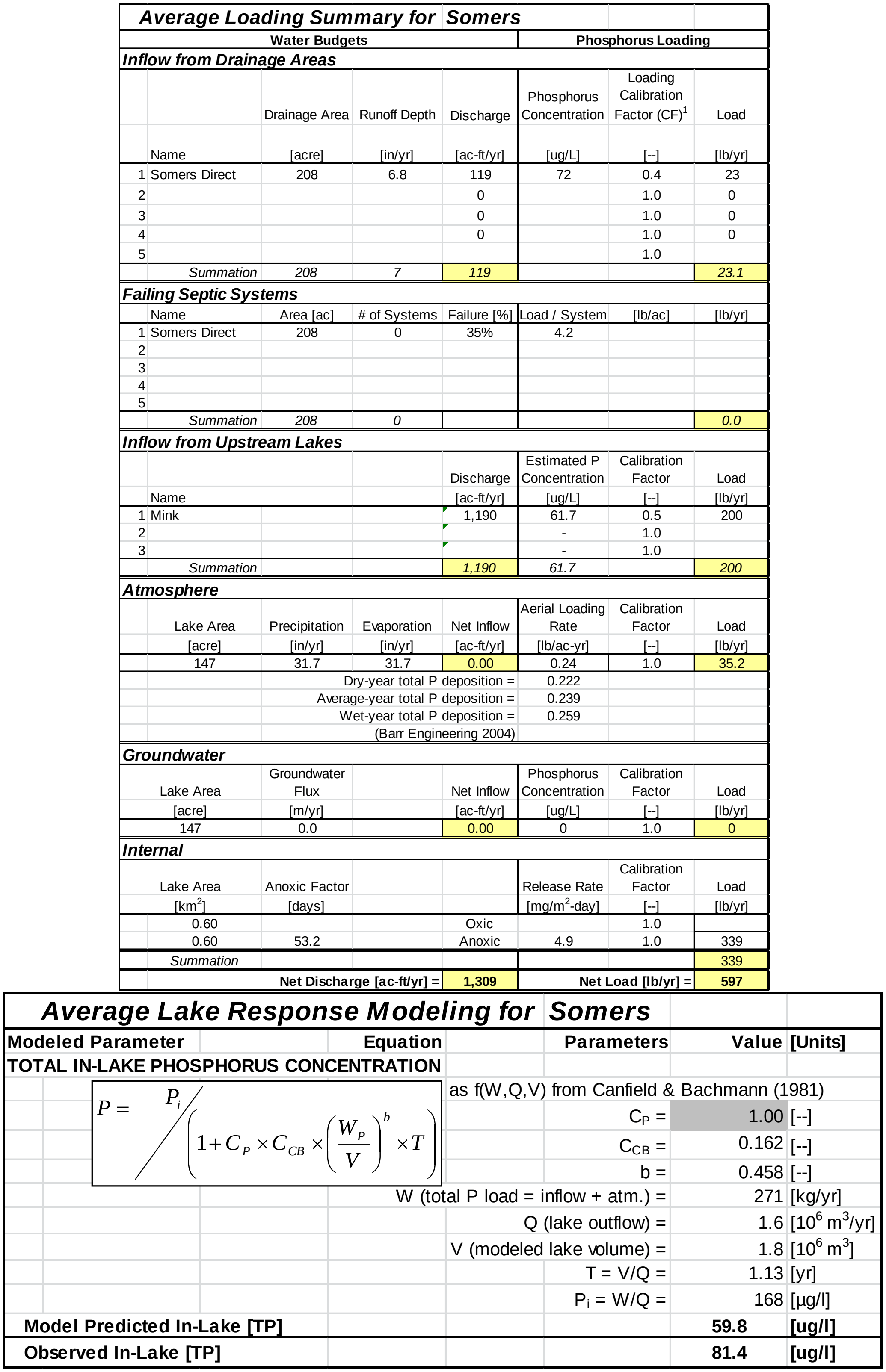
Net Discharge [ac-ft/yr] = 1,309 | **Net Load [lb/yr] = 1,025**

NOTES

Average Lake Response Modeling for Somers

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	465	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	1.8	[10^6 m^3]
		T = V/Q =	1.13	[yr]
		P_i = W/Q =	288	[µg/l]
Model Predicted In-Lake [TP]			**86.9**	**[ug/l]**
Observed In-Lake [TP]			**81.4**	**[ug/l]**

Somers Lake TMDL Conditions BATHTUB Lake Response Model



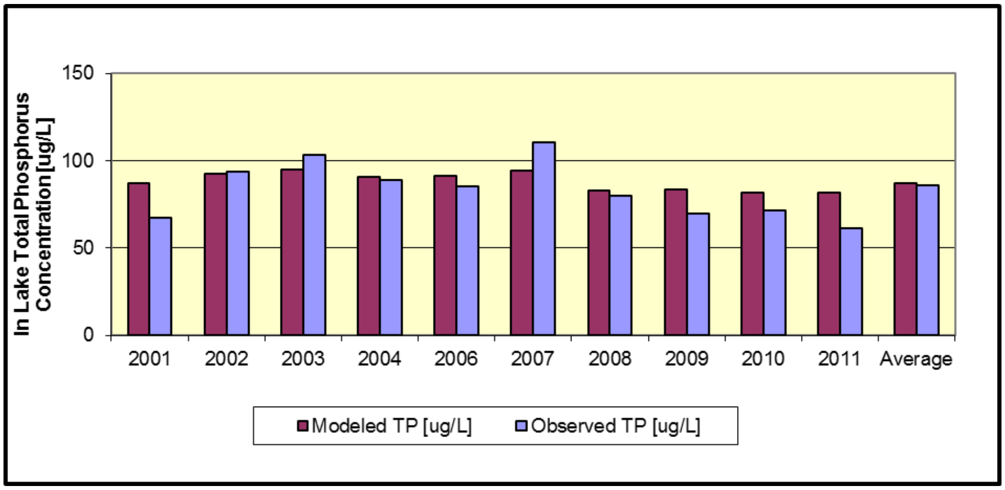
Average Loading Summary for Somers

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Somers Direct	208	6.8	119	72	0.4	23
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5						1.0	
	Summation	*208*	*7*	*119*			*23.1*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Somers Direct	208	0	35%	4.2		
2							
3							
4							
5							
	Summation	*208*	*0*				*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Mink			1,190	61.7	0.5	200
2					-	1.0	
3					-	1.0	
	Summation			*1,190*	*61.7*		*200*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	147	31.7	31.7	0.00	0.24	1.0	35.2
		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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	147	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.60			Oxic		1.0	
	0.60	53.2		Anoxic	4.9	1.0	339
	Summation						339
			Net Discharge [ac-ft/yr] =	**1,309**		**Net Load [lb/yr] =**	**597**

Average Lake Response Modeling for Somers

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	271	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	1.8	[10^6 m^3]
		T = V/Q =	1.13	[yr]
		P_i = W/Q =	168	[µg/l]
Model Predicted In-Lake [TP]			**59.8**	**[ug/l]**
Observed In-Lake [TP]			**81.4**	**[ug/l]**

Somers Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
150
100
50
0
2001
2002
2003
2004
2006
2007
2008
2009
2010
2011
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Silver Lake

Supporting Information

Silver Lake Average conditions BATHTUB Lake Response Model

Average Loading Summary for Silver 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	Silver Lake Direct	106	5.5	49	113	1.0	15
2	Sandy Creek	5,949	5.5	2,739	26.0	1.0	194
3	Silver Creek Inlet	9,893	5.5	4,555	199.9	1.0	2,477
4						1.0	
5						1.0	
	Summation	*15,948*	*17*	*7,343*			*2,686.2*
Failing Septic Systems							
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Silver Lake Direct	106	28	30%	4.2		
2	Sandy Creek	5,949		30%	4.2		
3	Silver Creek Inlet	9,893		30%	4.2		
4							
5							
	Summation	*15,948*	*28*				*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Mink-Somers			1,833	73.7	1.0	367
2					-	1.0	
3					-	1.0	
	Summation			*1,833*	*73.7*		*367*
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]
	83	0.0	0.0	0.00	0.22	1.0	18.4
		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]
	83	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.33			Oxic		1.0	
	0.33	42.1		Anoxic	2.0	1.0	62
	Summation						62
			Net Discharge [ac-ft/yr] =	**9,176**		**Net Load [lb/yr] =**	**3,134**

Average Lake Response Modeling for Silver 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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,422	[kg/yr]
		Q (lake outflow) =	11.3	[10^6 m^3/yr]
		V (modeled lake volume) =	1.7	[10^6 m^3]
		T = V/Q =	0.15	[yr]
		P_i = W/Q =	126	[µg/l]
Model Predicted In-Lake [TP]			**82.0**	**[ug/l]**
Observed In-Lake [TP]			**78.6**	**[ug/l]**

Silver Lake TMDL Conditions BATHTUB Lake Response Model

Average Loading Summary for Silver 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	Silver Lake Direct	106	5.5	49	65	0.6	9
2	Sandy Creek	5,949	5.5	2,739	26.0	1.0	194
3	Silver Creek Inlet	9,893	5.5	4,555	65.4	0.3	810
4						1.0	
5						1.0	
	Summation	*15,948*	*17*	*7,343*			*1,012.5*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Silver Lake Direct	106	28	30%	4.2		
2	Sandy Creek	5,949		30%	4.2		
3	Silver Creek Inlet	9,893		30%	4.2		
4							
5							
	Summation	*15,948*	*28*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Mink-Somers			1,833	60.0	0.8	299
2					-	1.0	
3					-	1.0	
	Summation			*1,833*	*60.0*		*299*

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]
	83	0.0	0.0	0.00	0.22	1.0	18.4
				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]
	83	0.0		0.00	0	1.0	0

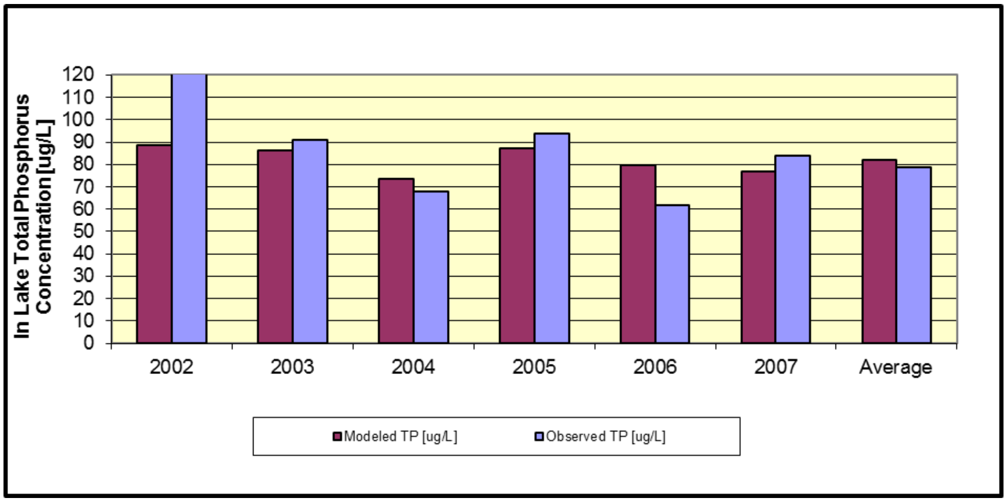
Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.33			Oxic		1.0	
	0.33	42.1		Anoxic	1.0	1.0	31
	Summation						31
			Net Discharge [ac-ft/yr] =	**9,176**		**Net Load [lb/yr] =**	**1,361**

Average Lake Response Modeling for Silver Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	617	[kg/yr]
		Q (lake outflow) =	11.3	[10^6 m^3/yr]
		V (modeled lake volume) =	1.7	[10^6 m^3]
		T = V/Q =	0.15	[yr]
		P_i = W/Q =	55	[μg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]		40	**78.6**	**[ug/l]**

Silver Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
120
110
100
90
80
70
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Indian Lake

Supporting Information

Indian Lake Average conditions BATHTUB Lake Response Model

Average Loading Summary for Indian 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	direct (includes tw	445	5.0	184	200	1.0	100
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*445*	*5*	*184*			*100.0*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	direct (includes tw	445	15	30%	4.2		
2							
3							
4							
5							
	Summation	*445*	*15*				*0.0*

Inflow from Upstream Lakes

	Name		Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	no upstream lakes			-	1.0	
2				-	1.0	
3				-	1.0	
	Summation		*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
135	0.0	0.0	0.00	0.22	1.0	29.9
			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]
135	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.54			Oxic		1.0	
0.54	77.0		Anoxic	2.0	1.0	185
Summation						185

		Net Discharge [ac-ft/yr] =	**184**		**Net Load [lb/yr] =**	**315**

Average Lake Response Modeling for Indian Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	143	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	2.8	[10^6 m^3]
		T = V/Q =	12.43	[yr]
		P_i = W/Q =	630	[µg/l]
Model Predicted In-Lake [TP]			**47.9**	**[ug/l]**
Observed In-Lake [TP]			**46.9**	**[ug/l]**

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

Indian Lake TMDL Conditions BATHTUB Lake Response Model

Average Loading Summary for Indian 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	direct (includes tw	445	5.0	184	160	0.8	80
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*445*	*5*	*184*			*80.0*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	direct (includes tw	445	15	30%	4.2		
2							
3							
4							
5							
	Summation	*445*	*15*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	no upstream lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
135	0.0	0.0	0.00	0.22	1.0	29.9
			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]
135	0.0		0.00	0	1.0	0

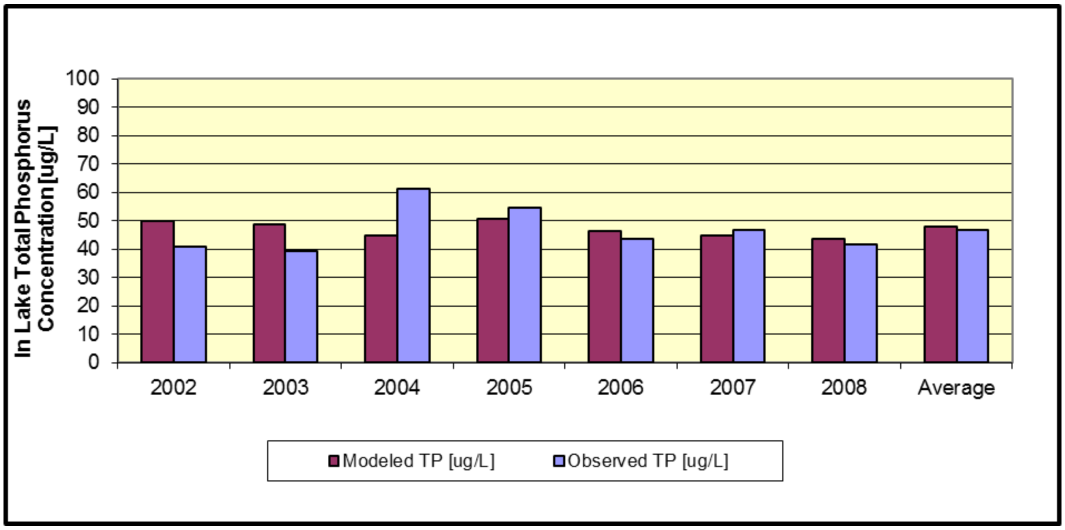
Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.54			Oxic		1.0	
0.54	77.0		Anoxic	1.3	1.0	121
Summation						121
		Net Discharge [ac-ft/yr] =	**184**		**Net Load [lb/yr] =**	**231**

Average Lake Response Modeling for Indian Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	105	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	2.8	[10^6 m^3]
		T = V/Q =	12.43	[yr]
		P_i = W/Q =	462	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**46.9**	**[ug/l]**

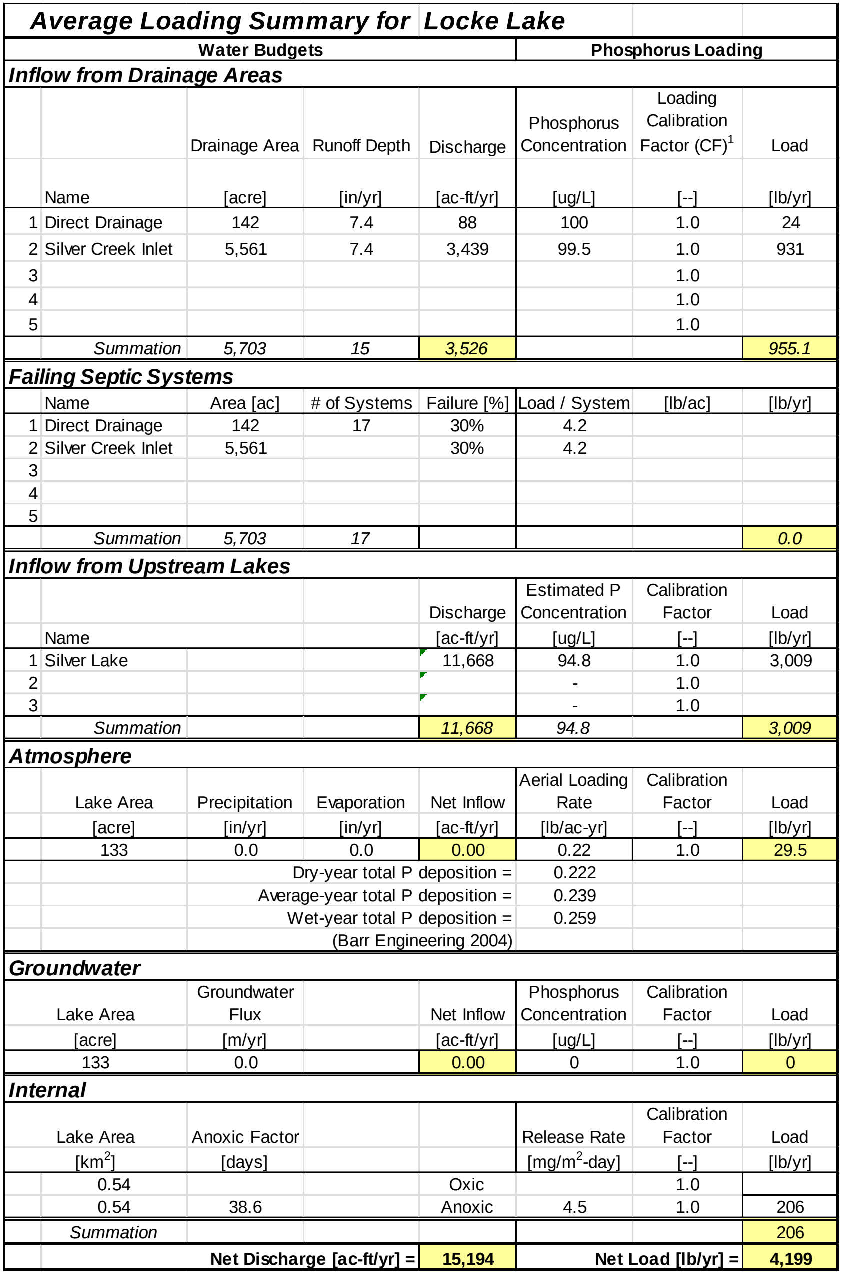
Indian Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
100
90
80
70
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
2008
Average
Modeled TP [ug/L]
Observed TP [ug/L]

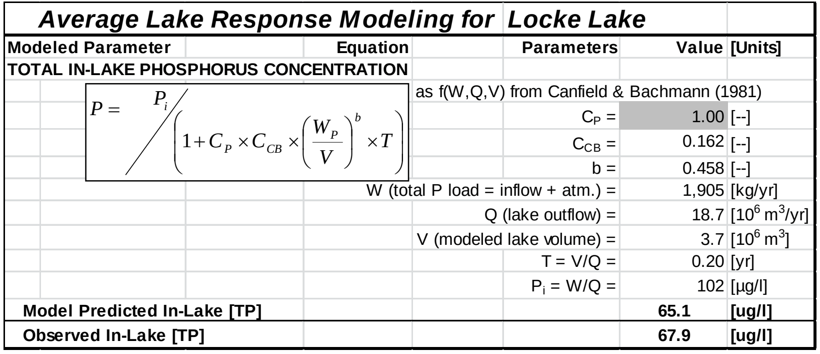
Locke Lake

Supporting Information

Locke Lake Average conditions BATHTUB Lake Response Model



	Average Loading Summary for Locke 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	Direct Drainage	142	7.4	88	100	1.0	24
2	Silver Creek Inlet	5,561	7.4	3,439	99.5	1.0	931
3						1.0	
4						1.0	
5						1.0	
	Summation	*5,703*	*15*	*3,526*			*955.1*
	Failing Septic Systems						
	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Direct Drainage	142	17	30%	4.2		
2	Silver Creek Inlet	5,561		30%	4.2		
3							
4							
5							
	Summation	*5,703*	*17*				*0.0*
	Inflow from Upstream Lakes						
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Silver Lake			11,668	94.8	1.0	3,009
2					-	1.0	
3					-	1.0	
	Summation			*11,668*	*94.8*		*3,009*
	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]
	133	0.0	0.0	0.00	0.22	1.0	29.5
				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]
	133	0.0		0.00	0	1.0	0
	Internal						
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.54			Oxic		1.0	
	0.54	38.6		Anoxic	4.5	1.0	206
	Summation						206
			Net Discharge [ac-ft/yr] =	**15,194**		**Net Load [lb/yr] =**	**4,199**



Average Lake Response Modeling for Locke Lake				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,905	[kg/yr]
		Q (lake outflow) =	18.7	[10^6 m^3/yr]
		V (modeled lake volume) =	3.7	[10^6 m^3]
		T = V/Q =	0.20	[yr]
		P_i = W/Q =	102	[µg/l]
Model Predicted In-Lake [TP]			**65.1**	**[ug/l]**
Observed In-Lake [TP]			**67.9**	**[ug/l]**

Locke Lake TMDL Conditions BATHTUB Lake Response Model

Average Loading Summary for Locke 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	Direct Drainage	142	7.4	88	90	0.9	21
2	Silver Creek Inlet	5,561	7.4	3,439	90.0	0.9	842
3						1.0	
4						1.0	
5						1.0	
	Summation	*5,703*	*15*	*3,526*			*863.3*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Direct Drainage	142	17	30%	4.2		
2	Silver Creek Inlet	5,561		30%	4.2		
3							
4							
5							
	Summation	*5,703*	*17*				*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Silver Lake			11,668	40.0	0.4	1,270
2					-	1.0	
3					-	1.0	
	Summation			*11,668*	*40.0*		*1,270*

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]
	133	0.0	0.0	0.00	0.22	1.0	29.5
				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]
	133	0.0		0.00	0	1.0	0

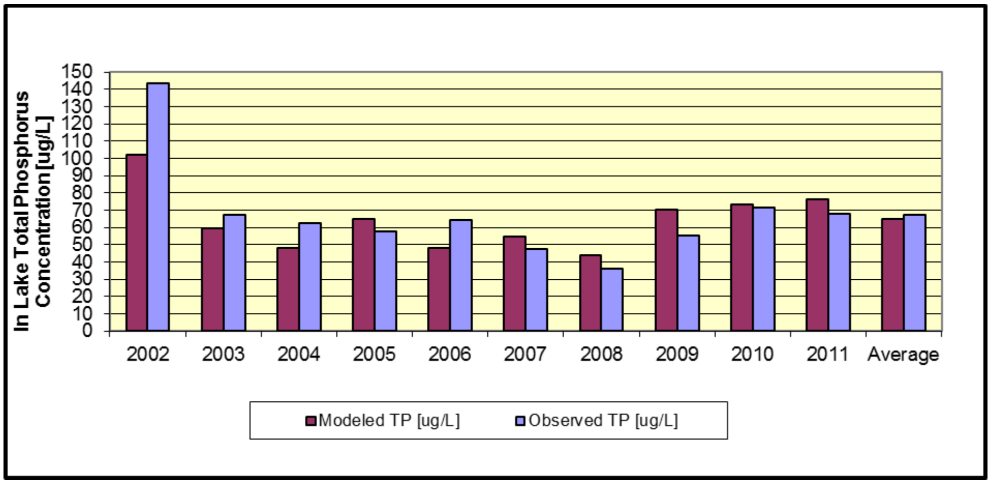
Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.54			Oxic		1.0	
	0.54	38.6		Anoxic	4.5	1.0	206
	Summation						206
			Net Discharge [ac-ft/yr] =	**15,194**		**Net Load [lb/yr] =**	**2,368**

Average Lake Response Modeling for Locke 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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,074	[kg/yr]
		Q (lake outflow) =	18.7	[10^6 m^3/yr]
		V (modeled lake volume) =	3.7	[10^6 m^3]
		T = V/Q =	0.20	[yr]
		P_i = W/Q =	57	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**67.9**	**[ug/l]**

Locke Lake Model Performance


In Lake Total Phosphorus Concentration [ug/L]
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Average
Modeled TP [ug/L]
Observed TP [ug/L]

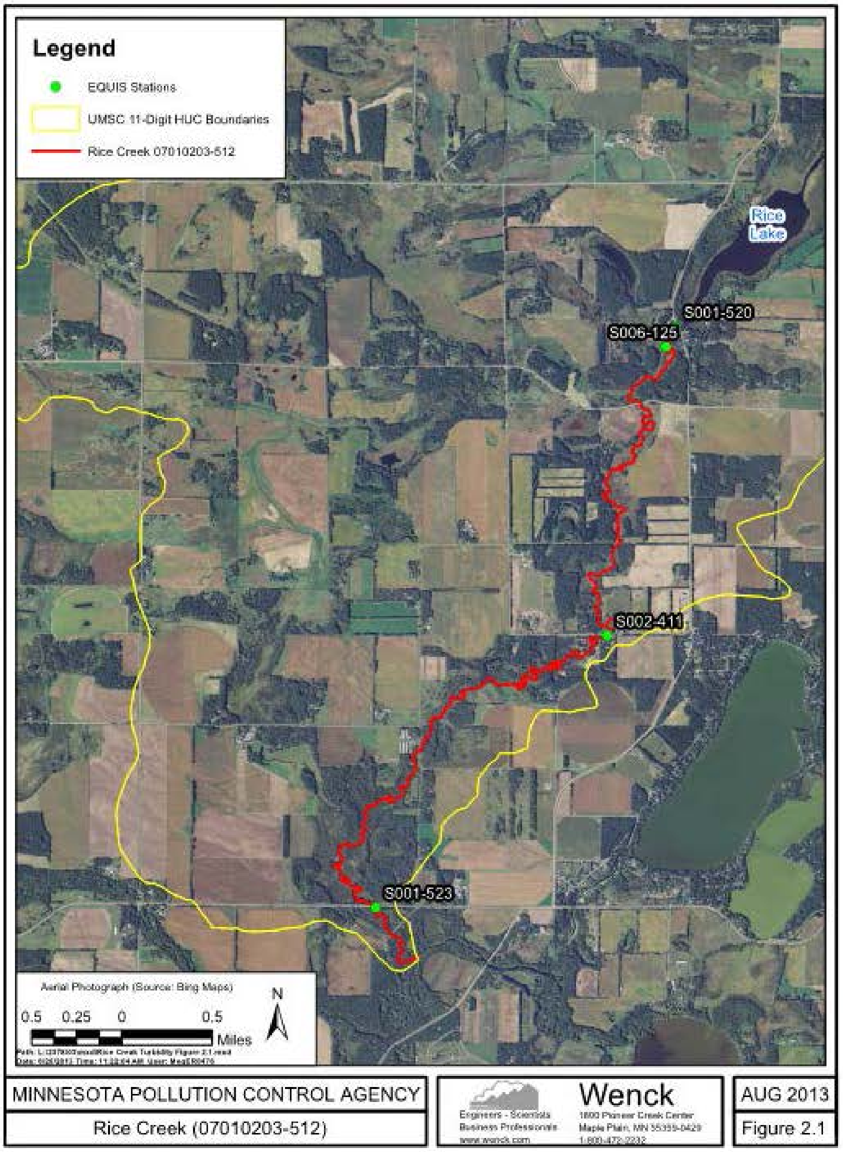
APPENDIX B - RICE CREEK TURBIDITY ANALYSIS TECHNICAL MEMOS

Turbidity is a measure of the cloudiness or haziness of water caused by suspended and dissolved substances in the water column. Turbidity can be caused by increased suspended soil or sediment particles, phytoplankton growth, and dissolved substances in the water column. Excess turbidity can degrade aesthetic qualities of water bodies, increase the cost of treatment for drinking water or food processing uses, and harm aquatic life. Adverse ecological impacts caused by excessive turbidity include hampering the ability of aquatic organisms to visually locate food, negative effects on gill function, and smothering of spawning beds and benthic organism habitat.

The turbidity standard found in Minn. R. 7050.0222 subpart 4 for 2B waters is 25 nephelometric turbidity units (NTUs). Impairment assessment procedures for turbidity are provided by MPCA (2005). A water body is considered to be impaired when greater than ten percent of the data points collected within the previous 10 year period exceed the 25 NTU standard (or equivalent values for total suspended solids or transparency tube data). This analysis is written for Class 2B waters, as this is the most protective class in these stream reaches.

2.0 OVERVIEW OF RICE CREEK REACH AND MONITORING STATIONS

Figure 2.1 shows the section of Rice Creek that was analyzed, the subwatershed that drains to the reach and the locations of the key monitoring stations for which flow and water quality data were collected to support this analysis.


Legend
● EQUIS Stations
UMSC 11-Digit HUC Boundaries
Rice Creek 07010203-512
Rice Lake
S001-520
S006-125
S002-411
S001-523
Aerial Photograph (Source: Bing Maps)
0.5 0.25 0 0.5
Miles
N
MINNESOTA POLLUTION CONTROL AGENCY
Rice Creek (07010203-512)
Engineers - Scientists
Business Professionals
www.wenck.com
Wenck
1800 Pioneer Creek Center
Maple Plain, MN 55359-0429
1-800-472-2232
AUG 2013
Figure 2.1

3.0 TURBIDITY RELATED WATER QUALITY DATA

Three types of data are collected to assess turbidity in surface waters. The first is a direct measure of turbidity using a turbidity meter in either a lab or in the field. The second is a measure of transparency of the water using a field transparency tube (T-tube). The third is a measure of the mass of solids in the water column typically measured as total suspended solids (TSS). The ERWSA and MPCA have collected turbidity, T-tube and TSS data at four different location along this reach of Rice Creek (Table 3.1).

Table 3.1. Available turbidity-related water quality measurements for AUID 07010203-512

STORET ID	Location	Type of Data	Years Monitored	Measurements
S001-520	Rice Creek Outlet at CSAH-6 Bridge	Turbidity	--	0
		Transparency	2000-2009	223
		TSS	2012	1
S006-125	Rice Creek, 550ft downstream of CSAH-6	Turbidity	--	0
		Transparency	2009	4
		TSS	--	0
S002-411	Rice Creek at 42nd Street	Turbidity	--	0
		Transparency	2003-2009	133
		TSS	--	0
S001-523	Rice Creek at CSAH-16 Bridge	Turbidity	2004-2007*	81
		Transparency	2000-2012	336
		TSS	1998-2012	108
		Flow	*2004-2011*	*1,521 days*

*No 2008 data was available and all of the 2009 data was measured in FNU and was not used in this analysis

4.0 STREAM FLOW DATA

Flow data for this section of Rice Creek is crucial to analyze the turbidity data. Flow data was used to develop a flow regime so that turbidity violations could be characterized based on whether they occurred most often during high, medium, or low flow events. This information helps provide insight on potential sources during low/base-flow as well as storm/run-off related events. There is one historic flow monitoring station located at the CSAH-16 Bridge (S001-523). This flow monitoring location coincides with the only turbidity data collection station (see Table 3.1 and Figure 2.1).

5.0 DEVELOPMENT OF A TSS SURROGATE

To determine the TSS equivalent to the 25 NTU turbidity standard, 66 paired lab turbidity and TSS samples collected between 2004 and 2007 were analyzed. All of the paired data are based on measurements taken with a meter that reads turbidity in Nephelometric Turbidity Ratio Units (NTRUs) instead of the standard Nephelometric Turbidity Units (NTUs). These two are not equivalent, but can be related using the following equation (MPCA 2007):

NTU = 10^(-0.0734+0.926*Log(NTRU))/1.003635

Since the turbidity standard is expressed in NTUs, all NTRU data were converted to "NTU equivalents" using the aforementioned equation prior to analyzing paired data relationships.

MPCA protocol recommends using only paired measurements with a turbidity value of 40 NTU or less and TSS values greater than 10 mg/L (MPCA 2008). 43 of the 66 paired turbidity/TSS samples met these criteria and were used to develop the relationship. A simple regression of the natural logarithm of TSS and turbidity was completed using the paired data available (Figure 5.1). The analysis indicates that the turbidity standard of 25 NTU corresponds to a surrogate TSS concentration of 63 mg/L for this data set.

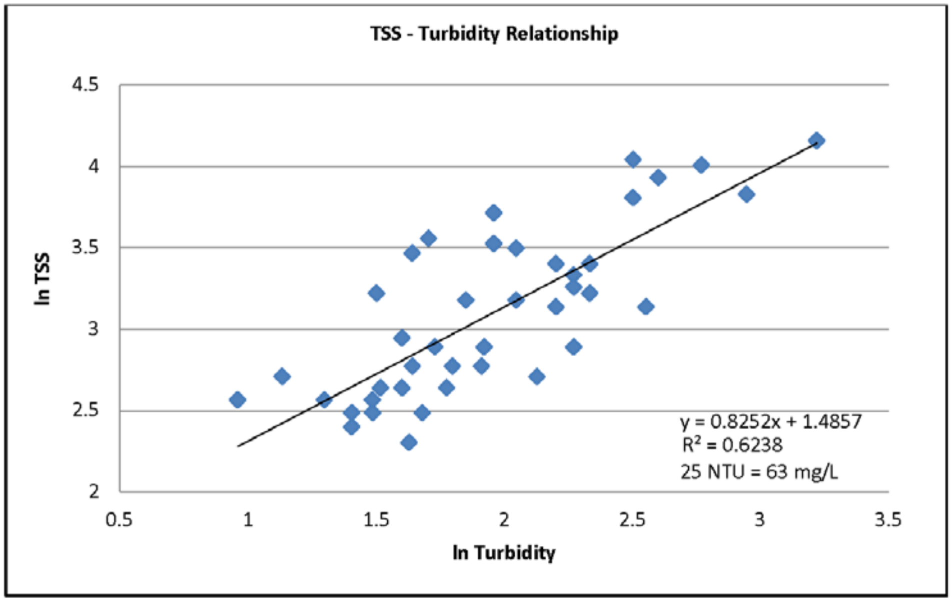


Figure 5.1. Turbidity/Total Suspended Solids Relationship for Rice Creek (AUID 07010203-512)

6.0 DEGREE OF IMPAIRMENT

The MPCA recognizes transparency and TSS as reliable surrogates of turbidity which can be used to assess impairments at sites where there are an inadequate number of turbidity observations (MPCA, 2010). For transparency, a transparency tube measurement of less than 20 centimeters indicates a violation of the 25 NTU turbidity standard. For TSS, a measurement of more than 30 mg/L indicates a violation of the turbidity standard in the Central River Nutrient (CRN) Region (MPCA 2011). If sufficient turbidity measurements exist, only turbidity measurements are used to determine impairment. For this analysis, all three parameters were evaluated to investigate trends and take full advantage of the dataset.

Table 6.1 summarizes the turbidity, transparency and TSS data collected throughout this reach of Rice Creek. To avoid double counting, data from all sites were grouped together and consolidated (averaged) by date to provide one dataset for the entire reach. This data suggest that less than 10% of the turbidity samples were in violation of their standard or assessment threshold. Transparency (16%) and TSS (18%) readings had significantly higher incidence of exceedence compared to turbidity. Both TSS violation thresholds, the surrogate and the CRN Region, are investigated in Table 6.1 due to the lack of a substantial (10-year) dataset to develop the surrogate.

Table 6.1 Turbidity related water quality exceedences for Rice Creek (AUID 07010203-512)

Parameter	Years Monitored	Violation Threshold	Measurements	Exceedences	Percent Exceedences
Turbidity	2004-2007	> 25 NTU	63	3	5%
TSS	2000-2012	> 30 mg/L	106	17	16%
		> 63 mg/L		4	4%
Transparency	1998-2012	< 20 cm	400	71	18%

Table 6.1 shows that the percent of TSS exceedences is consistent with both the turbidity and transparency exceedences depending on the violation threshold used.

7.0 ASSIMILATIVE CAPACITY

Assimilative capacities for the streams were developed from load duration curves (Cleland 2002). Load duration curves assimilate flow and TSS data across stream flow regimes and provide assimilative capacities from which reductions can be derived by comparing them to measured loads.

A flow duration curve was developed using the flow data discussed in Section 4 (Figure 7.1). The curved line relates mean daily flow to the percent of time those values have been met or exceeded. 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.

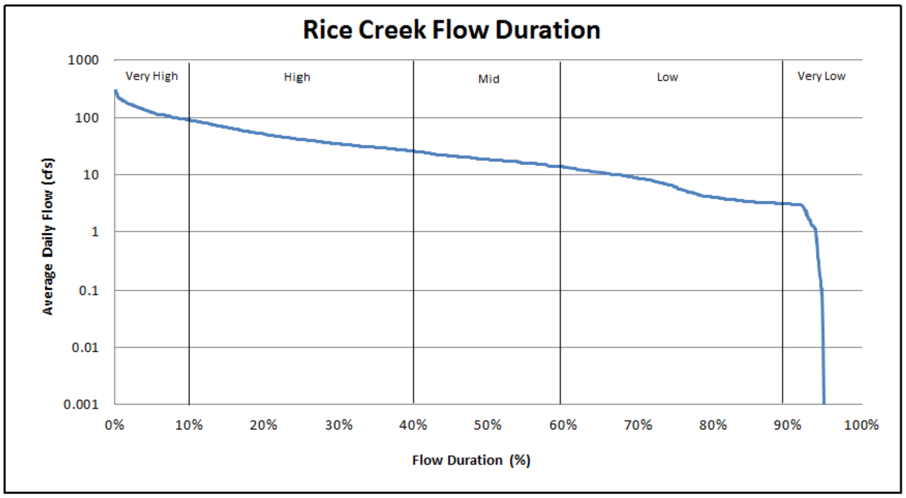


Figure 7.1 Flow duration curve for Rice Creek.

To develop a load duration curve, all average daily flow values were multiplied by the TSS-surrogate (63 mg/L) and the CRN Threshold (30 mg/L), and then converted to a daily load to create "continuous" load duration curves (Figure 7.2). Now the line represents the assimilative capacity of the stream for each daily flow.

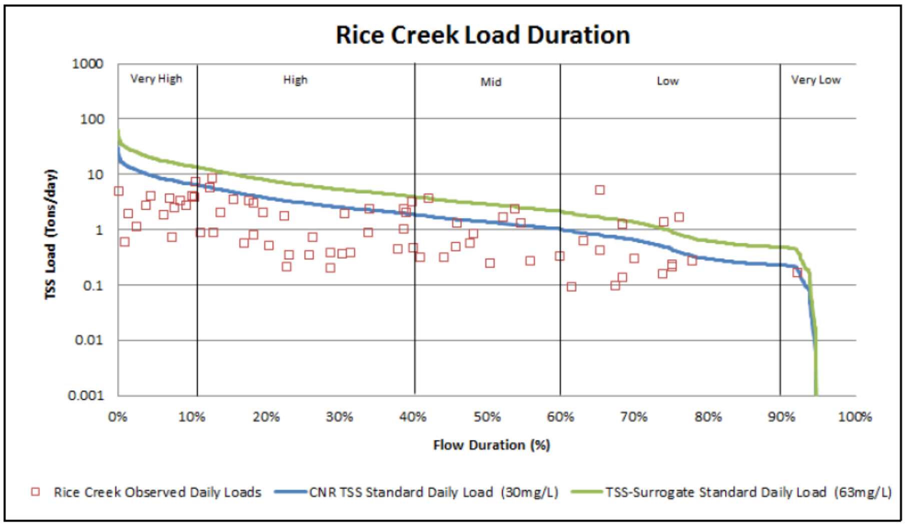


Figure 7.2 TSS Load duration curve for Rice Creek

The necessary reductions to meet the CRN Threshold standard can be calculated using the median values for each flow regime and 90th percentile values from the monitored TSS data. The 90th percentile value in each regime is the reading that is only exceeded by 10% of the data points and the median value is the target loading capacity for each flow regime. The data from Figure 7.2 is plotted with the 90th percentile and median values to determine load reductions in Figure 7.3.

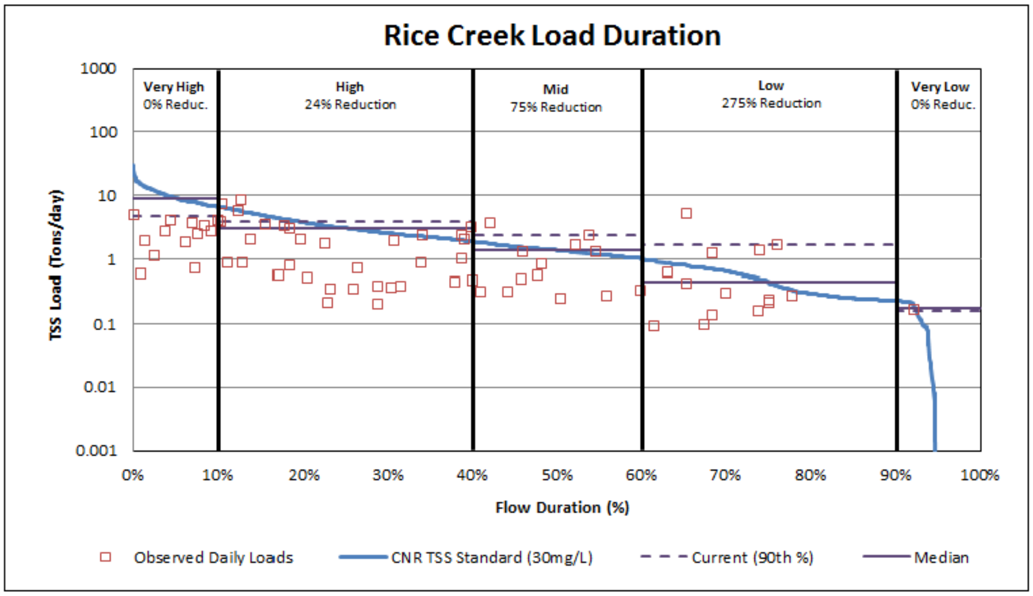


Figure 7.3 TSS Load Duration Curve and necessary TSS reductions

In Figure 7.3, an estimate for an overall load reduction percentage was calculated for each regime. Figure 7.3 compares the 90th percentile observed TSS load for each flow regime to the median loading capacity of the CNR TSS Standard. The difference between the loading capacity and the 90th percentile of sampled loads produced an estimated percent reduction in TSS that will be needed. The data indicate that the greatest reductions in TSS load will need to occur during the mid and low flow regimes.

It is important to note that these expressions do not represent the necessary reductions to meet state water quality standards on a daily basis. Rather, the expressed reductions demonstrate the necessary reductions to reduce TSS and turbidity below the 10% exceedence threshold for listing. The CNR Threshold of 30mg/L was used to calculate these reductions to be conservative and due to the lack of a substantial dataset in calculating the TSS-surrogate.

8.0 ASSESSMENT OF SOURCES

8.1 Permitted Sources

Permitted sources of turbidity can include industrial effluent, municipal wastewater treatment plants, construction runoff, concentrated animal feeding operations (CAFOs) and municipal stormwater.

Facilities with NPDES Permits

This reach, from the outlet of Rice Lake to its confluence with the Elk River, does not have any industrial facilities that directly discharge to the stream. The only industrial facility that discharges upstream of Rice Creek is the Foley Wastewater Treatment Facility (WWTF) which discharges to a marsh and ditch that are tributary to Stoney Brook. Stoney Brook becomes Rice Creek upstream of Rice Lake. Rice Lake is the upstream boundary condition for this assessment. According to MPCA permit, Foley WWTF cannot discharge flow from its ponds in the months of January through March, July and August.

MS4s

There are no NPDES Phase II permits for small municipal separate storm sewer systems (MS4s) that are tributary to Rice Creek.

Livestock Facilities with NPDES Permits

A Confined Animal Feeding Operation (CAFO) is a feedlot having 1,000 or more animal units, or a smaller feedlot with a direct man-made conveyance to surface water. There are no CFAOs that are tributary to Rice Creek.

8.2 Non-Permitted Sources

Watershed Sources

Watershed sources of turbidity derive from the dominant land use which is agriculture. Sources include field and gully erosion, crop farming, livestock grazing, and stormwater runoff from impervious surfaces.

In-Stream sources

In-stream erosion sources (stream banks and bed) result from the instability of the stream channel. Channel instability can result from overgrazing and/or high or flashy flow events. The slope of the bank, amount of moisture in the soil, and the cohesiveness of the material all play a role in bank failure. A substantial portion of the sediment derived from banks and beds may have originally come from upland soil eroded years earlier and deposited in riparian areas.

9.0 LOAD ALLOCATION

The load allocation is the remaining load after all upstream boundary conditions and wasteload allocations are subtracted from the total load capacity of each flow. Since there are no wasteloads (point sources, construction and industrial stormwater) for this reach, the focus of load allocation will be on in-stream sources and nonpoint (watershed) sources. The primary non-point sources of sediment in streams are sediment conveyed from the landscape (Watershed) and soil particles detached from the streambank (In-stream).

In-stream Allocation

The main source of in-stream sedimentation is streambank erosion. Streambank erosion is a natural process that can be accelerated significantly as a result of change in the watershed or to the stream itself.

A streambank assessment for Rice Creek has not been performed. However, results of streambank assessments for other streams within the Elk River Watershed showed that bank erosion was minimal. The results of those streambank assessments are shown in the Elk River Watershed Association TMDL Phase II Report.

Additionally, no chlorophyll-*a* data was available for Rice Lake. However, the results of an Aquatic Plant Inventory for Rice Lake (from June 6, 2012) showed that *Potomogeton crispus (curlyleaf pondweed)* is prevalent in the Lake and that the density of aquatic plants growing to the surface has increased in the past couple years. At the time of the Inventory the lake is hypertrophic, dominated by *P. crispus* and has limited ecological value.

Watershed Allocation

Due to the minimal bank erosion shown in the results of the ERWSA streambank assessment, it is assumed that the most of the sediment enters the stream from field runoff. No existing studies have been done on field erosion and field erosion modeling has is outside the scope of this analysis.

Table 9.1 shows the wasteload and load allocations for this section of Rice Creek (AUID 07010203-512). Since there are no point sources, the wasteload allocation for Rice Creek are set at zero. The table also shows the load allocations as the percentages of the total allowable load in each flow category.

Table 9.1 Rice Creek (AUID 07010203-512) TSS total daily loading capacities and allocations.

Rice Creek (AUID 07010203-512)		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		TSS Load (tons/day)				
Wasteload Allocation	Permitted Point Source Dischargers/ Construction Stormwater/ Industrial Stormwater	0.14	0.05	0.02	0.01	0.00
Load Allocation	Nonpoint source and in-stream	8.97	3.00	1.34	0.43	0.17
Total Daily Loading Capacity		**9.11**	**3.05**	**1.36**	**0.44**	**0.17**
Value expressed as percentage of total daily loading capacity						
Total Daily Loading Capacity		100%	100%	100%	100%	100%
Wasteload Allocation	Permitted Point Source Dischargers/ Construction Stormwater/ Industrial Stormwater	1.5%	1.5%	1.5%	1.5%	1.5%
Load Allocation	Nonpoint source and channel	98.5%	98.5%	98.5%	98.5%	98.5%

10.0 LITERATURE CITED

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Minnesota Pollution Control Agency. 2007. *Turbidity TMDL Protocols and Submittal Requirements.* <http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/project-resources/tmdl-policy-and-guidance.html>

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Minnesota Pollution Control Agency. 2010. *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List. 2010 Assessment Cycle.* <http://www.pca.state.mn.us/publications/wq-iw1-04.pdf>.

Minnesota Pollution Control Agency. 2011. Aquatic Life Water Quality Standards Draft Technical Support Document for Total Suspended Solids (Turbidity). May 2011 draft by H. Markus. 50 pgs.

APPENDIX C - RICE CREEK DO MODELING TECHNICAL MEMOS

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Engineers • Scientists
Business Professionals

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P.O. Box 249
Maple Plain, MN 55359-0249

800-472-2232
(763) 479-4200
Fax (763) 479-4242
wenckmp@wenck.com
www.wenck.com

TECHNICAL MEMORANDUM

TO: Tiffany Determan, Sherburne Soil and Water Conservation District (SCWD)

FROM: Rebecca Kluckhohn, PE, Wenck Associates
Jeff Strom, Wenck Associates, Inc.
Erik Megow, Wenck Associates, Inc.

DATE: August 22, 2013

SUBJECT: Rice Creek Dissolved Oxygen (DO) Modeling
Description of QUAL2K Modeling Methods and Results

CC: Phil Votruba, Minnesota Pollution Control Agency (MPCA)

This technical memorandum describes the methods and assumptions used to develop and calibrate a QUAL2K model of Rice creek between the outlet of Rice Lake and its confluence with Elk River. The AUID number for this section of Rice Creek is 07010203-512. The model was used to quantify and partition existing oxygen demand loads in the DO-impaired reach of Rice Creek. The work was performed in accordance with the scope of work dated October 19, 2012. Memo contents are summarized below:

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1.0 INTRODUCTION

1.1 Model Selection

Rice Creek violates state DO standard, with concentrations falling below the 5 mg/L daily minimum in the reach between Rice Lake and its confluence with the Elk River. A model of in-stream water quality, specifically DO and associated parameters, was set up to quantify the oxygen demand to this impaired reach of Rice Creek. The model will later be used to quantify the required reductions in oxygen demand necessary for Rice Creek to meet State DO standards. The QUAL2K (Version 2.11) model was selected for this purpose. It is a windows version of the EPA's QUA 2E model and is approved by the EPA for setting DO TMDLs in rivers. It is a one-dimensional, steady state model.

1.2 General Overview of the Model

The Rice Creek model was developed using water quality, hydrologic and hydraulic data collected by the MPCA and the Elk River Watershed Association (ERWSA). The model was calibrated to limited synoptic survey data which included

- continuous DO data measurements at 2 locations in the impaired reach between July 22 and August 10, 2011 and
- Longitudinal DO data measured 4 times at 4 locations in Rice Creek between June 28 and July 22, 2011.

The stream was broken into five reaches based on channel morphometry. An area-weighted runoff hydrograph based on continuous flow data collected near the outlet of the impaired reach (S001-523) was used to simulate hydrologic inputs. Diffuse sources were used to simulate direct watershed runoff inputs to the stream; one discrete input was used to simulate a major tributary at the beginning of Reach 4. Stream hydraulics were calibrated first, then temperature, carbonaceous biochemical oxygen demand (CBOD), phosphorous, and nitrogen series by adjusting diffuse and discrete contributions within the range of typical Minnesota water quality values for the North Central Hardwood Forest region. Last, bottom algae and sediment oxygen demand was adjusted for certain reaches to match observed DO data. A schematic diagram of the model is shown in Figure 1.1 and aerial overviews of the modeled drainage areas and reaches are shown in Figures 1.2 and 1.3, respectively.

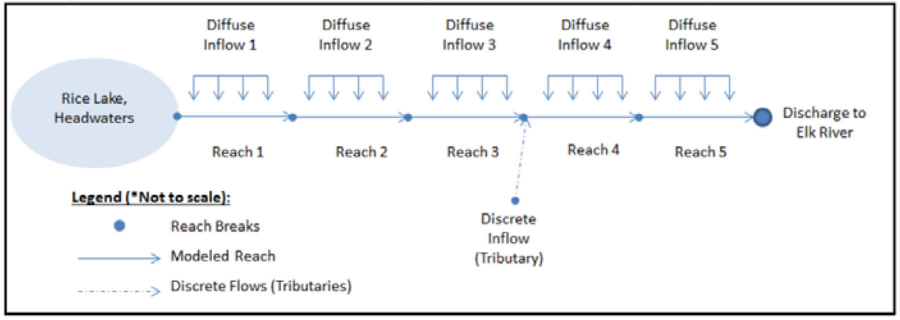

Figure 1.1 Model Schematic Diagram

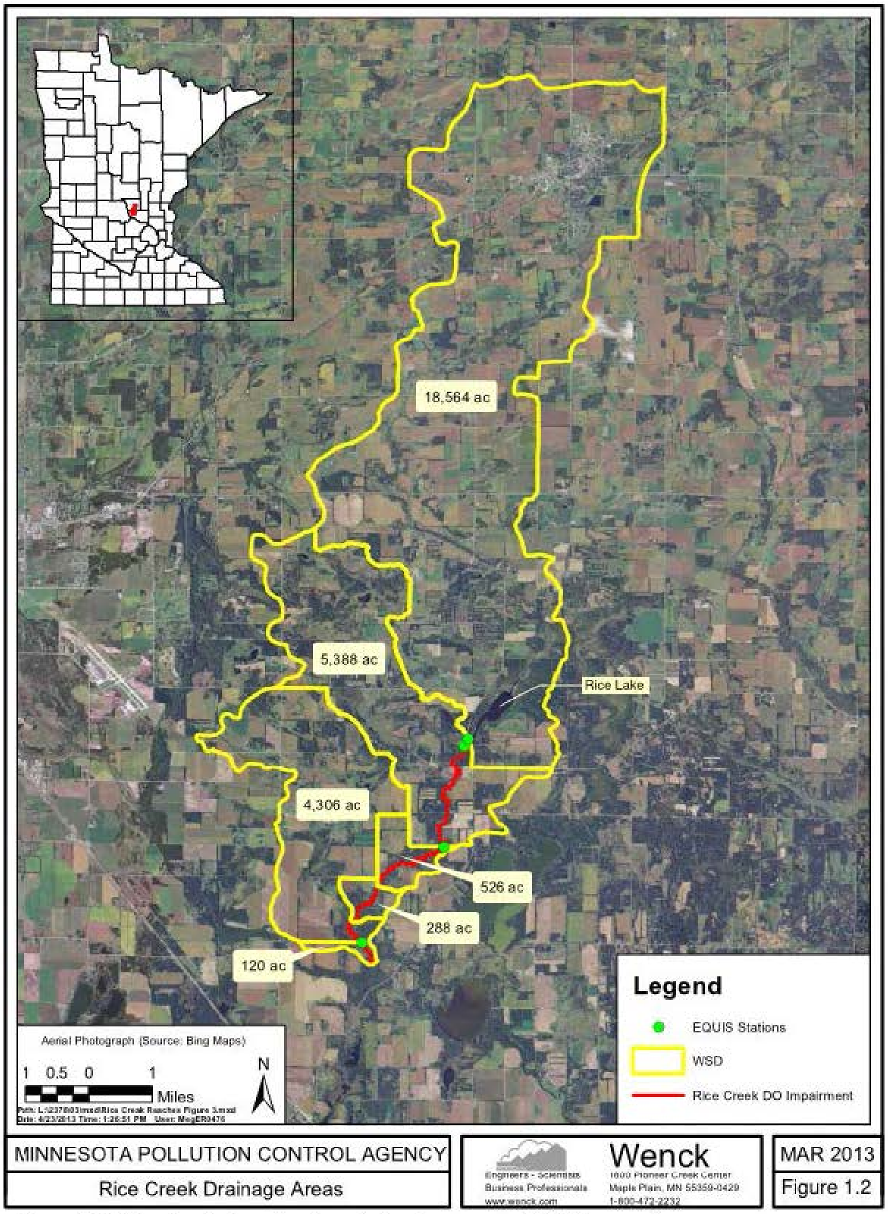

Figure 1.2 Rice Creek impaired reach drainage area (18,564 acres)

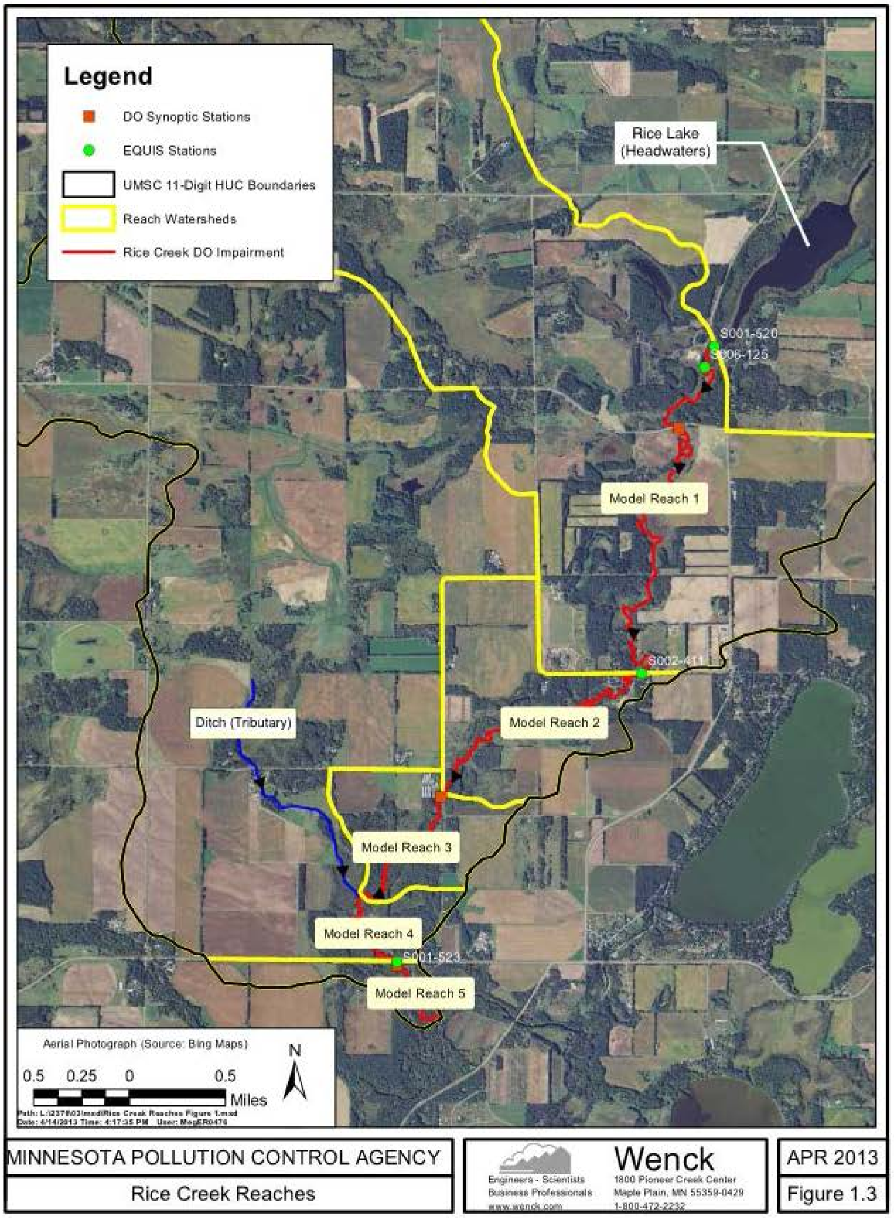

Figure 1.3 Monitoring stations and reaches on the modeled section of Rice Creek

2.0 MODEL CONFIGURATION

The model includes one main stem reach extending from the outlet of Rice Lake to Rice Creek's confluence with the Elk River (Figure 1.3, Table 2.1). This stretch of the creek, explicitly modeled, represents approximately 7.3 river miles (11.8 km) and was subdivided in to five reaches. The starts of each main stem reach correlate with a change in stream morphometry, or tributary inflow point.

Table 2.1 Rice Creek QUAL2K modeled reaches

Reach	Description	US River (km)	DS River (km)	Distance (km)	US Elevation (m)	US Elevation (m)	Slope (m/m)
1	Rice Lake Outlet to 42nd St.	11.7	6.8	4.94	299.2	298.1	0.000234
2	42nd St. to 90th Ave.	6.8	3.7	3.15	298.1	295.3	0.000662
3	90th Ave. to Ditch confluence	3.7	2.1	1.61	295.3	294.0	0.000805
4	Ditch confluence to Co. Rd. 16	2.1	0.9	1.16	294.0	293.7	0.000235
5	Co. Rd. 16 to Elk River confluence	0.9	0.0	0.90	293.7	293.2	0.000600

State variables in the QUAL2K model include DO, CBOD nitrogen series and phosphorous. Model processes include CBOD decay nitrification, algae photosynthesis/respiration, and sediment oxygen demand (SOD). Model inputs include flow rates and concentrations from non-point sources, headwater inflows, and tributaries.

The model was calibrated to data collected on the main stem of Rice Creek between 7/22/11 and 8/10/11 along with grab samples collected on 9/12/2012. The model simulated the flow on 7/28/2011 where synoptic data and flow measurements were available.

First, the model was calibrated to match monitored flow measurements, and water quality parameters were adjusted and calibrated. Kinetic coefficients used were either literature values, or determined using in-stream DO, CBOD and nitrogen series concentrations.

Reaeration was prescribed using the Tsivoglou-Neal reaeration model. This model uses channel slope and velocity to calculate reaeration in each reach. Average channel slopes are based on data from an elevation survey conducted by the MPCA on September 12, 2012 (Figure 2.1 and Table 2.3) No data was available for the upstream end of Reach 4, so Light Detection and Ranging (LiDAR) data was used to estimate elevations. Figure 2.1 shows the slope and of each of the modeled reaches. Mannings equation was used to calculate velocity (see Section 3.0).

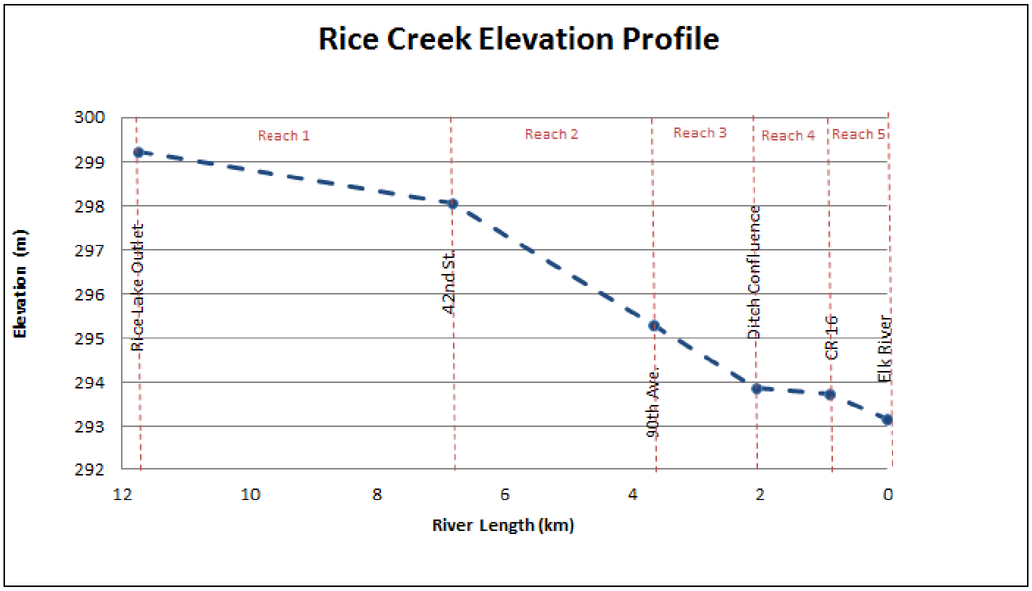

Figure 2.1 Survey elevations used to estimate reach slopes for Rice Creek

Data show that DO declines sharply in Reach 4 of the impaired reach where the creek widens and flows through a wetland with several backwater areas (Figure 2.2). This points to SOD as the primary driver of the impairment in Reach 4. To quantify SOD, the model was first calibrated to data collected during the synoptic survey. The SOD in Reach 4 was adjusted upwards to match observed DO concentrations downstream of the wetland.

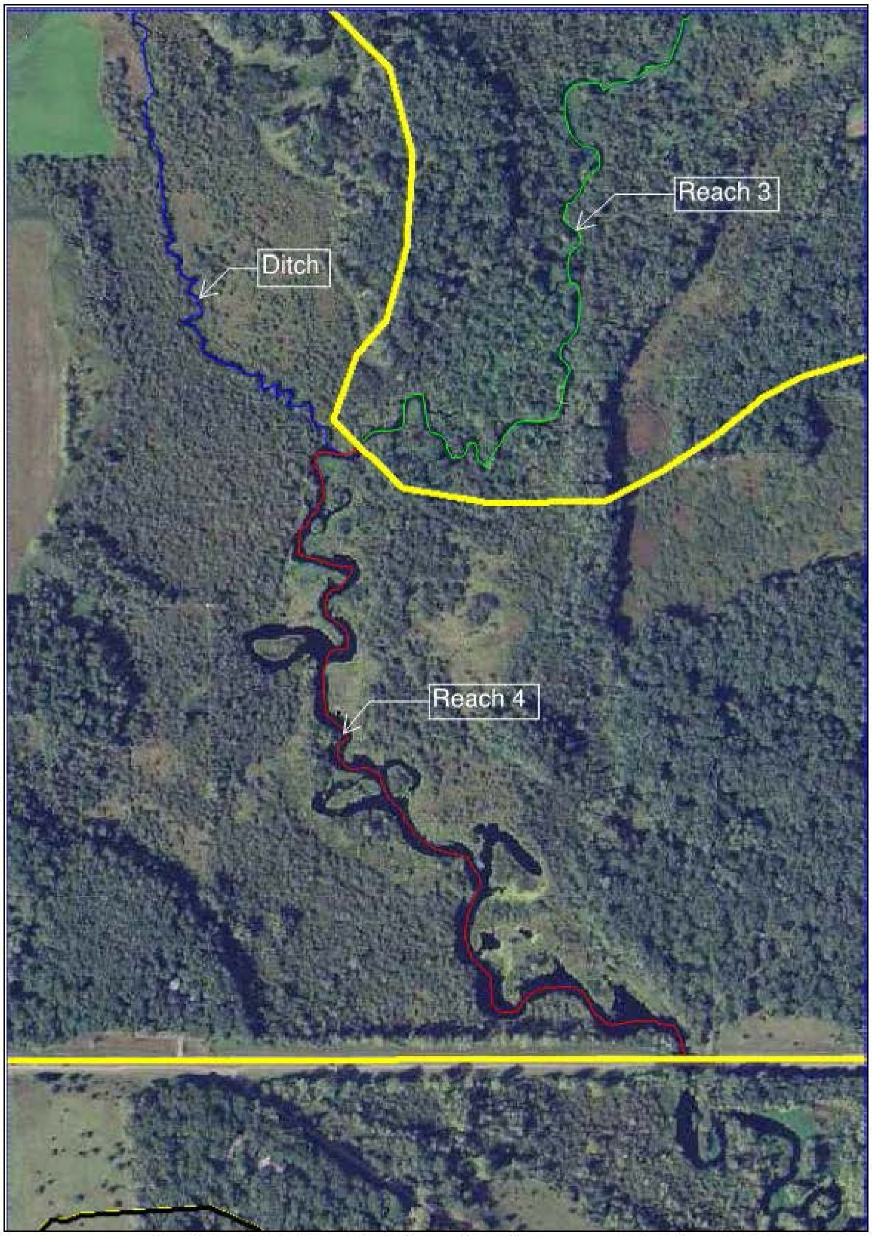

Figure 2.2 Reach 4 showing widening of channel and riparian wetland

3.0 MODEL INPUTS

3.1 Hydraulics

Manning's Equation was used to model the hydraulics of Rice Creek. The model assumes steady flow conditions in each reach and uses the following Manning's Equation to model the flow in each reach:

$$Q = \frac{S_0^{1/2}}{n} \cdot \frac{A_c^{5/3}}{P^{2/3}},$$

Where Q is the flow, S_0 is the bottom slope, n is the Manning roughness coefficient, A_c is the cross-sectional area, and P is the wetted perimeter.

For the QUAL2K model, the necessary inputs for Manning's equation are slide slopes (z_1 and z_2), bottom width (W_b), channel slope (S_0), and roughness coefficient (n). The side slopes and width are used to calculate the wetted perimeter (P) and cross-sectional area (A_c) in the equation above.

The channel slope for each reach is shown in Figure 2.1 and Table 2.1, while the side slopes and bottom width are shown in Table 3.1. The bottom width and side slopes were calculated by approximating a trapezoidal channel to match cross-section survey data from each of the model's reaches. The survey data and trapezoidal channel dimensions for reaches 1-3 and 5 are shown in Figure 3.1. At River km 2.01, the confluence of the main stem and an agricultural drainage ditch, the stream widens from 18.5 feet (5.9 m) to an average of about 62 feet (19.7 m). Reach 4, and the ditch confluence are shown in Figure 2.2.

Table 3.1 Manning Formula Inputs and Assumptions

Reach	n	W_0 (m)	Side Slope (Z_1)	Side Slope (Z_2)
1	0.04[1]	10.36	3.3	1.7
2	0.04	4.72	2.0	3.0
3	0.04	5.64	1.0	8.8
4[2]	0.04	18.90	1.0	1.0
5	0.04	8.23	1.0	1.0

[1] Roughness is assumed based on literature values (Mays, 2005)

[2] Slopes for reach four are assumed based on the slopes for reach 5 since no survey data was available

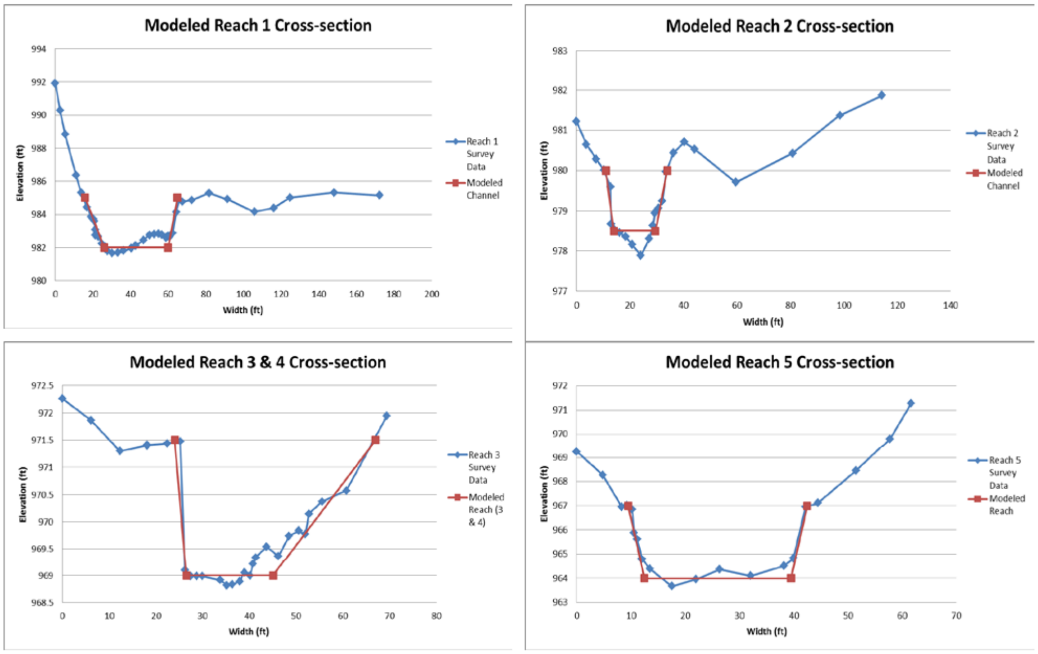

Figure 3.1 Reach cross-section survey data and trapezoidal channel approximation for all reaches.

Continuous flow data for Rice Creek was collected at County Road 16 (CASH 16) between 7-20-2011 and 7-31-2011. Missing data (7-26 to 7-28) was interpolated as shown in Table 3.2.

Table 3.2 Flow data from CSAH 16 (Rkm 0.9)

Site	Date	Average Daily Flow (cfs)	Average Daily Flow (m^3/s)	Average Daily Flow Quality/Notes
17038001	7/31/11	39	1.10	Fair Archived Daily Value
17038001	7/30/11	42	1.19	Fair Archived Daily Value
17038001	7/29/11	43	1.22	Fair Archived Daily Value
17038001	7/28/11	44	1.25	Interpolated (Data was missing)
17038001	7/27/11	46	1.30	Interpolated (Data was missing)
17038001	7/26/11	47	1.33	Interpolated (Data was missing)
17038001	7/25/11	48	1.36	Fair Archived Daily Value
17038001	7/24/11	49	1.39	Fair Archived Daily Value
17038001	7/23/11	54	1.53	Fair Archived Daily Value
17038001	7/22/11	60	1.70	Fair Archived Daily Value
17038001	7/21/11	59	1.67	Fair Archived Daily Value
17038001	7/20/11	68	1.92	Fair Archived Daily Value

Data indicates the section of the Rice Creek from Rice Lake to Elk River is a gaining. Reach inflow was modeled as diffuse inflow in reaches 1, 2, 3, & 5 and as one discrete input where an agricultural drainage ditch enters Rice Creek at River km 2.01, at the beginning of reach 4 (Figure 1.3, Table 3.3).

Both the diffuse source inflow and the discrete inflow were calculated based on a unit area flow derived from flow data collected at the watershed outlet. The drainage areas for each reach are shown in Table 3.3 and Figure 1.2.

Table 3.3 Modeled inflows for Rice Creek

Reach	DS Kilometer	Flow (cfs)	Flow (m^3/s)	Inflow[3] (m^3/s)	Drainage Area (ac)	Fraction of total Drainage Area[1]
Headwater	11.7	28.19	0.80	0.00	18,550	0.64
1	6.8	36.38	1.03	0.23	5,383	0.82
2	3.7	37.17	1.05	0.02	525	0.84
3	2.1	37.52	1.06	0.01	228	0.85
4[2]	0.90	**44.25**	1.25	0.19	4,306	0.99
5	0.00	44.43	1.26	0.01	120	1.00
				Total	29,114	

[1] The fraction of total drainage area represents the entire drainage area to the outlet of the reach (including the drainage area of the headwater) compared to the Total Drainage area (29,170 ac).

[2] The discrete source to Reach 4 is the ditch that enters the reach at River km 2.01. All other reaches were modeled as diffuse flow.

[3] The inflow for each reach was calculated by subtracting the flow from the preceding reach (or head water) from the total flow for each reach.

Groundwater was estimated assuming 2.2% (or 0.7 inches) of the 32 inches of annual rainfall is delivered to the stream as groundwater (Baker et al, 1979). Table 3.4 lists the estimated groundwater entering each reach which is only 0.9 cfs, or 2% of the stream flow during the critical flow condition.

Table 3.4 Groundwater contribution to the modeled reaches

Reach	Watershed	Groundwater			
	Area (ac)	Inch/yr	Acre-feet/yr	CFS	m^3/s
1	5,388	0.7	314	0.43	0.012
2	4,306	0.7	251	0.35	0.010
3	526	0.7	31	0.04	0.001
4	288	0.7	17	0.02	0.001
5	120	0.7	7	0.01	0.000
			Total	0.86	0.024

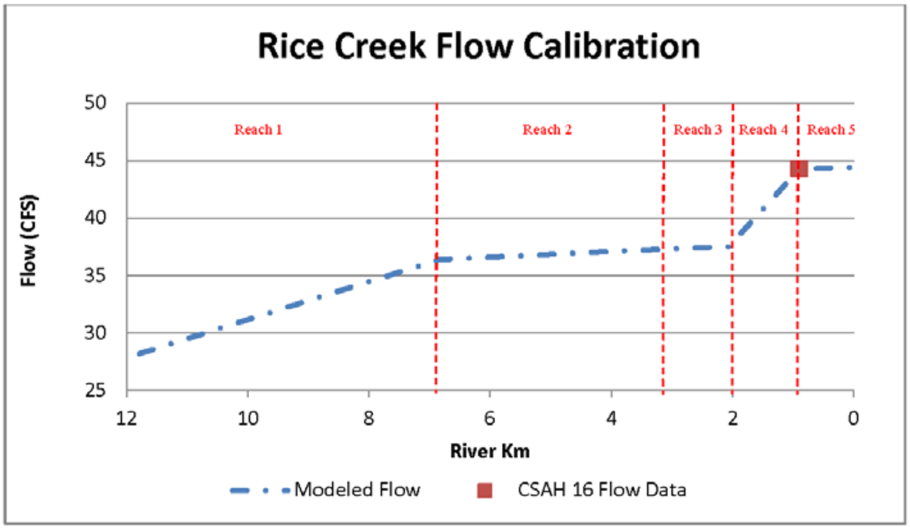

Figure 3.2 Final Rice Creek Flow calibration with diffuse and tributary inflows

Model simulated time of travel showed that travel times in reaches 1 through 3 (from River Km 11.6 to 2.1) are faster compared to reaches 4 and 5 (from River Km 2.1 to 0.0) which are wider, more moderately sloped (Figure 3.3). No velocity data or dye tests were available to calibrate Rice Creek time of travel.

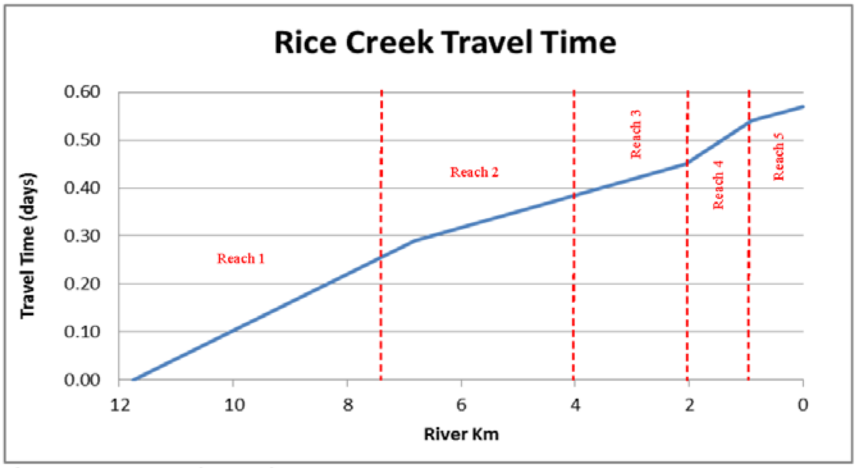

Figure 3.3 Rice Creek Travel Time

3.2 Water Quality Inputs

Water quality model inputs were derived from in-stream data collected during the July 22 – August 10, 2011 synoptic survey and the grab samples retrieved on September 19, 2012.

3.2.1 Headwaters:

Rice Lake represents the upstream boundary for this section of Rice Creek as the Lake served as the headwaters for this model. Historically, the MPCA has monitored two sites at the outlet of Rice Lake and water quality and flow data collected at these stations (S001-520, S006-125) was used to populate headwater conditions in the QUAL2K model. If data was unavailable for certain parameters, values from downstream or a nearby lake were used (Phytoplankton). Table 3.8 lists the values for each headwater parameter modeled and the justification for each value.

3.2.2 Tributary:

Water quality for the tributary inflow at River km 2.01 was derived from in-stream values. The average in-stream value was used and then adjusted within the range of in-stream water quality values to match observed water quality conditions (Table 3.9).

3.2.3 Groundwater:

Groundwater, making up only 2% of the inflow to the stream is represented in the diffuse inputs to the main stem. Groundwater was incorporated into the diffuse inputs since 2% of the flow with typical groundwater water quality values would not adjust the water quality outside of the in-stream ranges. Table 3.10 shows the adjusted in-stream water quality with a weighted groundwater chemistry incorporated.

3.2.4 Point Sources:

There are no point sources to the Rice Creek impaired section of Rice Creek, and therefore no point sources are represented in the model. The Foley WWTP is tributary to Rice Creek, 17 miles upstream of the Rice Lake (the upstream impaired reach boundary) of this model. Impacts of that point source are outside the scope of this evaluation.

3.2.5 Non-Point Sources:

As discussed previously, watershed loads are represented by diffuse and tributary flows along the main stem of Rice Creek. Data from monitoring stations was used to generate diffuse and tributary inputs. Table 3.6 provides a brief summary of the monitoring locations where data was available.

Table 3.6 Monitoring locations

Reach	Reach Start Monitoring Location ID	Description	Data Collected
1	S001-520	Rice Lake Outlet	Grab [9/19/2012]
1	S006-125	DS of Rice Lake Outlet	*No data*
2	S002-411	42nd St.	*Precip. And Temp. Only*
3	No ID	90th Ave.	Sonde [7/28/2011]
4	No ID	Ditch Confluence	*No data*
5	S001-523	Co. Rd. 16	Q, Grab [9/19/2012], Sonde [7/28/2011]

Q = Continuous flow data
Grab = Water quality grab sample collected and lab analyzed for typical pollutants (total kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_2-N), 5-day and ultimate carbonaceous biological oxygen demand (CBOD), total phosphorus (TP), ortho-phosphorus (soluble reactive phosphorus), total organic carbon (TOC), and chlorophyll-*a*).
Sonde = continuous data sonde deployed to record hourly temperature, DO, pH, conductivity data

Temperature, DO, conductivity, and pH were measured continuously at 90th Avenue (Rkm 3.7); these data were used to develop model headwater inputs. A grab sample was collected at the Rice Lake outlet on September 19, 2012 analyzed for BOD, inorganic nitrogen, organic phosphorus, and inorganic phosphorus. Organic N and phytoplakton, TKN and Chl-*a,* values from nearby Lake Julia (MPCA Station 71-0145-00-203) on July 26, 2011 were used to estimate concentrations for these lakes. Lake Julia was chosen as it is similar in size, landuse and drainage area and located within 3 miles of Rice Lake- the closest data available.

DO values measured at Rkm 3.7 were adjusted based on grab samples collected at both 90th Avenue (Rkm 3.7) and the Rice Lake Outlet (Rkm 11.6) on 6/28/2011, 6/29/2011, 7/7/2011, and 7/22/2011. These four samples were used to draw an average of ratios between the DO at Rkm 3.7 and Rkm 11.6. Table 3.7 shows the DO values for those 4 dates and the average correlation between those readings. It should be noted that all samples collected on the same day were collected within 30 minutes of each other. Based on this analysis, DO at the headwaters (Rkm 11.6) was multiplied by 1.02 to simulate headwater DO conditions.

3.2.6 Carbonaceous Biochemical Oxygen Demand (CBOD):

5-day BOD samples were collected at the Rice Lake outlet (Site S001-520) and County Highway 16 (site S001-523) on September 19, 2012. It is assumed that all BOD-5 measurements are approximately equal to the 5-day CBOD due to the low levels of ammonia (non-detect) recorded at the same time and locations. These BOD-5 measurements were used to represent the breakdown of organic carbon in the model since ultimate BOD has never been monitored and travel time through the impaired reach is less than 5 days (about 1 day, see Figure 3.4).

Table 3.7 DO measurements to support modeled Headwater DO

Sample Date[1]	Rkm 11.6 DO (mg/L)	Rkm 3.7 DO (mg/L)	Correlation (Rkm 11.6 / Rkm 3.7)
6/28/2011	5.01	4.87	1.03
6/29/2011	4.73	4.10	1.15
7/7/2011	3.37	3.09	1.09
7/22/2011	1.56	1.91	0.82
		Average	1.02

Average in-stream water quality parameters were adjusted within the range of typical Minnesota water quality conditions for the North Central Hardwood Forest ecoregion values to simulate in-stream water quality results. Tables 3.8 and 3.9 summarize the modeled water quality parameters.

Table 3.8 Modeled headwater parameters for the Rice Lake outlet

Parameter	Input/Value	Justification
Temp (C)	hourly between 23.91-25.72	Continuous data from Rkm 3.7 for 7/28/2011: Synoptic survey taken at 90th Ave. SE from 7/22/11 to 8/10/11.
Sp. Cond (umhos)	hourly between 2421-2481	Continuous data from Rkm 3.7 for 7/28/2011: Synoptic survey taken at 90th Ave. SE from 7/22/11 to 8/10/11.
DO (mg/L)	hourly between 3.22-5.37	Adjusted based on grab samples collected at both 90th Avenue (Rkm 3.7) and the Rice Lake outlet (Rkm 11.6).
CBOD	4.1	Grab from Rkm 11.6 for 9/19/2012; It is assumed that all of the BOD-5 measured in the Headwaters is CBOD due to the low levels of Ammonia. The only BOD-5 value we have for headwater is 4.1mg/L on 9/19/2012
Organic- N (µg/L)	1,950	TKN values from two nearby lakes of similar size were taken on 7/9/08; Lake Julia and Rush Lake had values of 1.6 and 2.4mg/L, respectively. The average was used to calculate the organic nitrogen for Rice Lake TKN - Ammonia = organic nitrogen; 2.00mg/L - 0.05mg/L = 1.95mg/L = 1,950ug/L
Ammonia (µg/L)	0	Grab from Rkm 11.6 for 9/19/2012; Location S001-520 located at the outlet of Rice Lake. This value was ND, so 0 was used.
Nitrate (µg/L)	50	Grab from Rkm 11.6 for 9/19/2012; Location S001-520 located at the outlet of Rice Lake. This value is 0.05mg/L
Organic-P (µg/L)	22.5	Grab from Rkm 11.6 for 9/19/2012; Location S001-520 located at the outlet of Rice Lake. This value is 1/2 of TP detection limit of 0.045mg/L
Inorganic-P (µg/L)	22.5	Grab from Rkm 11.6 for 9/19/2012; Location S001-520 located at the outlet of Rice Lake. This value is 1/2 of TP detection limit of 0.045mg/L
Phytoplankton (µg/L)[2]	26.9	Calcuated from a 7-26-11 sample of chl-a of 26.9 ug/L from Lake Julia [MPCA Station ID: 71-0145-00-203]. Lake Julie was chosen at it is nearby Lake Rice and is approximately the same size as Rice Lake.
pH	hourly between 7.23-7.3	Continous data from Rkm 3.67 for 7/28/2011: Synoptic survey taken at 90th Ave. SE from 7/22/11 to 8/10/11.

Table 3.9 Modeled diffuse and discrete source parameters for Rice Creek

Parameter	In-stream Values[1]		Reach 1-3 Diffuse	Reach 4-5 Discrete and Diffuse	Justification
	Range	Average			
Temp (C)	26.2-23.9	25.2	25	25	Adjusted within range of in-stream values
Sp. Cond (umhos)	2,438-2,277	2,392	2,300	2,300	Adjusted within range of in-stream values
CBOD	4.1-1.2	2.65	1.2	1.2	Adjusted within range of in-stream values
DO (mg/L)	5.37-0.35	3.18	2	0.5	Adjusted within range of in-stream values
Organic- N (µg/L)	1,950-1,030	1,490	1,050	1,050	Adjusted within range of in-stream values
Nitrate (µg/L)	50-1,700	875	1,700	1,700	Adjusted within range of in-stream values
Ammonia (µg/L)	50-60	55	50	60	Adjusted within range of in-stream values
Organic-P (µg/L)	40-23.5	31.8	23.5	23.5	Adjusted within range of in-stream values
Inorganic-P (µg/L)	5-23.5	14.3	23.5	23.5	Adjusted within range of in-stream values
Phytoplankton (µg/L)[2]	26.9	26.9	5	5	Adjusted within MPCA typical lake values; 5-25 µg/L

[1] These values represent the range of values from headwater (RM 7.3) to CSAH 16 (RM 0.56); the first number represents the headwater value and the second value represents the CSAH 16 value.

[2] No downstream values for Phytoplankton were available. 5 µg/L was used to fit the Chl-a results.

Table 3.10 Average In-stream conditions adjusted for groundwater

Parameter	In-stream Values		Typical MN Groundwater Values[1]	Adjusted Values to incorporate 2% Groundwater
	Range	Average		
Temp (C)	26.2-23.9	25.2	9.0	24.9
Sp. Cond (umhos)	2,438-2,277	2,392	490	2,354
DO (mg/L)	5.37-0.35	3.18	3.0	3.2
Nitrate (µg/L)	50-1,700	875	5.0	857.6
Organic-P (µg/L)	40-23.5	31.8	69.0	32.5
Inorganic-P (µg/L)	5-23.5	14.3	69.0	15.4

[1] These values represent typical groundwater values for the Upper Mississippi River (MPCA, 1999)

3.3 Weather and Physical Processes

Hourly weather measurements of temperature, cloud cover, relative humidity and wind speed were downloaded from the National Weather Service (NWS) NOAA St. Cloud, MN Airport. Channel canopy coverage was estimated based on 2010 air photos in GIS (Table 3.11).

Table 3.11 Rice Creek canopy cover per reach

Reach	Description	Canopy coverage (%)
1	Rice Lake Outlet to 42nd St.	10
2	42nd St. to 90th Ave.	50
3	90th Ave. to Ditch confluence	60
4	Ditch confluence to Co. Rd. 16	0
5	Co. Rd. 16 to Elk River confluence	80

3.4 Sediment Oxygen Demand

Sediment oxygen demand (SOD) is calculated in QUAL2K based on the delivery and breakdown of particulate organic matter from the water column. Currently, the model does not have a macrophyte or riparian vegetation SOD component, nor does it incorporate any upland sediment transported and deposited during non-steady state storms events. The model does allow the user to prescribe SOD to specific reaches that is added to the model predicted rate to account for SOD outside the modeling framework. SOD in streams varies depending on sediment type but is typically between 0.05 (mineral soils) and 2.00 (estuarine mud) g O_2/m^2/day (Thomann and Mueller, 1987). Rice Creek receives inflow from a ditch at the beginning of Reach 4 and then the reach widens from 5.6 meters to about 18.9 meters. The increase in channel width and depth through this wetland slows travel time and velocity and aeration drops drastically.

Model predicted DO concentrations for the hydraulic/phytoplankton/bottom algae/nutrient calibrated model were slightly higher than observed in the downstream portion of Rice Creek (Reaches 4 and 5). Therefore, high levels of SOD were assigned to Reach 4 and 5 to lower mean oxygen concentrations to match observed values (Table 3.12). The 8 g O_2/m^2/day value assigned to Reach 4 is slightly outside of typical values used for SOD, but is necessary to simulate the sharp drop in DO observed throughout this reach.

Table 3.12 Reach specific SOD and bottom algae coverage

Reach	SOD $g\ O_2/m^2/day$	Bottom Algae Coverage (%)	Justification
1	0.00	5	Minimum vegetation and no SOD prescribed due to fast moving reach
2	0.00	5	Minimum vegetation and no SOD prescribed due to fast moving reach
3	0.00	5	Minimum vegetation and no SOD prescribed due to fast moving reach
4	8.00	10	Minimum-to-moderate vegetation and high SOD based on slow-moving, wide channel through wetland
5	2.00	10	Minimum-to-moderate vegetation and moderate SOD based on slow-moving, wide channel

3.5 General Kinetic Rates

Kinetic rates used in the model are shown in Table 3.13.

Table 3.13 QUAL2K kinetic rate settings and adjustments

Rate	Default Rate	Calibrated Rate	Literature Range	Citation/Study Area
Reaeration Model	Tsivoglou and Neal	Adjusted Rate	Thomann and Mueller, 1987 cite that Tsivoglou and Neal, 1976; is accurate for streams 10 < CFS < 300	
Fast CBOD oxidation rate (day^{-1})	0.20	0.60	0.02 – 0.60	Bowie et al., 1985 Table 3-17 p152 Kansas (6 rivers) Michigan (3 rivers) reported by Bansal, 1975
Organic-N Hydrolysis (day^{-1}) *The release of ammonia due to decay of organic nitrogen*	0.30	0.20	0.1 – 0.4	Baca et al., 1973
Organic-N Settling Velocity (m/d)	0.05	0.10	influenced by a material's size, shape, and density and the speed of water	
Organic-P Hydrolosis (day^{-1}) *The release of phosphate due to decay of organic phosphorus*	0.30	0.20	0.02 – 0.80	Bowie et al., 1985 Table 5-5 p266 Jorgenson, 1976 Bowie et al., 1980
Organic-P Settling Velocity (m/d)	0.05	0.10	influenced by a material's size, shape, and density and the speed of water	
Inorganic-P settling (m/d)	0.01	0.25	influenced by a material's size, shape, and density and the speed of water	
Phytoplankton Settling (m/d)	0.25	0.50	0 – 2	Bowie et al., 1985 Table 6-19 p352 Chen & Orlob, 1975 and Smith, 1978

4.0 MODEL CALIBRATION

Following the hydrologic calibration, CBOD, temperature, specific conductivity, and all forms of nitrogen and phosphorus were calibrated by adjusting water quality parameters within the range of observed values. The model performed well in predicting temperature, CBOD, organic nitrogen, organic phosphorus, and other water quality parameters. The model performs well in predicting diurnal average minimum and maximum DO concentrations at the three locations where DO was continuously measured (Figure 4.1).

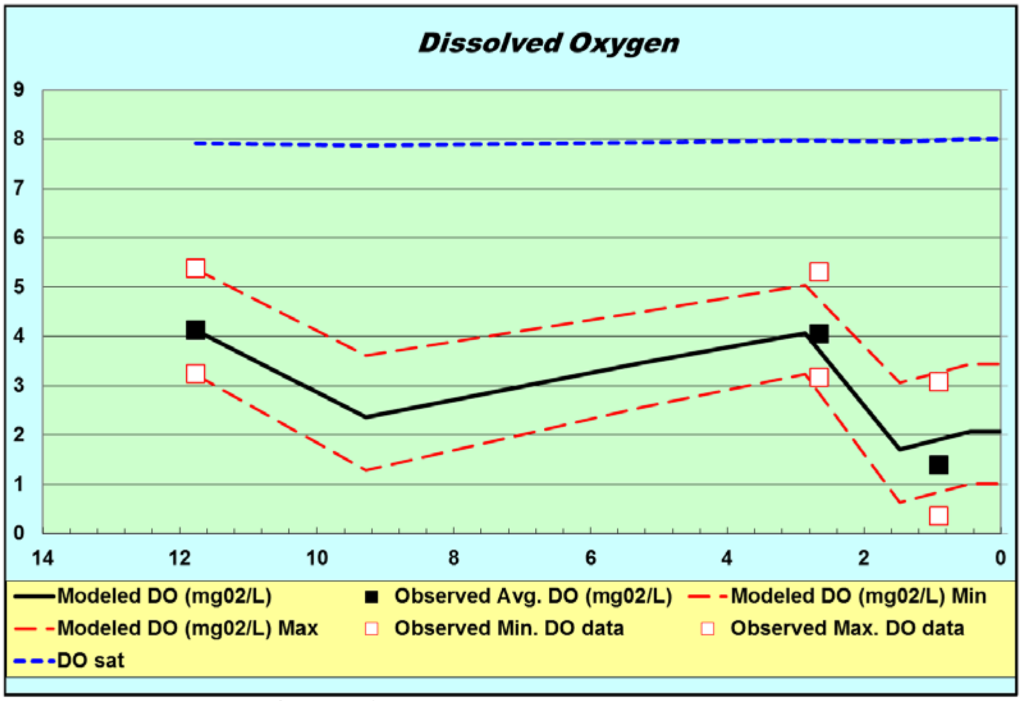

Figure 4.1 Model-predicted (Modeled) and Observed DO concentrations for Rice Creek

5.0 SENSITIVITY

To evaluate the sensitivity of model predicted DO to changes in model variables, seven kinetic rates (Table 5.1), two reach specific rates (Table 5.2), and channel slopes (Table 5.3) were removed or adjusted by specific percentages. The following tables summarize the affect these changes have on the average model-predicted DO concentration for the entire modeled stretch of Rice Creek. Results show DO throughout the system is most sensitive to the breakdown of organic carbon (CBOD) and organic nitrogen (organic-N hydrolosis), phytoplankton settling, as well as prescribed SOD settings in reaches 4 and 5. Phosphorus reactions appear to have very little effect on dissolved oxygen throughout Rice Creek. This exercise suggests sediment processes likely play a large role over water column processes in consuming DO during this particular calibration/sampling event.

Table 5.1 DO sensitivity to kinetic rates

Kinetic rate	+25%	-25%	Default
$CBOD_u$ oxidation rate (day^{-1})	-1.4%	1.7%	4.6%
Organic-N Hydrolosis (day^{-1})	-1.1%	1.1%	-2.0%
Organic-N Settling (m/d)	-1.7%	2.3%	0.6%
Organic-P Hydrolosis (day^{-1})	0.0%	0.0%	0.0%
Organic-P Settling (m/d)	0.0%	0.0%	0.0%
Inorganic-P Settling (m/d)	0.0%	0.0%	0.0%
Phytoplankton Settling (m/d)	-1.7%	1.7%	4.6%

Table 5.2 DO sensitivity to reach rates

Action	DO Sensitivity
Remove prescribed SOD in all reaches	15.2%
Remove all SOD by setting SOD channel coverage to 0%	37.6%

Table 5.3 DO sensitivity to channel slope

Channel Slope	DO Sensitivity
Increased by 25%	14.4%
Decreased by 25%	-13.2%

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APPENDIX D - BATTLE BROOK DO MODELING TECHNICAL MEMOS

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TECHNICAL MEMORANDUM

TO: Tiffany Determan, Sherburne Soil and Water Conservation District (SCWD)

FROM: Rebecca Kluckhohn, PE, Wenck Associates, Inc.
Jeff Strom, Wenck Associates, Inc.
Erik Megow, Wenck Associates, Inc.

DATE: August 22, 2013

SUBJECT: Battle Brook Dissolved Oxygen (DO) Modeling
Description of QUAL2K Modeling Methods and Results

CC: Phil Votruba, Minnesota Pollution Control Agency (MPCA)

This technical memorandum describes the methods and assumptions used to develop and calibrate a QUAL2K model of Battle Brook from County Road 42 to Elk Lake. The AUID number for this section of Battle Brook is 07010203-535. The model was used to quantify and partition existing oxygen demand loads in the DO-impaired reach of Battle Brook. The work was performed in accordance with the scope of work dated October 19, 2012. Memo contents are summarized below:

Contents:

1. Introduction
    1.1. Model Selection
    1.2. General Overview of Model
2. Model Configuration
3. Model Inputs
    3.1. Hydraulics
    3.2. Water Quality Inputs
        3.2.1. Headwaters
        3.2.2. Tributaries
        3.2.3. Groundwater
        3.2.4. Point Sources
        3.2.5. Non-point Source Inputs
        3.2.6. Carbonaceous Biochemical Oxygen Demand (CBOD)
    3.3. Weather and Physical Processes
    3.4. Sediment Oxygen Demand
    3.5. General Kinetic Rates
4. Model Calibration
5. Sensitivity
6. References

Technical Memo
Battle Brook Dissolved Oxygen Modeling
August 22, 2013

1.0 INTRODUCTION

1.1 Model Selection

Battle Brook violates state DO standard, with concentrations falling below the 5 mg/L daily minimum in the reach between County Road 42 and Elk Lake. A model of in-stream water quality, specifically DO and associated parameters, was set up to quantify the oxygen demand to this impaired reach of Battle Brook. The model will later be used to quantify the required reductions in oxygen demand necessary for Battle Brook to meet State DO standards. The QUAL2K (Version 2.11) model was selected for this purpose. It is a windows version of the EPA's QUAL2E model and is approved by the EPA for setting DO TMDLs in rivers. It is a one-dimensional, steady state model.

1.2 General Overview of the Model

The Battle Brook model was developed using water quality, hydrologic and hydraulic data collected by the MPCA and the Elk River Watershed Association (ERWSA). The model was calibrated to limited synoptic survey data which included

- continuous DO data measurements at 2 locations in the impaired reach during July 9-16, 2012 and
- Longitudinal DO data measured 2 times at 3 locations in Battle Brook on July 9 and July 16, 2012.

The stream was broken into three reaches based on channel morphometry. An area-weighted runoff hydrograph based on continuous flow data collected at three locations along the impaired reach was used to simulate hydrologic inputs. Diffuse sources were used to simulate direct watershed runoff inputs to the stream; three discrete inputs were used to simulate major tributaries. Stream hydraulics were calibrated first, then temperature, carbonaceous biochemical oxygen demand (CBOD), phosphorous, and nitrogen by adjusting diffuse and discrete contributions within the range of typical Minnesota water quality values for the North Central Hardwood Forest region. Last, bottom algae and sediment oxygen demand were adjusted to match observed dissolved oxygen data. A schematic diagram of the model is shown in Figure 1.1 and aerial overviews of the modeled drainage areas and reaches are shown in Figures 1.2 and 1.3, respectively.

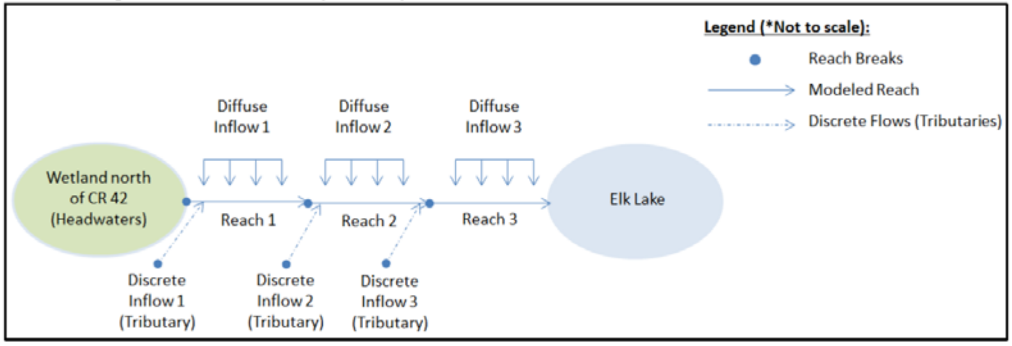

Figure 1.1 Model Schematic Diagram

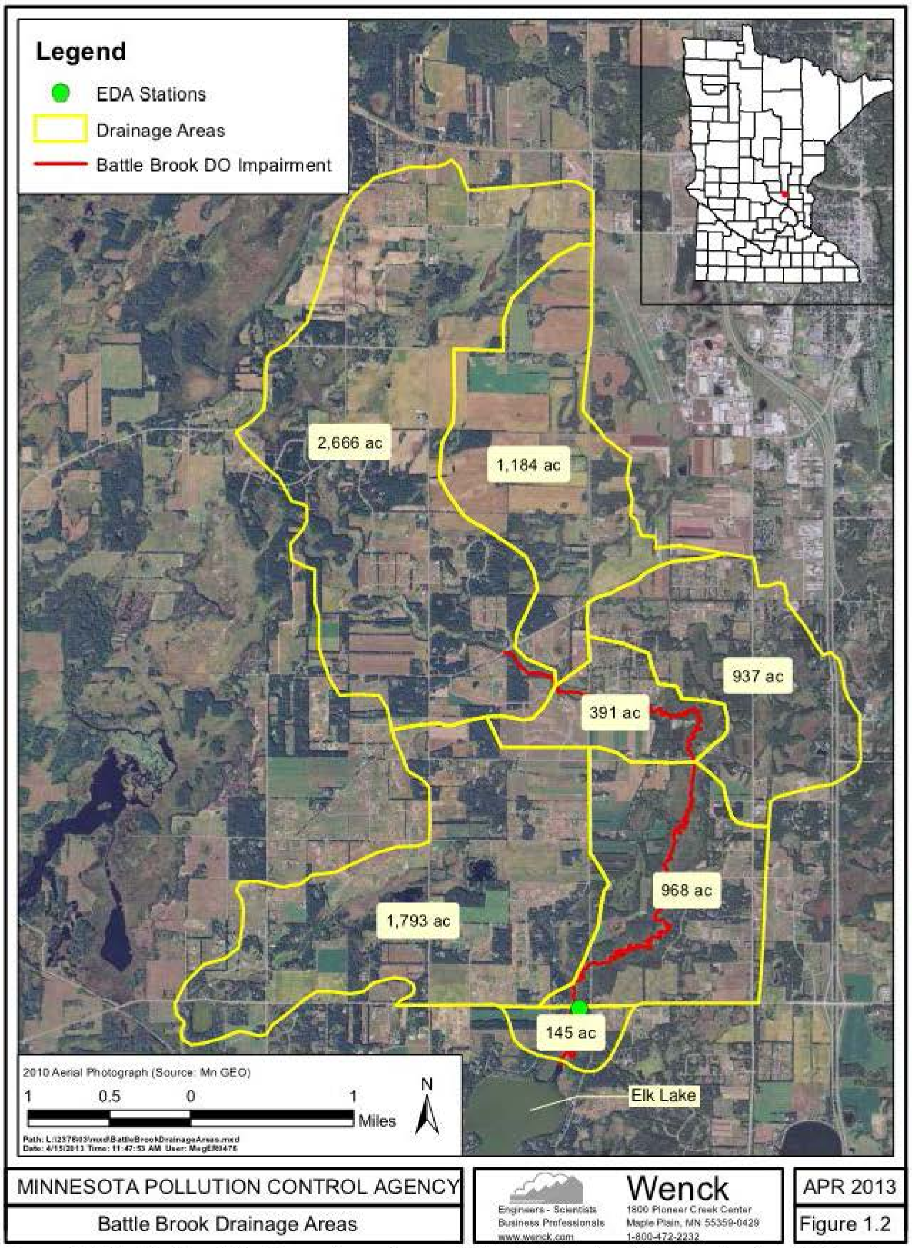

Figure 1.2 Battle Brook Drainage Areas for each Reach including the Headwater (2,666 ac)

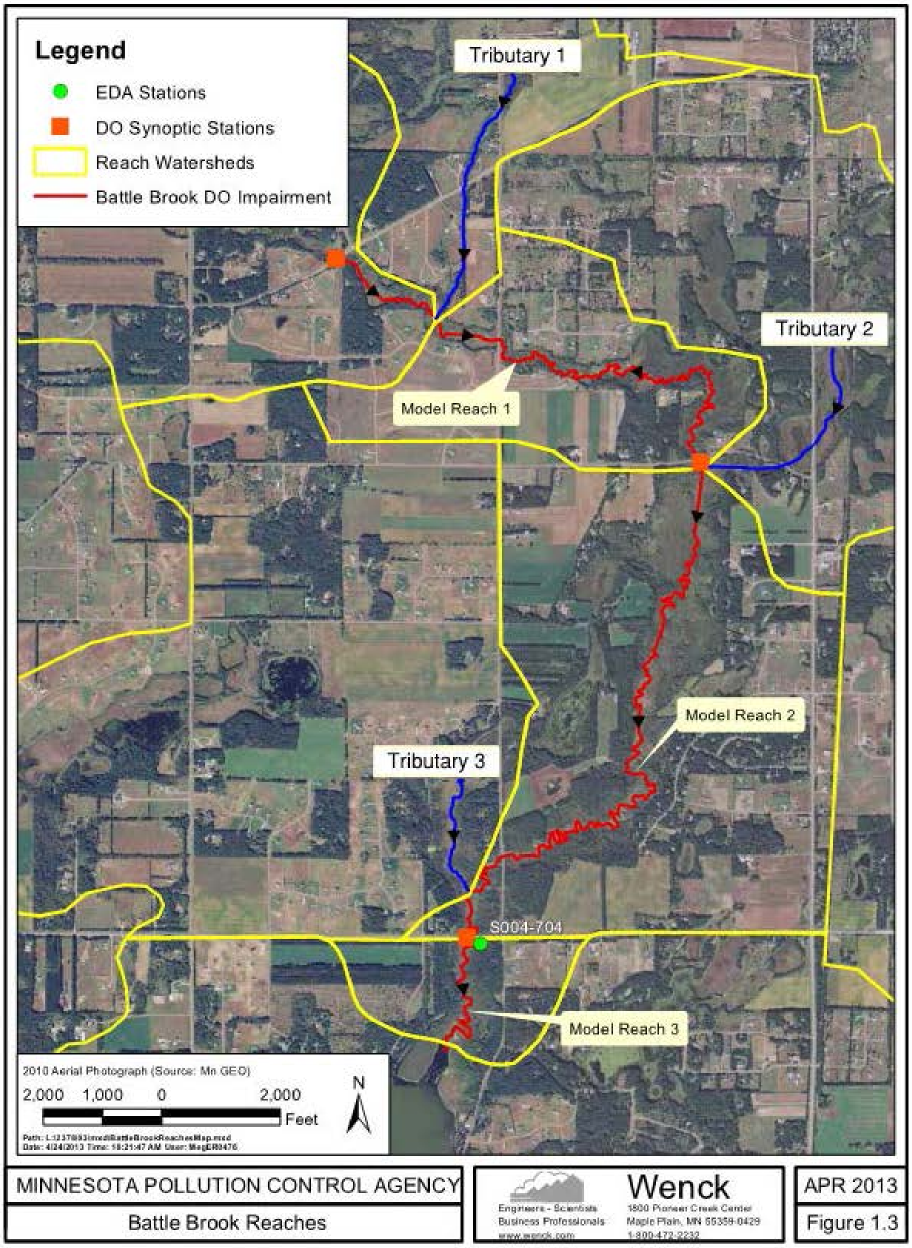

Figure 1.3 Monitoring stations and reaches on the modeled section of Battle Brook

2.0 MODEL CONFIGURATION

The model includes one main stem extending from County Road 42 to Elk Lake (Figure 1.3, Table 2.1). This stretch of the brook, explicitly modeled, represents 5.98 river miles (9.62 km) subdivided in to three reaches. The starts of each main stem reach correlate with a change in stream morphometry, or tributary inflow point.

Table 2.1 Battle Brook QUAL2K Modeled reaches

Reach	Description	US River (km)	DS River (km)	Distance (km)	US Elevation (m)	US Elevation (m)	Slope (m/m)
1	County Road 42 to 305th Ave.	9.62	5.95	3.67	294.0	290.9	0.000830
2	305th Ave. to County Road 9	5.95	1.01	4.94	290.9	289.3	0.000316
3	County Road 9 to Elk Lake	1.01	0.00	1.01	289.3	289.0	0.000316

State variables in the QUAL2K model include DO, CBOD, nitrogen series and phosphorous. Model processes include CBOD decay, nitrification, algae photosynthesis/respiration, and sediment oxygen demand (SOD). Model inputs include flow rates and concentrations from non-point sources, headwater inflows, and tributaries.

The model was calibrated to data collected on the main stem of Battle Brook between 7/9/12 and 7/16/2012 along with grab samples collected on 7/9/2012. The model simulated the flow on 7/9/2012 where synoptic data and flow measurements were available.

First, the model was calibrated to match monitored flow measurements, and then water quality parameters were adjusted and calibrated. Default values for kinetic coefficients were used and were then adjusted within literature ranges to match in-stream DO, CBOD and nitrogen series concentrations. See Table 3.11 for further detail.

Reaeration was prescribed using the Tsivoglou-Neal reaeration model. This model uses channel slope and velocity to calculate reaeration in each reach. Average channel slopes are based on data from an elevation survey conducted by the MPCA on September 12, 2012 (Figure 2.1 and Table 2.3). Figure 2.1 shows the slope of each of the modeled reaches. Mannings equation was used to calculate velocity (see Section 3.0).

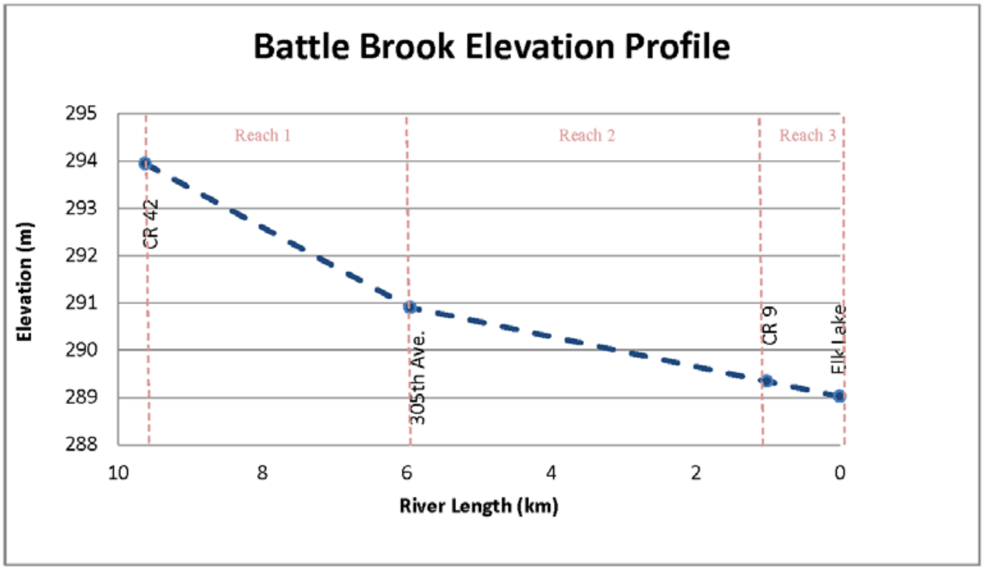

Figure 2.1 Survey elevations used to estimate reach slopes for Battle Brook

Data show that DO declines sharply in a Reaches 2 and 3 of the impaired reach where the brook flows through a wetland. This points to SOD as the primary driver of the impairment in Reach 2 and 3. To quantify SOD, the model was first calibrated to data collected during the synoptic survey, and then SOD in Reaches 2 and 3 was adjusted within typical in-stream values to match observed DO concentrations downstream of the wetland.

3.0 MODEL INPUTS

3.1 Hydraulics

Manning's Equation was used to model the hydraulics of Battle Brook. The model assumes steady flow conditions in each reach and uses the following Manning's Equation to model the flow in each reach:

$$Q = \frac{S_0^{1/2}}{n} \cdot \frac{A_c^{5/3}}{P^{2/3}},$$

Where Q is the flow in m^3/s, S_0 is the bottom slope in m/m, n is the Manning roughness coefficient, A_c is the cross-sectional area in m^2, and P is the wetted perimeter in m.

For the QUAL2K model, the necessary inputs for Manning's equation are slide slopes (z_1 and z_2), bottom width (W_b), channel slope (S_0), and roughness coefficient (n). The side slopes and width are used to calculate the wetted perimeter (P) and cross-sectional area (A_c) in the equation above.

The channel slope for each reach is shown in Figure 2.1 and Table 2.1, while the side slopes and bottom width are shown in Table 3.1. The bottom width and side slopes were calculated by approximating a trapezoid to match cross-section survey data collected by the MPCA for two of the model's reaches. The survey data and trapezoids for reaches 1-3 are shown in Figure 3.1. Survey data at CR 9 was used to approximate the channel geometry for Reaches 2 and 3.

Table 3.1 Manning Formula Inputs

Reach	n	W_0 (m)	*Side Slope* Z_1	*Side Slope* Z_2
1	0.04[1]	2.44	0.75	1.50
2	0.04	4.27	1.00	3.00
3	0.04	4.27	1.00	3.00

[1] Roughness is assumed based on literature values (Mays, 2005)

[2] Width and side slopes for reach 2 and 3 were taken from the CR9 crossing.

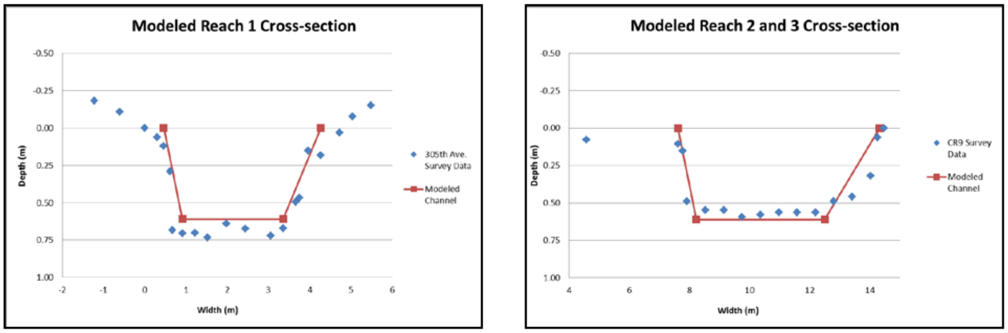

Figure 3.1 Reach cross-section survey data and trapezoidal approximation for reaches 1, 2, and 3.

Flow data for Battle Brook was collected on July 9, 2012 at three locations: CR 42, 305th Avenue, and CR 9. These flow values are shown in Table 3.2.

Table 3.2 Flow Data from July 9th, 2012

Site	Timestamp	Flow (cfs)	Flow (m^3/s)
CR 42	11:30 am	0.69	0.0195
305th Ave	10:50 am	3.49	0.1116
CR 9	10:00 am	6.03	0.1708

Incremental increases in flow between gauging stations were built in to the model as diffuse sources or tributaries where appropriate with flows based on an unit-area hydrograph (Table 3.3). Diffuse and tributary sources were calculated based on the drainage area of shown in Figure 1.2. The flow at the beginning of each reach was gauged (see Table 3.2).

Table 3.3 Modeled diffuse and tributary inflow for Battle Brook

Reach	Runoff Area (ac)[1]	Inflow (m^3/s)	Total Flow (m^3/s)	Flow Type	Location (KM)
Headwater	2,666	0.0195	0.0195	Initial	9.62
1	1,184	0.0692	0.1116	Tributary 1	8.95
1	391	0.0229		Diffuse	9.62 – 5.95
2	937	0.0150	0.1708	Tributary 2	5.87
2	1,793	0.0287		Tributary 3	1.30
2	968	0.0155		Diffuse	5.95 – 1.01
3[2]	145	0.0023	Unknown	Diffuse	1.01 – 0.00

[1] The diffuse and tributary flows were calculated by multiplying the total flow for that reach by the fraction of runoff for that source compared to the runoff area of the entire reach.

[2] The total flow for Reach 3 was unknown. The inflow used for Reach 3 was calculated based on the diffuse inflow of reach 2 and weighted based on their respective runoff areas.

Groundwater was estimated using 32 inches of annual rainfall for this area, and 2.2% (or 0.7 inches) of rainfall is delivered to the stream as groundwater (Baker et al, 1979). Table 3.4 lists the estimated groundwater entering each reach which is 0.44 cfs, or 7% of the stream flow during this flow condition.

Table 3.4 Estimated groundwater as diffuse flow for each modeled reach

Inflow	Watershed Area (ac)	Groundwater			
		Inch/yr	Acre-feet/yr	CFS	m^3/s
Reach 1 - Tributary 1	1,184	0.7	69	0.10	0.0027
Reach 1 - Diffuse	391	0.7	23	0.03	0.0009
Reach 2 - Tributary 2	937	0.7	55	0.08	0.0021
Reach 2 - Tributary 3	1,793	0.7	105	0.14	0.0041
Reach 2 - Diffuse	968	0.7	56	0.08	0.0022
Reach 3 - Diffuse	145	0.7	8	0.01	0.0003
			Total	0.44	0.0124

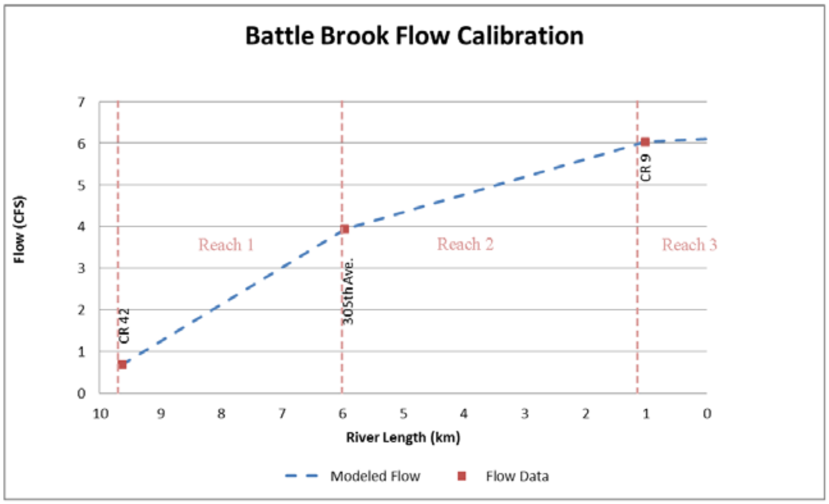

Figure 3.2 Final Battle Brook Flow calibration with diffuse and point source inflows

Model simulated time of travel showed that travel time in the first reach (from River Km 9.62 to 5.95) is faster compared to the wider, more moderately sloped reach 2 and 3 (from River Km 5.98 to 0.00). No velocity data or dye tests were available to calibrate Battle Brook time of travel.

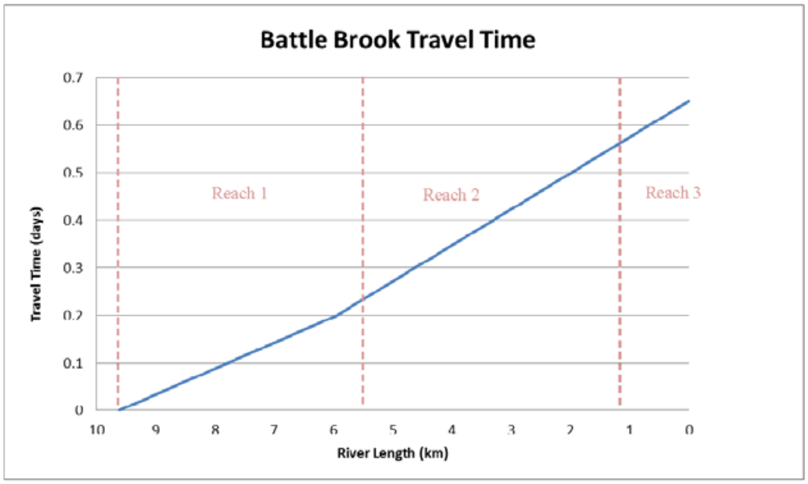

Figure 3.3 Battle Brook Travel Time

3.2 Water Quality Inputs

Water quality model inputs were derived from in-stream data collected during the July 9 – July 16, 2012 synoptic survey and the grab samples retrieved on July 9 and July 16, 2012.

3.2.1 Headwaters:
The wetland northwest and upstream of CR 42 represents the upstream boundary for this section of Battle Brook and served as the headwaters for this model (Figure 1.2). Water quality data collected at CR 42 were used to simulate headwater concentrations in the QUAL2K model. If data was unavailable for certain parameters, values from downstream (305th Ave.) were used. Table 3.8 lists the values for each headwater parameter modeled and the justification for each value.

3.2.2 Tributary:
Water quality for the tributaries was derived from in-stream values. The average in-stream value was used and then adjusted within the range of in-stream water quality values to match observed water quality conditions (Table 3.7).

3.2.3 Groundwater:
Groundwater, making up only 7% of the inflow to the stream is represented in the diffuse inputs to the main stem. Groundwater was incorporated into the diffuse inputs since 7% of the flow with typical groundwater water quality values would not adjust the water quality outside of the in-stream ranges. Table 3.8 shows the adjusted in-stream water quality with a weighted groundwater chemistry incorporated.

3.2.4 Point Sources:
There are no point sources to the DO-impaired section of Battle Brook, and therefore no point sources are represented in the model.

3.2.5 Non-Point Sources:
As discussed previously, watershed loads are represented by diffuse and tributary flows along the main stem of Battle Brook. In-stream water quality data was used to simulate diffuse and tributary inputs. Table 3.5 provides a brief summary of the monitoring locations where data was available.

Table 3.5 Monitoring locations

Reach	Reach Start Monitoring Location ID	Description	River Mile	Data Collected
1	No ID	CR 42	5.98	Q, Grab, Sonde
1	No ID	136th	5.30	Grab
2	No ID	305th Ave.	3.65	Q, Grab, Sonde
2	No ID	136th	1.05	Grab
3	S004-704	CR 9	0.60	Q, Grab, Sonde

Q = Measured flow

Grab = Water quality grab sample collected and lab analyzed for typical pollutants (total kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_2-N), 5-day and ultimate carbonaceous biological oxygen demand (CBOD), total phosphorus (TP), ortho-phosphorus (soluble reactive phosphorus), total organic carbon (TOC), and chlorophyll-*a*).

Sonde = continuous data sonde deployed to record hourly temperature, DO, pH, conductivity data

Since continuous DO was not measured at the headwater for the modeled period, values measured at 305th Avenue (RM 3.65) during the modeling period were adjusted based on the relationship between DO values at the two sites for other monitoring events. Grab data taken within 15 minutes of each other on 7/9/2012 at 305th Avenue and CR 42 (headwaters) showed that DO was 1.69 times higher at CR42 than 305th Avenue. The DO samples taken at CR 42 and 305th Avenue were 13.5 mg/L and 8.0 mg/L, respectively.

3.2.6 Carbonaceous Biochemical Oxygen Demand (CBOD):

5-day CBOD samples were collected at CR 42, 305th Avenue, and CR 9 (site S004-704) on July 9, 2012. These CBOD-5 measurements were used to represent the breakdown of organic carbon in the model since total CBOD has never been monitored and since CBOD remains relatively constant after five days (Thomann & Mueller 1987).

In-stream water quality values were adjusted within the range of typical Minnesota water quality conditions for the North Central Hardwood Forest ecoregion values to simulate in-stream water quality results. Tables 3.6 and 3.7 summarize the modeled water quality parameters.

Table 3.6 Modeled headwater parameters for the DO-impaired section of Battle Brook

Parameter	Input/Value	Justification
Temp (C)	Continuous from 19.6 - 22.5	-Continuous data from RM-5.98 for 7/10/2012: Synoptic survey taken at CR-42 (Site #3) from 7/9/2012 to 7/16/2012. -Data from 7/10/2012 was used since the data from 7/9/2012 was incomplete as it only consisted of half the day
Sp. Cond (umhos)	Continuous from 1972 - 2762	-Continuous data from RM-5.98 for 7/10/2012: Synoptic survey taken at CR-42 (Site #3) from 7/9/2012 to 7/16/2012. -Data from 7/10/2012 was used since the data from 7/9/2012 was incomplete as it only consisted of half the day
DO (mg/L)	Continuous from 3.32 - 12.48	-Continuous data from RM-3.70 for 7/10/2012: Synoptic survey taken at 305th Ave. (Site #2) from 7/9/2012 to 7/16/2012. -Data from 7/10/2012 was used since the data from 7/9/2012 was incomplete as it only consisted of half the day. -Data for 305th Ave was used instead of CR-42 data because the CR-42 data did not record correctly.
CBOD (mg/L)	1	-Grab from RM 5.98 (CR 42) for 7/9/2012. CBOD5 grab; all CBOD5 is considered CBODfast
Organic- N (µg/L)	1,010	-Grab from RM 5.98 (CR 42) for 7/9/2012. -TKN - Ammonia = organic nitrogen; 1.24mg/L - 0.23mg/L = 1.01mg/L = 1010 ug/L
Ammonia (µg/L)	230	-Grab from RM 5.98 (CR 42) for 7/9/2012. The grab value is 0.23 mg/L
Nitrate (µg/L)	0	-Grab from RM 5.98 (CR 42) for 7/9/2012. The grab value is 0.00 mg/L
Organic-P (µg/L)	73	-Grab from RM 5.98 (CR 42) for 7/9/2012. The grab value is 0.073 mg/L
Inorganic-P (µg/L)	359	-Grab from RM 5.98 (CR 42) for 7/9/2012. The TP grab value is 0.432 mg/L and TOP is 0.073 mg/L, so IOP is 0.432-0.073 = 0.359mg/L
Phytoplankton (µg/L)	5.23	-Grab from RM 5.98 (CR 42) for 7/9/2012. The grab value is 5.23 mg/L. This value was assumed to be in ug/L.
pH	hourly between 7.22-7.52	-Continuous data from RM-5.98 for 7/10/2012: Synoptic survey taken at CR-42 (Site #3) from 7/9/2012 to 7/16/2012. -Data from 7/10/2012 was used since the data from 7/9/2012 was incomplete and only consisted of half the day

Table 3.7 Modeled diffuse and discrete (tributary) source parameters for Battle Brook

Parameter	In-stream Values		Reach 1 Discrete and Diffuse	Reach 2 Discrete and Diffuse	Reach 3 Discrete and Diffuse	Justification
	Range[1]	Average				
Temp (C)	22.5-19.6	22.1	21.1	19.0	19.0	Adjusted within MPCA typical stream values; 2-21°C
Sp. Cond (umhos)	3268 - 1969	2744	3,250	3,200	2,800	Adjusted to in-stream values
CBOD (mg/L)	1.2-1.0	1.1	1.0	2.5	3.0	Adjusted within in-stream or MPCA typical stream values; 1.5 – 3.2 mg/L
DO (mg/L)	12.48-0.72	7.52	7.5	2.0	1.0	Adjusted to in-stream values
Organic- N (µg/L)	1,010-650	810	800	750	650	Adjusted to in-stream values.
Nitrate (µg/L)	270-0	90	0	0	270	Adjusted to in-stream values
Ammonia (µg/L)	230-0	77	230	0	0	Adjusted to in-stream values
Organic-P (µg/L)	73-23	40	25	30	30	Adjusted to in-stream values
Inorganic-P (µg/L)	359-26	144	30	30	30	Adjusted to in-stream values
Phytoplankton (µg/L)	5.23-2.46	4.22	3	3	3	Adjusted to in-stream values

[1] These values represent the maximum and minimum values from headwater (CR 42) to CR 9.

Table 3.8 Average In-stream conditions adjusted for groundwater

Parameter	In-stream Values		Typical MN Groundwater Values[1]	Adjusted Values to incorporate 2% Groundwater
	Range	Average		
Temp (C)	22.5-19.6	22.1	9.0	21.2
Sp. Cond (umhos)	3268 - 1969	2744	490	2,586.2
DO (mg/L)	12.48-0.72	7.52	3.0	7.2
Nitrate (µg/L)	270-0	90	5.0	84.1
Organic-P (µg/L)	73-23	40	69.0	42.0
Inorganic-P (µg/L)	359-26	144	69.0	138.8

[1] These values represent typical groundwater values for the Upper Mississippi River (MPCA, 1999)

3.3 Weather and Physical Processes

Hourly weather measurements of temperature, cloud conditions, relative humidity and wind speed were downloaded from the National Weather Service (NWS) NOAA St. Cloud, MN Airport.

Channel canopy coverage was established based on 2010 air photos in GIS and calculated based on the percent of river miles in each reach located in dense woods. The only reach with canopy coverage was Reach 1 where 0.5 of the reaches 2.28 river miles flowed through dense woods (Table 3.9).

Table 3.9 Battle Brook canopy cover per reach

Reach	Description	Canopy coverage (%)
1	County Road 42 to 305th Ave.	22
2	305th Ave. to County Road 9	0
3	County Road 9 to Elk Lake	0

3.4 Sediment Oxygen Demand

Sediment oxygen demand (SOD) is calculated in QUAL2K based on the delivery and breakdown of particulate organic matter from the water column. Currently, the model does not have a macrophyte or riparian vegetation SOD component. The model does allow the user to prescribe SOD to specific reaches that is added to the model predicted rate to account for SOD outside the modeling framework. SOD in streams varies depending on sediment type but is typically between 0.05 (mineral soils) and 2.00 (estuarine mud) g O_2/m^2/day (Thomann and Mueller, 1987).

Dissolved oxygen concentrations should be close to calibration as long as reasonable assumptions were made in allocating nutrient loads and adjusting kinetic rates. Model predicted dissolved oxygen concentrations for the hydraulic/phytoplankton/bottom algae/nutrient calibrated model were slightly higher than observed in the downstream portion of Battle Brook (Reaches 2 ad 3). Therefore, typical levels of SOD were assigned to Reach 2 and 3 to lower mean oxygen concentrations to match observed values (Table 3.10). A 2.0 g O_2/m^2/day value was assigned to Reach 2 and 3 to decrease the Dissolved Oxygen rates to meet the observed rates.

Table 3.10 Reach specific SOD and bottom algae coverage

Reach	**SOD** g O_2/m^2/day	**Bottom Algae Coverage** (%)	**Justification**
1	0.00	25	Medium vegetation and no SOD prescribed due to fast moving reach
2	2.00	10	Minimum vegetation and typical SOD prescribed due to fast moving reach
3	2.00	10	Minimum vegetation and typical SOD prescribed due to fast moving reach

3.5 General Kinetic Rates

Kinetic rates used in the model are shown in Table 3.11.

Table 3.11 QUAL2K kinetic rate settings and adjustments

Rate	Default Rate	Calibrated Rate	Literature Range	Citation/Study Area
Reaeration Model	Tsivoglou and Neal	User Specified	Thomann and Mueller, 1987 cite that Tsivoglou and Neal, 1976; is accurate for streams 10 < CFS < 300	
Fast CBOD oxidation rate (day^{-1})	0.20	0.60	0.02 – 0.60	Bowie et al., 1985 Table 3-17 p152 Kansas (6 rivers) Michigan (3 rivers) reported by Bansal, 1975
Organic-N Hydrolysis (day^{-1}) *The release of ammonia due to decay of organic nitrogen*	0.30	0.01	0.1 – 0.4	Baca et al., 1973
Organic-N Settling Velocity (m/d)	0.05	0.03	influenced by a material's size, shape, and density and the speed of water	
Organic-P Hydrolosis (day^{-1}) *The release of phosphate due to decay of organic phosphorus*	0.30	0.80	0.02 – 0.80	Bowie et al., 1985 Table 5-5 p266 Jorgenson, 1976 Bowie et al., 1980
Organic-P Settling Velocity (m/d)	0.05	0.01	influenced by a material's size, shape, and density and the speed of water	
Phytoplankton Settling (m/d)	0.25	0.20	0 – 2	Bowie et al., 1985 Table 6-19 p352 Chen & Orlob, 1975 and Smith, 1978

4.0 MODEL CALIBRATION

Following the hydrologic calibration, CBOD, temperature, specific conductivity, and all forms of nitrogen and phosphorus were calibrated by adjusting water quality parameters within the range of observed values. The model performed well in predicting temperature, CBOD, organic nitrogen, organic phosphorus, and other water quality parameters. The model performs well in predicting diurnal average minimum and maximum DO concentrations at the three locations where DO was continuously measured (Figure 4.1).

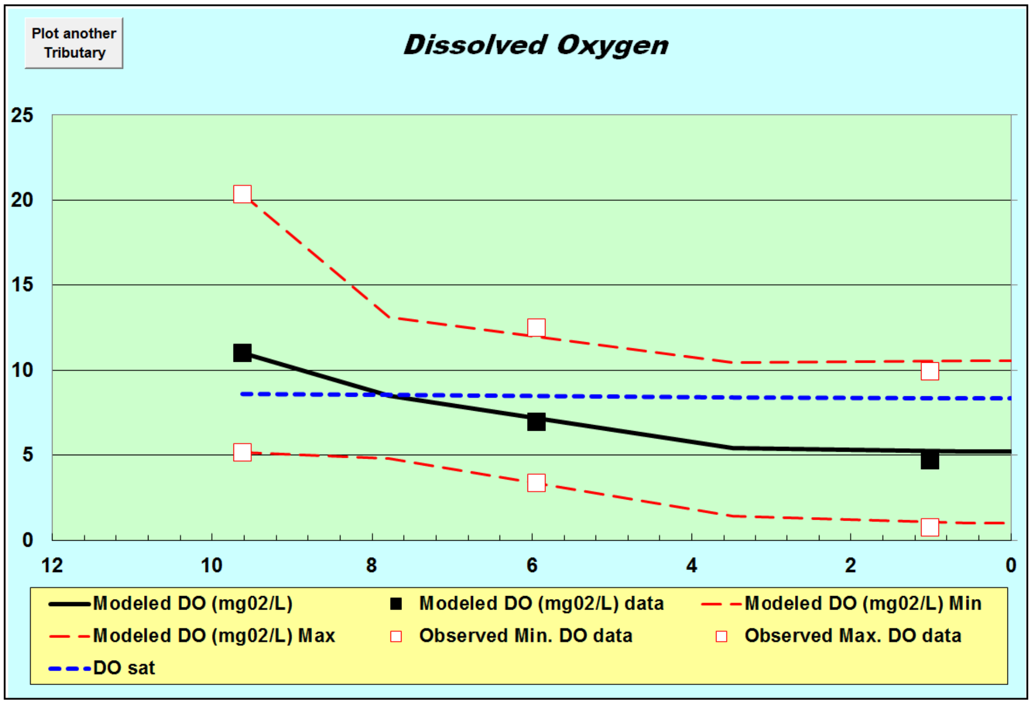

Figure 4.1 Model-predicted (Modeled) and Observed DO concentrations for Battle Brook

5.0 MODEL SENSITIVITY

To evaluate the sensitivity of model predicted dissolved oxygen to changes in model variables, seven kinetic rates (Table 5.1), two reach specific rates (Table 5.2), and channel slopes (Table 5.3) were removed or adjusted by specific percentages. The following tables summarize the affect these changes have on the average model-predicted dissolved oxygen concentration for the entire modeled stretch of Battle Brook. In Table 5.1, the DO results were compared to results where the kinetic rates were increased and decreased 25%. Additionally, the DO results were compared to results where the default kinetic rates were used. Results show DO throughout the system sensitive to the breakdown of organic carbon and nitrogen (CBOD oxidation and organic-N hydrolosis). However, the system is most sensitive to the SOD settings. Phosphorus reactions appear to have very little effect on dissolved oxygen throughout Battle Brook. This exercise suggests sediment processes play a bigger role than water column processes in consuming dissolved oxygen during this particular calibration/sampling event.

Table 5.1 DO sensitivity to kinetic rates

Kinetic rate	25%	-25%	Default
$CBOD_u$ oxidation rate (day^{-1})	-0.5%	0.5%	1.8%
Organic-N Hydrolosis (day^{-1})	-0.4%	0.2%	-1.5%
Organic-N Settling (m/d)	-0.5%	0.4%	-1.3%
Organic-P Hydrolosis (day^{-1})	0.0%	0.0%	0.0%
Organic-P Settling (m/d)	0.0%	0.0%	0.0%
Phytoplankton Settling (m/d)	-0.2%	0.0%	-0.2%

Table 5.2 DO sensitivity to reach rates

Action	DO Sensitivity
Remove prescribed SOD in all reaches	39.56%
Remove all SOD by setting SOD channel coverage to 0%	41.94%

Table 5.3 DO sensitivity to channel slope

Channel Slope	DO Sensitivity
Increased by 25%	4.95%
Decreased by 25%	-4.21%

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APPENDIX E – CLEARWATER RIVER WATERSHED MODELING TECHNICAL MEMOS

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TECHNICAL MEMORANDUM

TO: Tiffany Determan, Sherburne Soil and Water Conservation District (SCWD)

FROM: Rebecca Kluckhohn, PE, Wenck Associates
Jeff Strom, Wenck Associates, Inc.
Erik Megow, Wenck Associates, Inc.

DATE: October 7, 2013

SUBJECT: Clearwater River Dissolved Oxygen (DO) Modeling
Description of QUAL2K Modeling Methods and Results

CC: Phil Votruba, Minnesota Pollution Control Agency (MPCA)

This technical memorandum describes the methods and assumptions used to develop and calibrate a QUAL2K model of Clearwater River between the outlet of Clearwater Lake and the dam at the Mississippi River. The AUID number for this section of Clearwater River is 07010203-511. The model was used to quantify and partition existing oxygen demand loads in the DO-impaired reach of Clearwater River. The work was performed in accordance with the scope of work dated October 19, 2012. Memo contents are summarized below:

Contents:

1. Introduction
    1.1. Model Selection
    1.2. General Overview of Model
2. Model Configuration
3. Model Inputs
    3.1. Hydraulics
    3.2. Water Quality Inputs
        3.2.1. Headwaters
        3.2.2. Tributaries
        3.2.3. Groundwater
        3.2.4. Point Sources
        3.2.5. Non-point Source Inputs
        3.2.6. Dissolved Oxygen
        3.2.7. Carbonaceous Biochemical Oxygen Demand (CBOD)
    3.3. Weather and Physical Processes
    3.4. Sediment Oxygen Demand
    3.5. General Kinetic Rates
4. Model Calibration
5. Sensitivity
6. References

Technical Memo
Clearwater River Dissolved Oxygen Modeling
ERWSA TMDL
October 7, 2013

1.0 INTRODUCTION

1.1 Model Selection

The Clearwater River violates the state DO standard, with concentrations falling below the 5 mg/L daily minimum in the reach between Clearwater Lake and the Mississippi River. A model of in-stream water quality, specifically DO and associated parameters, was set up to quantify the oxygen demand to this impaired reach of Clearwater River. The model will later be used to quantify the required reductions in oxygen demand necessary for Clearwater River to meet State DO standards. The QUAL2K (Version 2.11) model was selected for this purpose. It is a windows version of the EPA's QUAL2E model and is approved by the EPA for setting DO TMDLs in rivers. It is a one-dimensional, steady state model.

1.2 General Overview of the Model

The Clearwater River model was developed using water quality, hydrologic and hydraulic data collected by the MPCA and the Clearwater River Watershed District (CRWD). The model was calibrated to synoptic survey data which included

- continuous DO data measurements at 3 locations in the impaired reach between July 3 and September 4, 2007 and
- longitudinal DO data measured 4 times at 3 locations (12 total measurements) in Clearwater River between 6/29/2011 and 8/30/2011.

The stream was broken into an upstream and downstream section with Wiegand Lake serving as the downstream boundary for the upstream model and the headwaters for the downstream model. Each of the models were broken into 3 reaches based on channel morphometry. An area-weighted runoff hydrograph based on continuous flow data collected near the outlet of Grass Lake (S003-582) was used to simulate hydrologic inputs. Diffuse sources were used to simulate direct watershed runoff inputs to the stream; one discrete input was used to simulate a major tributary at the beginning of Reach 2 in the downstream model. Stream hydraulics were calibrated first, then temperature, carbonaceous biochemical oxygen demand (CBOD), phosphorous, and nitrogen series by adjusting diffuse and discrete contributions within the range of typical Minnesota water quality values for the North Central Hardwood Forest region. Last, bottom algae and sediment oxygen demand was adjusted for certain reaches to match observed DO data. A schematic diagram of the models is shown in Figure 1.1 and aerial overviews of the modeled drainage areas and reaches are shown in Figures 1.2 and 1.3, respectively.

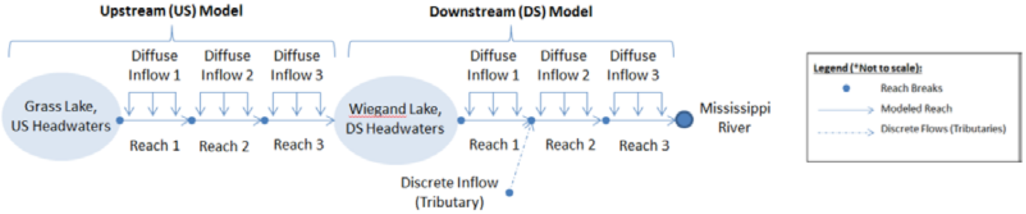

Figure 1.1 Model Schematic Diagram

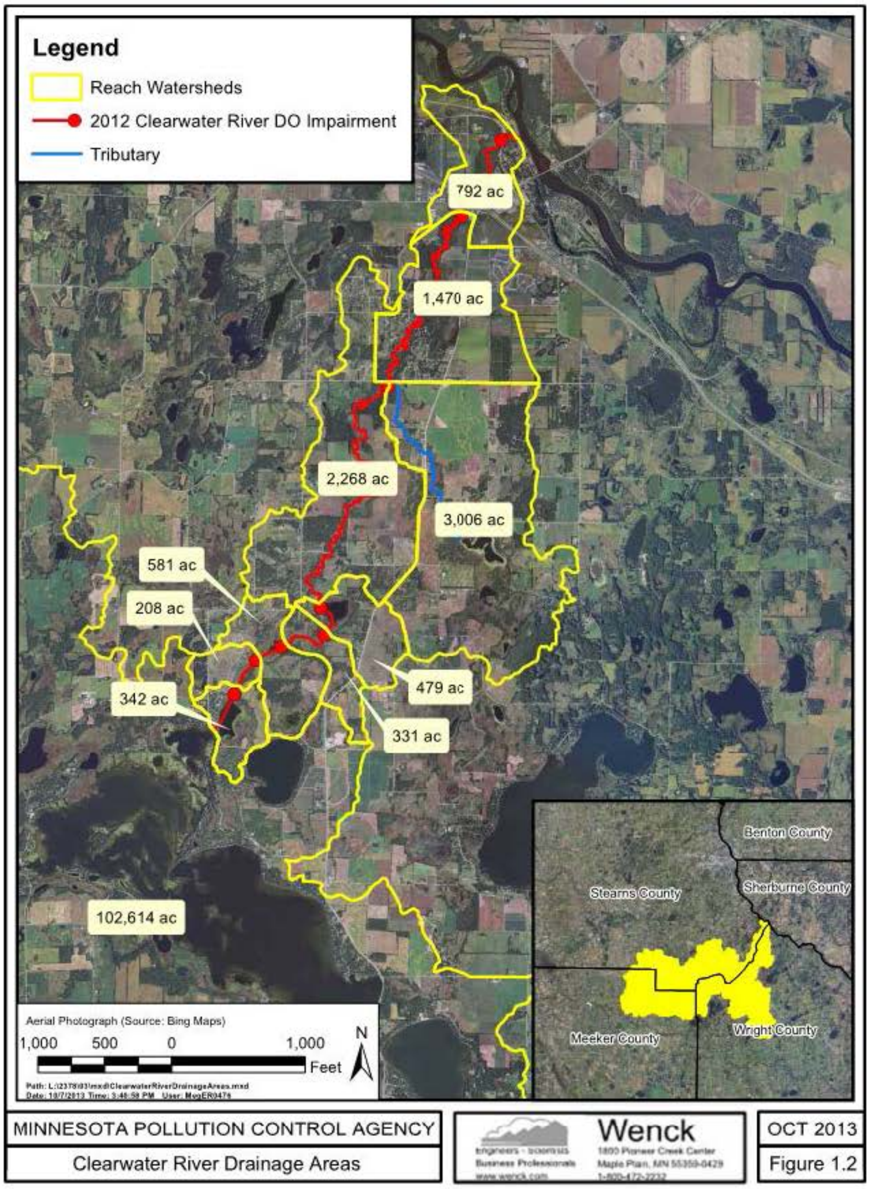

Figure 1.2 Clearwater River impaired reach drainage area

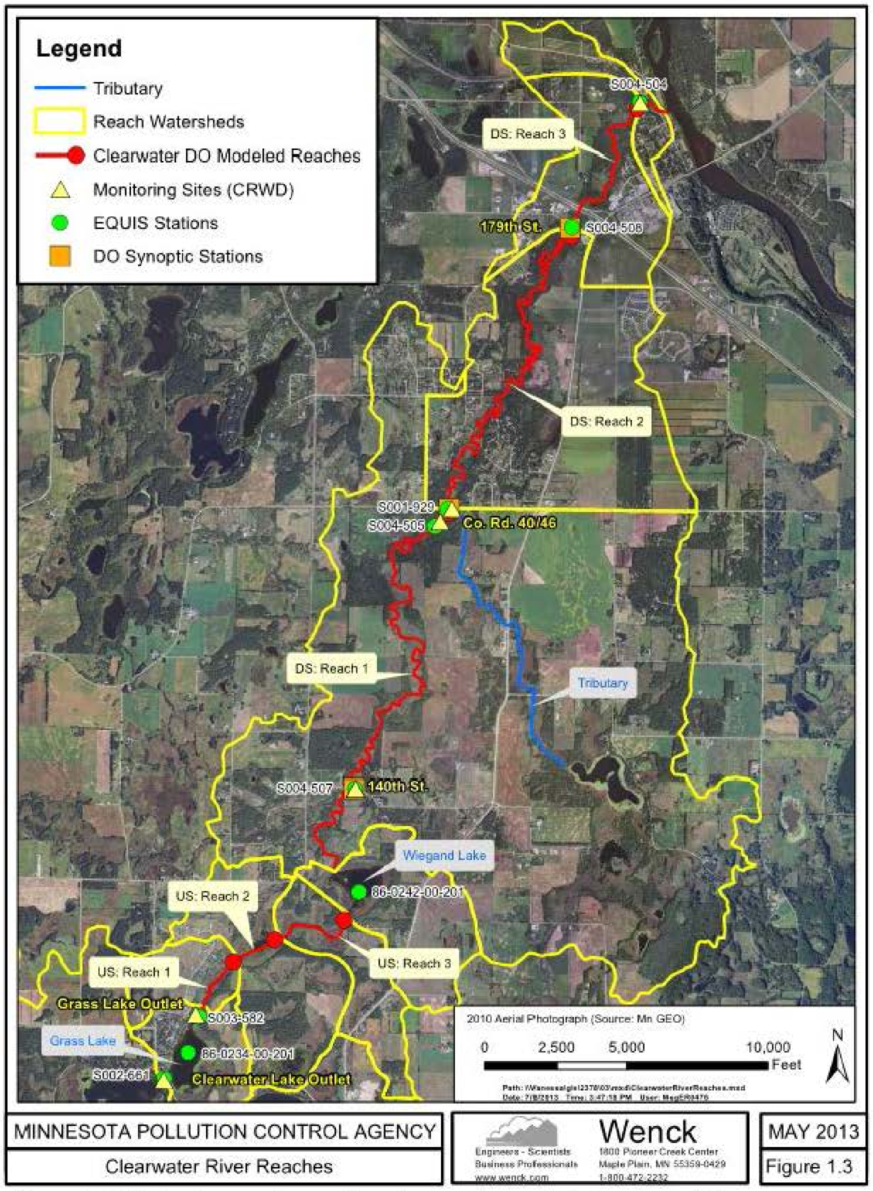

Figure 1.3 Monitoring stations and reaches on the modeled section of Clearwater River

2.0 MODEL CONFIGURATION

The DO analysis was broken down into two models; an upstream and downstream model. Each model includes one main stem reach extending from a lake outlet (Figure 1.3, Table 2.1) with the each corresponding lake serving as its headwater. Each model is then broken into three reaches which align with changes in stream morphometry or a water quality sampling site.

Table 2.1 Clearwater River QUAL2K modeled reaches

Model	Reach	Description	US River (km)	DS River (km)	Distance (km)	US Elevation (m)	DS Elevation (m)	Slope (m/m)
Upstream	HW	Grass Lake	US model headwaters					
	1	Outlet of Grass Lake to Upstream end of wide spot	2.3	1.5	0.8	No apparent elevation changes were visible in LiDAR data. The slopes were developed and adjusted based on time of travel (dye study).		0.000010
	2	Length of wide spot south of Wiegand Lake	1.5	1.0	0.5			0.000005
	3	Downstream end of wide spot to Wiegand Lake	1.0	0.0	1.0			0.000010
Downstream	HW	Wiegand Lake	DS model headwaters					
	1	Outlet of Wiegand Lake to Co. Rd. 40/46	15.5	8.6	6.9	297.7	296.9	0.00133
	2	Co. Rd. 40/46 to 179th St.	8.6	2.3	6.3	296.9	292.0	0.00067
	3	179th St. to Mississippi River	2.3	0.0	2.3	292.0	289.6	0.00028

State variables in the QUAL2K model include DO, CBOD nitrogen series and phosphorous. Model processes include CBOD decay nitrification, algae photosynthesis/respiration, and sediment oxygen demand (SOD). Model inputs include flow rates and concentrations from non-point sources, headwater inflows, and tributaries.

The model was calibrated to DO data collected on the downstream stem of Clearwater River between 6/29/11 and 8/30/11. The model simulated the flow on 7/22/2011 where synoptic data and high flow conditions were observed.

First, a single model was calibrated to match a dye study from July 18, 2007. Then, observed hydraulic data from July 22, 2011 and headwater water quality data was used to model high flow, DO impaired scenarios (i.e. the critical condition, which in this case is high flow) in the upstream and downstream sections of the river. Last, kinetic coefficients were adjusted and calibrated to match the observed, low DO synoptic data.

Reaeration was prescribed using the Tsivoglou-Neal reaeration model. This model uses channel slope and velocity to calculate reaeration in each reach. Average channel slopes were based on Minnesota DNR Light Detection and Ranging (LiDAR) data, where available. The LiDAR data showed channel slopes in the upstream model to be essentially flat, so channel slopes in the upstream model were calculated based on LiDAR and then adjusted to match dye study results. LiDAR data was used to determine channel slopes in the downstream model. Figure 2.1 shows the slope and elevation of downstream model reaches. Manning's equation was used to calculate velocity (see Section 3.0).

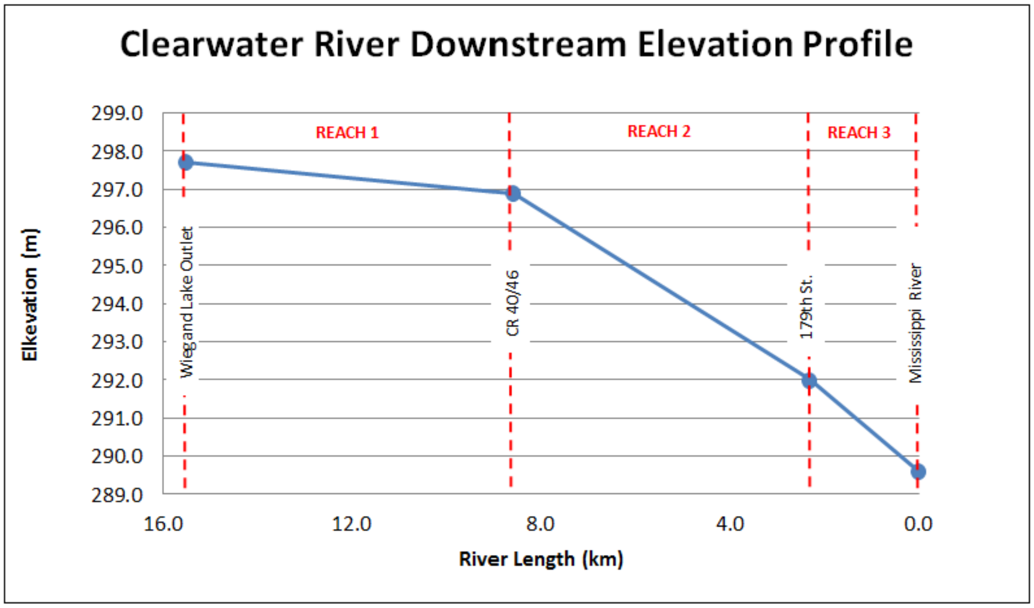

Figure 2.1 MN LiDAR elevations used to estimate reach slopes for Clearwater River Downstream model

3.0 MODEL INPUTS

3.1 Hydraulics

Manning's Equation was used to model the hydraulics of Clearwater River. The model assumes steady flow conditions in each reach and uses the following Manning's Equation to model the flow in each reach:

$$Q = \frac{S_0^{1/2}}{n} \cdot \frac{A_c^{5/3}}{P^{2/3}},$$

Where Q is the flow, S_0 is the bottom slope, n is the Manning roughness coefficient, A_c is the cross-sectional area, and P is the wetted perimeter.

For the QUAL2K model, the necessary inputs for Manning's equation are slide slopes (z_1 and z_2), bottom width (W_b), channel slope (S_0), and roughness coefficient (n). The side slopes and width are used to calculate the wetted perimeter (P) and cross-sectional area (A_c) in the equation above.

The channel slope for each reach is shown in Figure 2.1 and Table 2.1, while the side slopes and bottom width are shown in Table 3.1. The bottom width and side slopes were calculated by approximating a trapezoidal channel to match cross-sectional survey data from each of the model's downstream reaches. The cross-section survey data and trapezoidal channel dimensions for the downstream reaches 1-3 are shown in Figure 3.1. Cross section data for the upstream portion of Clearwater River was available at river km 16.8 near the Grass lake outlet. The river km 16.8 tape-down cross-section data was used to approximate a trapezoid for all upstream reaches. The widths of the upstream reaches were calculated based on aerial photography. The cross-sectional survey data and trapezoidal channel dimensions for the upstream reaches is shown in Figure 3.1. Table 3.1 shows the width and side slopes used for the Manning formula inputs.

Table 3.1 Manning Formula Inputs and Assumptions

Model	Reach	n	W_0 (m)	Side slope (Z_1)	Side slope (Z_2)
Upstream[2]	1	0.05[1]	12.6	2.6	7.3
	2	0.05	128.0	2.6	7.3
	3	0.05	11.2	2.6	7.3
Downstream	1	0.05	2.4	17.5	18.8
	2	0.05	11.6	4.7	1.3
	3	0.05	3.7	1.4	3.4

[1] Roughness values were adjusted to calibrate time of travel and are based on literature values (Mays, 2005)

[2] Side slopes of all Upstream are assumed based on the side slopes for reach 5 since no survey data was available

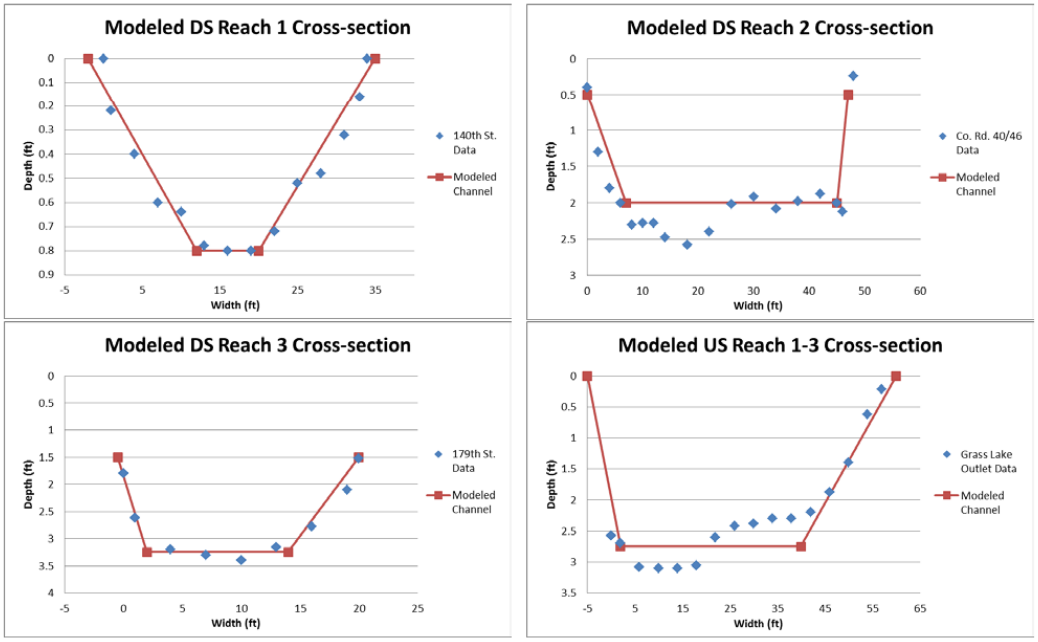

Figure 3.1 Reach cross-section tape-down data and trapezoidal channel approximation for downstream reach.

Continuous flow data for Clearwater River was collected at the Grass Lake between 6-20-2011 and 8-10-2011.

Table 3.2 Flow data from Clearwater Lake Outlet

Date	Time	Flow (cfs)
6/20/2011	1:00PM	270
6/24/2011	11:00AM	308
6/27/2011	4:00PM	332
7/2/2011	1:00PM	332
7/7/2011	12:00PM	339
7/13/2011	6:00PM	339
7/14/2011	8:00AM	339
7/22/2011	**9:30AM**	**570**
8/5/2011	7:10AM	512
8/8/2011	10:50AM	521

8/10/2011	7:00AM	518

Violation of the DO standards were observed in high flow conditions, as such, the high flow condition observed on 7/22/2011 was modeled as the critical condition for the DO impairment. Diffuse inflow represents groundwater and overland flow in all reaches, one discrete input represents a major tributary which enters Clearwater River at the beginning of the DS Reach 2 (Figure 1.3).

Both the diffuse source inflow and the discrete inflow were calculated based on a unit area flow derived from flow data collected at the Clearwater River outlet. The modeled section was assumed to be a gaining reach in terms of groundwater based on longitudinal flow data, and on regional shallow groundwater data, Upper Watershed TMDL Studies for CRWD [CRWD, 2009]. The drainage areas for each reach and the two lakes (Grass and Wiegand) are shown in Table 3.3 and Figure 1.2.

Table 3.3 Modeled inflows for Clearwater River on 7/22/2011

Reach	US km	DS km	Flow (cfs)	Flow (m^3/s)	Inflow[3] (m^3/s)	Drainage (ac)	Drainage Area Fraction[1]	Flow Type[2]
Upstream	Clearwater Lake		**570.0**	16.1		102,614	0.915	Diffuse
Lake	Grass Lake		571.9	16.2	0.05	342	0.003	Diffuse
US Reach 1	2.3	1.5	573.0	16.2	0.03	208	0.002	Diffuse
US Reach 2	1.5	1.0	576.3	16.3	0.09	581	0.005	Diffuse
US Reach 3	1.0	0.0	578.1	16.4	0.05	331	0.003	Diffuse
Lake	Grass Lake		**580.7**	16.4	0.07	479	0.004	Diffuse
DS Reach 1	15.5	8.6	593.1	16.8	0.35	2,267	0.020	Diffuse
DS Reach 2	N/A	8.6	609.3	17.2	0.46	3,006	0.027	Discrete
DS Reach 2	8.6	2.3	617.3	17.5	0.23	1,470	0.013	Diffuse
DS Reach 3	2.3	0.0	621.7	17.6	0.12	791	0.007	Diffuse
					Total	112,089		

[1] The fraction of total drainage area represents the entire drainage area to the outlet of the reach or lake (including the drainage area of the headwater) compared to the Total Drainage area (112,089 ac).

[2] The discrete source to Reach 2 is the tributary that enters stream at km 8.6. All other reaches were modeled as diffuse flow.

[3] The inflow for each reach was calculated by subtracting the flow from the preceding reach (or head water) from the total flow for each reach.

To calibrate channel hydraulics, a second flow scenario was modeled to match flow and time of travel based on dye studies conducted 7/17/2007-7/19/2007. Table 3.4 shows the results and flows of the dye study from and Figure 3.2 shows the travel time calibration.

Table 3.4 Dye Study Results used for Time of Travel calibration

	Site	Dye Dump Time	Dye Peak Time	Time of Travel (hours)	Total Time of Travel (days)	Gauged Flow (cfs)
Dye Dump #1	Grass Lake Outlet	7/17/2007 12:20	--	--	0.00	11.75
	140th St.	--	7/19/2007 18:00	53.7	2.24	12.53
Dye Dump #2	140th St.	7/17/2007 11:00	--	--		12.53
	Co. Rd. 40/46	--	7/18/2007 2:00	15.0	2.87	11.34
	Dam @ Co. Rd. 75	--	7/18/2007 21:00	34.0	3.66	13.84

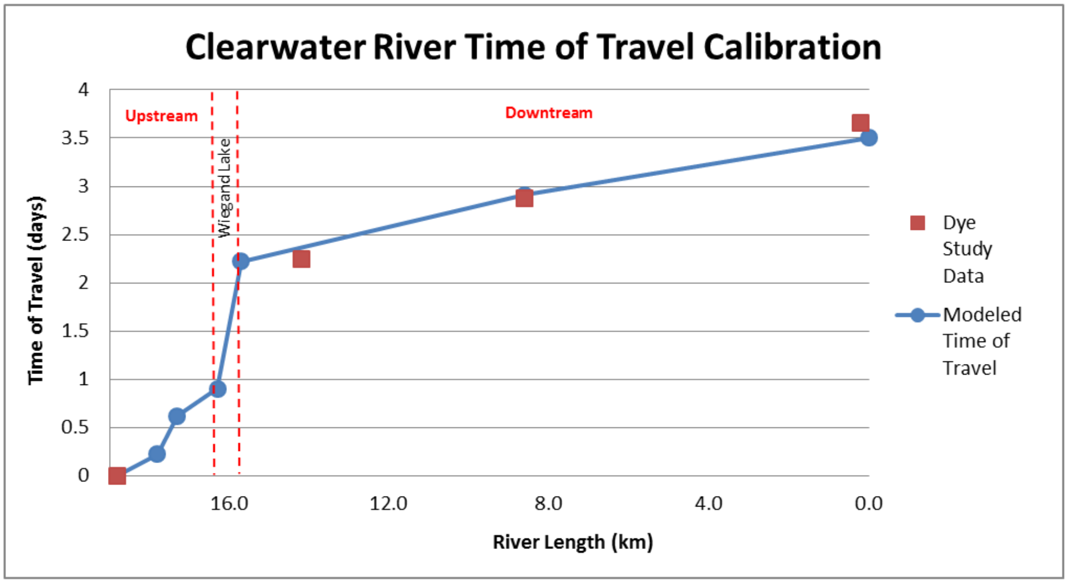

Figure 3.3 Clearwater River Travel Time Calibration

To calibrate the travel time, flow through Wiegand Lake had to be modeled. The adjustments that were made to the Manning Equation inputs (Table 3.1) to calibrate the time of travel were the slopes of the upstream reaches and the roughness value (n) of the downstream reaches. The roughness value was adjusted to 0.05 from 0.04 in order to matched observed travel time. The roughness values were adjusted within literary values (Mays, 2005).

3.2 Water Quality Inputs

3.2.1 Headwaters:

Grass Lake represents the upstream boundary for the Upstream DO model and Wiegand Lake represents the upstream boundary for the Downstream DO model. Historically, the CRWD has monitored a site at Wiegand Lake (86-0242-00-201), Grass Lake (86-0234-201), the outlet of Grass Lake (S003-582), and the outlet of Clearwater Lake (S002-661). These stations, along with additional data collected by CRWD from 2009-2011, was used to populate headwater conditions in the QUAL2K models. If data was unavailable for certain parameters in Wiegand Lake, values from 140th St. (S004-507) or Grass Lake were used. Tables 3.5 and 3.6 list the values for each headwater parameter modeled and the justification for each value.

Table 3.5 Modeled headwater parameters for the Downstream model from Wiegand Lake

Parameter	Input/Value	Justification
Temp (C)	21.68	Average of 3 grab samples between 06/18/2009 - 08/03/2009 at Wiegand Lake
Sp. Cond (umhos)	343	Average of 3 grab samples from July, 2007 at Grass Lake Outlet
DO (mg/L)	5.44	Downstream value from Upstream DO model Results (see *Section 3.2.6*)
CBOD	12	Average of 3 grab samples from July, 2007 at Grass Lake Outlet
Organic- N (µg/L)	840	Average TKN of 4 grabs from Wiegand Lake from 2009: TKN = 1,000 µg/L Org. N = TKN - NH4 = 1,000 - 160 = 840 ug/L
Ammonia (µg/L)	160	Average of 11 grabs from 140th St. (S004-507) from 2007
Nitrate (µg/L)	909	Average of 3 grabs during the summer months of 2005 in Weigand Lake.
Organic-P (µg/L)	13.9	Average of 7 TP grabs during the summer months from 2002-2009 in Wiegand Lake; TP = 25.7 µg/L Org. P = TP - OrthoP = 25.7 – 11.8 = 13.9 µg/L
Inorganic-P (µg/L)	11.8	Average of 7 grabs during the summer months from 2002-2009 in Wiegand Lake: Orthophosphate = 11.8 µg/L
Phytoplankton (µg/L)[2]	3.28	Average of 7 grabs during the summer months from 2002-2009 in Wiegand Lake.
pH	8.1	Average of 7 grabs during the summer months from 2002-2009 in Wiegand Lake.

Table 3.6 Modeled headwater parameters for the Upstream Model from Grass Lake

Parameter	Input/Value	Justification
Temp (C)	27.9	Grab taken on 7/21/2011 in Grass Lake
Sp. Cond (umhos)	343	Average of 3 grab samples from July, 2007 at Grass Lake Outlet
DO (mg/L)	7.79	Grab taken on 7/21/2011 in Grass Lake
CBOD	12	Average of 3 grab samples from July, 2007 at Grass Lake Outlet
Organic- N (µg/L)	840	Average TKN of 4 grabs from Weigand Lake from 2009: TKN = 1,000 µg/L Org. N = TKN - NH4 = 1,000-160 = 840 µg/L
Ammonia (µg/L)	160	Average of 2 grabs from July 2008 and 2009 in Grass Lake.
Nitrate (µg/L)	200	Grab taken on 7/29/2011 in Grass Lake.
Organic-P (µg/L)	21	Grab taken on 7/21/2011 in Grass Lake: TP = 144 µg/L Org. P = TP - OrthoP = 144 - 123 = 21 µg/L
Inorganic-P (µg/L)	123	Grab taken on 7/21/2011 in Grass Lake: Orthophosphate = 123 µg/L
Phytoplankton (µg/L)[2]	4.7	Average of 2 grabs from July 2008 and 2009 in Grass Lake.
pH	8.6	Average of 2 grabs from July 2008 and 2009 in Grass Lake.

3.2.2 Discrete Inflow:

One discrete inflow simulates a major tributary in the Downstream model and no discrete inflows were modeled in the Upstream model, as shown in Figure 1.3. The flow rate of the discrete inflow entering the main stem is 2% of the total flow. Table 3.7 lists the water quality model inputs for the tributary. The water quality inputs were derived from typical Minnesota water quality values for the North Central Hardwood Forest Region (MPCA, 2010).

Table 3.7 Modeled Tributary water quality values

Parameter	Typical MN Stream Water Quality Values for the North Central Hardwood Forest Region[1]	Modeled Tributary Water Quality Values
Temp (C)	2-21	21
BOD (mg/L)	1.5-3.3	2.0
Nitrate (µg/L)	40-260	260
Organic-P (µg/L)	23-50	40
Inorganic-P (µg/L)	23-50	40
pH	7.9-8.3	8.1

[1] MPCA, 2010

3.2.3 Groundwater:

Headwater flow constitutes 92% of the flow in the impaired reach as shown in hydrograph in Table 3.3. The relative contribution from overland flow from the direct watershed is 2% of the total flow in the upstream model and 4% of the flow in the downstream model. Due to the small contribution of overland flow from the direct watershed, diffuse inflows of the reaches represent both groundwater and diffuse overland flow from the direct watershed. The groundwater for the upstream and downstream model was defined using typical groundwater values for the Upper Mississippi River (MPCA, 1999). Table 3.8 lists the parameters used to model the groundwater diffuse sources.

Table 3.8 Modeled Groundwater water quality values

Parameter	Typical MN Groundwater Values[1]
Temp (C)	9.0
Sp. Cond (umhos)	490
DO (mg/L)	3.0
Nitrate (µg/L)	5.0
Organic-P (µg/L)	69.0
Inorganic-P (µg/L)	69.0

[1] These values represent typical groundwater values for the Upper Mississippi River (MPCA, 1999)

3.2.4 Point Sources:

There are no point sources to the impaired section of Clearwater River, and therefore no point sources are represented in the model.

3.2.5 Non-Point Sources:

As discussed previously, watershed loads are represented by diffuse and tributary flows along the main stem of Clearwater River. Groundwater chemistry was used to represent modeled diffuse sources since headwaters flow comprises 92% of the total flow, and groundwater comprises 6% of the remaining flow in the Upstream model and 4% in the downstream model. Typical low DO concentration observed in the groundwater results in conservative DO TMDL.

3.2.6 Dissolved Oxygen

DO values measured at the Grass Lake Outlet on 7/21/2011 were used to model the DO in the Upstream model headwaters. The DO at the Grass Lake Outlet was 7.79 mg/L at 10:00 am. The upstream model predicted that the DO would decrease from 7.79 to 5.44 mg/L by the time it reaches Wiegand Lake. Figure 3.4 shows the modeled DO from the Upstream model. No recorded DO was available during the summer months of 2011 to compare the Upstream model.

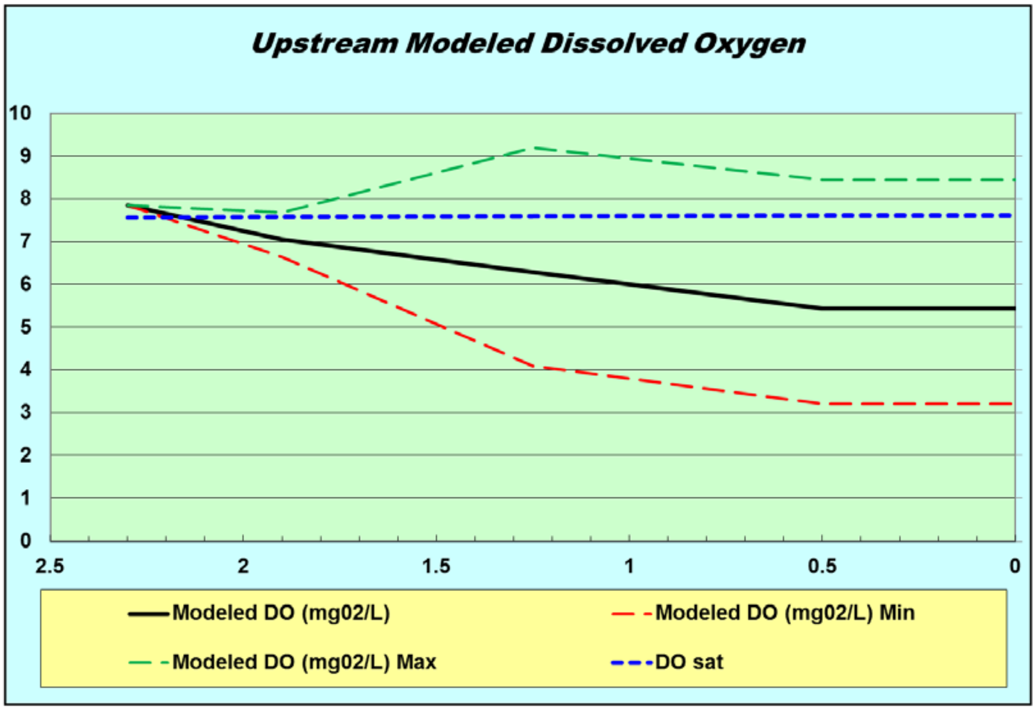

Figure 3.4 Model-predicted (Modeled) DO concentrations for the Upstream model of Clearwater River

Due to the results of the dye study and the preliminary results from the Downstream model, the downstream DO (5.44 mg/L) was used as the headwater DO in the downstream model. The dye study and preliminary results showed that the stream is short circuiting Wiegand Lake and that the streamflow is not fully mixing with the lake. Figure 3.5 shows the flow path through Wiegand Lake.

Figure 3.5 Clearwater River short-circuiting Wiegand Lake

3.2.7 Carbonaceous Biochemical Oxygen Demand (CBOD):

5-day CBOD samples were collected at the Grass Lake (Site S003-582) during the month of July, 2007. All samples were CBOD-5 measurements. These CBOD-5 measurements were used to represent the breakdown of organic carbon in the model since ultimate BOD has never been monitored and since CBOD remains relatively constant after five days (Thomann & Mueller 1987).

3.3 Weather and Physical Processes

Hourly weather measurements of temperature, cloud cover, relative humidity and wind speed were downloaded from the National Weather Service (NWS) NOAA St. Cloud, MN Airport. Channel canopy coverage was estimated based on 2010 air photos in GIS (Table 3.9).

Table 3.9 Clearwater River canopy cover per reach

Model	Reach	Description	Canopy coverage (%)
Upstream	1	Outlet of Grass Lake to Upstream end of wide spot	0
	2	Length of wide spot south of Wiegand Lake	0
	3	Downstream end of wide spot to Wiegand Lake	0
Downstream	1	Outlet of Wiegand Lake to Co. Rd. 40/46	10
	2	Co. Rd. 40/46 to 179th St.	30
	3	179th St. to Mississippi River	40

3.4 Sediment Oxygen Demand

Sediment oxygen demand (SOD) is calculated in QUAL2K based on the delivery and breakdown of particulate organic matter from the water column. Currently, the model does not have a macrophyte or riparian vegetation SOD component, nor does it incorporate any upland sediment transported and deposited during non-steady state storms events. The model does allow the user to prescribe SOD to specific reaches that is added to the model predicted rate to account for SOD outside the modeling framework. SOD in streams varies depending on sediment type but is typically between 0.05 (mineral soils) and 2.00 (estuarine mud) g O_2/m^2/day (Thomann and Mueller, 1987).

Model predicted DO concentrations for the hydraulic/phytoplankton/bottom algae/nutrient calibrated model were slightly higher than observed in Reach 1 where the slope is much lower (see Figure2.1). Therefore, SOD were assigned to Reach 1 to lower mean oxygen concentrations to match observed values (Table 3.10).

Table 3.10 Reach specific SOD and bottom algae coverage for the Downstream Model

Reach	**SOD** g O_2/m^2/day	**Bottom Algae Coverage** (%)	**Justification**
1	2.00	30	Some vegetation and SOD prescribed due to long residence time
2	0.00	40	Some vegetation and no SOD prescribed due to short residence time and data
3	0.00	50	Some vegetation and no SOD prescribed due to short residence time and data

3.5 General Kinetic Rates

Kinetic rates used in the model are shown in Table 3.13.

Table 3.13 QUAL2K kinetic rate settings and adjustments

Rate	Default Rate	Calibrated Rate	Literature Range	Citation/Study Area
Reaeration Model	Tsivoglou and Neal	User Specified	Thomann and Mueller, 1987 cite that Tsivoglou and Neal, 1976; is accurate for streams 10 < CFS < 300	
Fast CBOD oxidation rate (day^{-1})	0.20	0.60	0.02 – 0.60	Bowie et al., 1985 Table 3-17 p152 Kansas (6 rivers) Michigan (3 rivers) reported by Bansal, 1975
Organic-N Hydrolysis (day^{-1}) *The release of ammonia due to decay of organic nitrogen*	0.30	0.4	0.1 – 0.4	Baca et al., 1973
Organic-N Settling Velocity (m/d)	0.05	0.10	influenced by a material's size, shape, and density and the speed of water	
Organic-P Hydrolosis (day^{-1}) *The release of phosphate due to decay of organic phosphorus*	0.30	0.40	0.02 – 0.80	Bowie et al., 1985 Table 5-5 p266 Jorgenson, 1976 Bowie et al., 1980
Organic-P Settling Velocity (m/d)	0.05	0.10	influenced by a material's size, shape, and density and the speed of water	
Inorganic-P settling (m/d)	0.01	0.10	influenced by a material's size, shape, and density and the speed of water	
Phytoplankton Settling (m/d)	0.25	1.00	0 – 2	Bowie et al., 1985 Table 6-19 p352 Chen & Orlob, 1975 and Smith, 1978

4.0 MODEL CALIBRATION

Following the hydrologic calibration, CBOD, temperature, specific conductivity, and all forms of nitrogen and phosphorus were calibrated by adjusting water quality parameters within the range of observed values. The model performed well in predicting temperature, CBOD, organic nitrogen, organic phosphorus, and other water quality parameters. The model performs well in predicting diurnal average minimum and maximum DO concentrations at the three locations where DO was continuously measured (Figure 4.1).

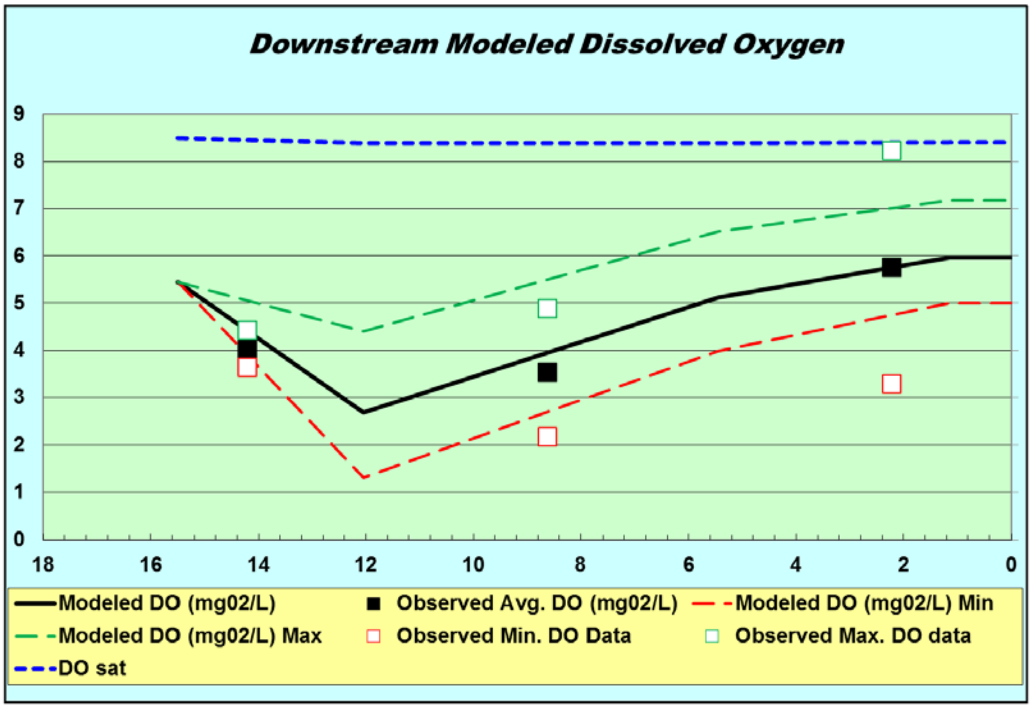

Figure 4.1 Model-predicted (Modeled) and Observed DO concentrations for the Downstream Clearwater River Model

5.0 SENSITIVITY

To evaluate the sensitivity of model predicted DO to changes in model variables, seven kinetic rates (Table 5.1), two reach specific rates (Table 5.2), and channel slopes (Table 5.3) were removed or adjusted by specific percentages. The following tables summarize the affect these changes have on the average model-predicted DO concentration for the entire modeled stretch of the Clearwater River. Results show DO throughout the system is most sensitive to the breakdown of organic carbon (CBOD) and organic nitrogen (organic-N hydrolosis), as well as prescribed SOD settings in Reach 1. Phosphorus reactions appear to have very little effect on dissolved oxygen throughout this stretch of the Clearwater River. This exercise suggests sediment processes likely play a large role over water column processes in consuming DO during this particular calibration/sampling event.

Table 5.1 DO sensitivity to kinetic rates

Kinetic rate	+25%	-25%	Default
$CBOD_u$ oxidation rate (day^{-1})	-2.6%	3.0%	9.1%
Organic-N Hydrolosis (day^{-1})	-0.4%	0.6%	0.6%
Organic-N Settling (m/d)	0.0%	0.2%	0.2%
Organic-P Hydrolosis (day^{-1})	0.0%	0.0%	0.0%
Organic-P Settling (m/d)	0.0%	0.2%	0.2%
Inorganic-P Settling (m/d)	0.0%	0.0%	0.0%
Phytoplankton Settling (m/d)	0.0%	0.0%	0.2%

Table 5.2 DO sensitivity to reach rates

Action	DO Sensitivity
Remove prescribed SOD in all reaches	4.37%
Remove all SOD by setting SOD channel coverage to 0%	10.34%

Table 5.3 DO sensitivity to channel slope

Channel Slope	DO Sensitivity
Increased by 25%	5.17%
Decreased by 25%	-5.96%

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APPENDIX F – DO TMDL ALLOWABLE LOAD CALCULATIONS TECHNICAL MEMOS

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TECHNICAL MEMORANDUM

TO: Tiffany Determan, Sherburne Soil and Water Conservation District (SCWD)

FROM: Rebecca Kluckhohn, PE, Wenck Associates, Inc.
Erik Megow, Wenck Associates, Inc.

DATE: November 12, 2013

SUBJECT: TMDL Allowable Load Calculations for Dissolved Oxygen (DO) limited reaches of Battle Brook, Rice Creek, and Clearwater River

CC: Phil Votruba, Minnesota Pollution Control Agency (MPCA)

Introduction

This technical memorandum describes the TMDL calculations for DO-limited reaches of Battle Brook, Rice Creek, and Clearwater River. The DO-limited reaches of these streams are as follows:

- **Battle Brook:** From County Road 42 to Elk Lake (AUID 07010203-535),
- **Rice Creek**: From the outlet of Rice Lake and its confluence with Elk River (AUID 07010203-512),
- **Clearwater River:** From the outlet of Clearwater Lake and the dam at the Mississippi River (AUID 07010203-511).

For each of these streams, there was at least one DO violation measured during each of the critical flow synoptic survey sampling events. DO violations are captured by the calibrated QUAL2K models for each system. Headwaters, diffuse sources, tributaries, and in-stream sources (sediment fluxes and algae production) are modeled in each of the impaired streams.

The numerical TMDL is the sum of the load allocation (LA), waste load allocation (WLA), Reserve Capacity (RC) and margin of safety (MOS). The TMDL for each impaired stream was written using the critical-flow condition from the calibrated model to solve the TMDL equation for a numeric dissolved oxygen target of 5.0 mg/L (daily minimum).

Margin of Safety is implicitly defined in each of the cases and is described for each section. Reserve capacity is not explicitly enumerated for the following reason: the dominant land use tributary to each listed reach is agricultural. Development or conversion of agricultural lands to residential (high or low density) would likely come with a reduction in CBOD and NBOD and an increase in flows, which should improve aeration by increasing velocity. For this reason, reserve capacity is essentially negative in that any planned developments should reduce loads that impact dissolved oxygen.

Oxygen Deficit Terms

Dissolved oxygen is consumed both in the water column and at the sediment interface. For water quality samples, oxygen demand is typically expressed as a concentration in terms of the mass of oxygen consumed per liter of water (mg-O_2/L). For this TMDL, oxygen demand will be expressed throughout the entire impaired reach/stream as mass of oxygen-demanding substances available per day.

Carbonaceous biochemical oxygen demand (CBOD) represents the oxygen equivalent (amount of oxygen that microorganisms require to breakdown and convert organic carbon to CO_2) of the carbonaceous organic matter in a sample.

A second source is nitrogenous biochemical oxygen demand (NBOD). A wide variety of micro-organisms rapidly transform organic nitrogen (ON) to ammonia nitrogen (NH_3-N). Bacteria then transform NH_3-N to nitrate through an oxygen consuming process called nitrification. For this TMDL, NBOD was calculated by multiplying the sum of organic nitrogen and ammonia nitrogen by 4.33. The factor 4.33 is the stoichiometric ratio (mass basis) of oxygen demand to nitrogen that is used in the QUAL-2K modeling and TMDL calculations.

Finally, sediment oxygen demand (SOD) is the aerobic decay of organic materials in stream bed sediments and in peat soils in wetlands. SOD rates are defined in units of oxygen used per surface area per day (g-O_2/m^2/day). QUAL2K predicts SOD by calculating the delivery and breakdown of particulate organic matter from the water column. There are two sources of SOD – model-predicted and additional SOD prescribed by the modeler. Prescribed SOD was necessary in model reaches to adequately calibrate the model to observed data. Prescribed SOD represents additional SOD generated by contact with riparian wetlands when flushing rates are low. SOD rates are defined in units of oxygen used per surface area per day (g-O_2/m^2/day).

Existing Loads

The existing loads to each of the streams under the modeled critical flow conditions were determined and are tabulated in terms of C-BOD, N-BOD, and SOD in Table 1. Table 1 does not list any waste loads as no NPDES wastewater discharges or stormwater loads are located in the watersheds of these reaches nor were they modeled in the DO-violation scenarios.

Table 1. Existing daily oxygen demand loads during critical flow conditions

Stream	Loads	CBOD (lbs/day)	NBOD (lbs/day)	SOD (lbs/day)
Battle Brook	Headwater Watershed	4	20	--
	Diffuse & Tributary	9	115	--
	SOD	--	--	105
	Total	**13**	**135**	**105**
Rice Creek	Headwater Watershed	626	1,290	--
	Diffuse & Tributary	79	419	--
	SOD	--	--	847
	Total	**705**	**1,709**	**847**
Clearwater River	Headwater Watershed	37,571	13,557	--
	Diffuse & Tributary	87	0	--
	SOD	--	--	721
	Total	**37,658**	**13,557**	**721**

Assimilative Load Capacity

For dissolved oxygen TMDLs, the loading capacity is the maximum allowable oxygen demand (CBOD+NBOD+SOD) the stream can withstand and still meet water quality standards. To determine this number, SOD rates and loading from headwaters and/or tributary/diffuse sources are reduced until model-predicted minimum daily DO in each reach remains above the 5.0 mg/L standard. Following is the assimilative load capacity determination for the three streams.

Battle Brook

Reaching the DO standard in this section of Battle Brook will require both load reductions from headwater, direct watershed and in stream sources as well as morphometric modification or aeration. Modeled scenarios show that 80% reductions in both watershed and SOD load alone are not sufficient to achieve dissolved oxygen concentrations above the daily minimum of 5.0 mg/L at the critical location (Table 2).

Table 2. Battle Brook (AUID 07010203-535) load reduction scenarios

Modeled Reduction	**DO at CR9 for Each Scenario**	
	Watershed Load Reduction	**WS + SOD Load Reduction**
No Reduction	Measured: 0.72 mg/L DO Modeled: 1.01 mg/L DO	Modeled: 1.38 mg/L DO
20% Reduction	Modeled: 1.13 mg/L DO	Modeled: 2.18 mg/L DO
40% Reduction	Modeled: 1.24 mg/L DO	Modeled: 2.85 mg/L DO
60% Reduction	Modeled: 1.28 mg/L DO	Modeled: 3.44 mg/L DO
80% Reduction	Modeled: 1.38 mg/L DO	Modeled: 3.57 mg/L DO

Improvements in headwater DO concentrations were then modeled to determine the required improvement to meet standards. Table 3 shows that an improvement of 110% is necessary to achieve standards in addition the 80% SOD and watershed load reductions. Since this is likely not achievable, additional scenarios were considered.

Table 3. Battle Brook (AUID 07010203-535) DO increase scenarios with 80% load reductions

Headwater DO Increase	DO at CR9 for Each Scenario
	DO Increase with 80% WS & SOD Reduction
No Increase	Modeled: 3.57 mg/L DO
20% Increase	Modeled: 3.83 mg/L DO
40% Increase	Modeled: 4.10 mg/L DO
60% Increase	Modeled: 4.35 mg/L DO
80% Increase	Modeled: 4.66 mg/L DO
100% Increase	Modeled: 4.95 mg/L DO
110% Increase	Modeled: 5.22 mg/L DO

Morphometric alteration to the stream or aeration is required in Battle Brook to meet DO standards. The last scenarios investigated were based on changes in channel morphometry. The scenarios in Table 4 list the modeled DO results if a low flow channel of various widths were to be constructed within this wide, slow-moving reach of Battle Brook. Again, these results in Table 4 show how an 80% reduction of watershed and SOD loads, along with a change in channel morphometry will affect the DO at the critical point, CR9.

Table 4. Battle Brook (AUID 07010203-535) channel width scenarios with 80% load reductions

Bottom Width (ft)	Normal Depth (ft)	Modeled DO at CR9 (mg/L)
14 (Existing)	0.77	**3.57**
7	1.12	**4.43**
5	1.31	**4.79**
2	1.74	**5.25**

The results of Table 4 show that the minimum daily concentration of 5.0 mg/L can be met if both an 80% reduction of watershed and SOD loads were implemented with a low flow channel of 2 feet in width. As such, the assimilative capacity was determined to be a simultaneous 80% reduction of watershed loads and SOD load along with a change in channel morphometry such that it meets state nutrient standards (Table 5)

Table 5. Battle Brook (AUID 07010203-535) assimilative capacity (includes MOS)

	CBOD (lbs/day)	NBOD (lbs/day)	SOD (lbs/day)
Headwater Watershed	0.7	4.0	--
Tributary Watershed	1.9	36.9	--
SOD	--	--	21.1
Headwater DO	--	--	--
Total	**2.6**	**40.9**	**21.1**

Rice Creek

Reaching the DO standard in Rice Creek will require both load reductions from watershed and in stream sources as well as an improvement in headwater conditions. DO in the modeled upstream boundary condition, Rice Lake, was between 3.2 and 5.4 mg/L, equivalent to the upstream-most reading collected in the system.

This concentration was adjusted upwards to 7.6 mg/L to represent Rice Lake water quality meeting state nutrient standards. This concentration, 7.6 mg/ L is the average July DO from nearby Lake Julia between 2002 and 2012. Lake Julia was chosen to represent Rice Lake in an improved condition because it is similar in size, landuse and drainage area and is located within 3 miles of Rice Lake- the closest data available. This represents and conservative assumption for achievable load reductions given that Lake Julia is currently impaired. No data is available for Rice Lake currently, as additional data is collected and the TMDL reduction scenarios are implemented, this assumption should be re-evaluated.

With the new headwater DO concentration representing an improvement in Rice Lake water quality, additional watershed and in-stream load reductions scenarios were evaluated. First, watershed C-BOD and N-BOD were simultaneously reduced by 20%, 40%, 60%, and 80%. When it was evident that watershed load reduction alone was not going to increase the DO to acceptable levels, 4 more scenarios were created where both the watershed loads (C-BOD and N-BOD) and the SOD was reduced by 20%, 40%, 60%, and 80%. The resulting modeled DO concentrations at the critical location, County Road (CR) 16 were then compared to the standard and are tabulated in Table 6.

Table 6. Rice Creek (AUID 07010203-512) load reduction scenarios

Reduction Scenarios	Lowest Modeled DO (mg/L)	
	C-BOD and N-BOD	C-BOD, N-BOD, & SOD
No Reduction	2.08	2.08
20% Reduction	2.29	2.72
40% Reduction	2.50	3.35
60% Reduction	2.71	4.40
80% Reduction	2.92	5.55

The lowest in-stream DO concentration recorded was 0.35 mg/L at CR 16. The lowest modeled DO was 0.72 mg/L, also at CR 16. Using the Lake Julia DO of 7.6 mg/L as the headwaters concentration, rather than the upstream hourly DO of between 3.2 and 5.4mg/L, the lowest modeled DO in the TMDL model is 1.50 mg/L at CR 16.

To account for diurnal DO variations in determining assimilative capacity, headwater watershed load reductions were made until DO a concentration at the critical location (CR 16) met or was better than the 5mg/L standard. While modeling shows that reducing only the watershed load produces a DO concentration over 5 mg/L in the critical reach, the relative difference between model results and the state standard is within the uncertainty of the model and data collection efforts. As such, the assimilative capacity was determined to be a simultaneous 80% reduction of watershed loads and SOD load along with improvement to the headwater water quality such that it meets state nutrient standards to provide an implicit Margin of Safety (Table 7).

Table 7. Rice Creek (AUID 07010203-512) assimilative capacity (includes MOS)

Load	CBOD (lbs/day)	NBOD (lbs/day)	SOD (lbs/day)
Headwater Watershed	125	258	--
Tributary Watershed	16	84	--
SOD	--	--	169
Total	**141**	**342**	**169**

Clearwater River

The Clearwater River is modeled in two reaches broken by Wiegand Lake. The calibrated downstream DO model uses the outlet of the upstream model as the headwater condition, instead of measured concentrations in Weigand Lake. This model construct assumes that the river short-circuits Weigand Lake, especially in critical condition high flows, instead of mixing well. This assumption is supported by the data available.

To achieve the state standard, the headwater DO needs to be improved in the critical condition. This can be done physically by installing a structure to mix the Clearwater River with Weigand Lake. The impacts to Weigand Lake, a high quality lake should be considered. Aeration structures are also possible.

To simulate the TMDL scenario, this mixing was modeled by using the lowest DO recorded in Weigand Lake during the summer months since 2009, The DO of 7.8 mg/ L, as the headwater condition. Typically, DO in Weigand Lake will be higher as the critical condition is high flow, therefore the model is conservative.

With the new headwater DO, reductions scenarios were evaluated. First, watershed C-BOD and N-BOD were simultaneously reduced by 20%, 40%, 60%, and 80%. Then prescribed SOD was decreased to reduce the overall SOD to observe the impact on modeled in-stream DO. The resulting modeled DO concentrations at the critical location, River Kilometer (Rkm) 12 were then compared to the standard and are tabulated in Table 8.

Table 8. Clearwater River (AUID 07010203-511) load reduction scenarios

Reduction Scenarios	**Modeled DO at Rkm 12 (mg/L)**
No Reduction of Watershed CBOD and NBOD	**2.60**
20% Reduction of Watershed CBOD and NBOD	**3.31**
40% Reduction of Watershed CBOD and NBOD	**3.80**
60% Reduction of Watershed CBOD and NBOD	**4.53**
80% Reduction of Watershed CBOD and NBOD	**5.11**
80% Reduction of Watershed CBOD and NBOD, with 10% SOD Reduction	**5.84**

The lowest in-stream DO, 2.16 mg/L, was measured at County Road 40/46 located at Rkm 12 (1.30 mg/L). Using the Weigand Lake DO of 7.8 mg/L, rather than the calibrated model headwaters DO of 5.4 mg/L, the lowest modeled DO in the TMDL model is 2.60 mg/L at Rkm 12.

To account for diurnal DO variations in determining assimilative capacity, headwater watershed load reductions were made until DO concentrations at the critical location (Rkm 12) met or exceeded the 5mg/L standard. While modeling shows that reducing only the watershed load produces a DO concentration over 5 mg/L in the critical reach, the relative difference between model results and the state standard is within the uncertainty of the model and data collection efforts. As such, the assimilative capacity was determined to be a simultaneous improvement in the headwater DO, 80% reduction of watershed loads and 10% reduction of SOD load to provide an implicit Margin of Safety (Table 9).

Table 9. Clearwater River (AUID 07010203-511) assimilative capacity (includes MOS)

Load	CBOD (lbs/day)	NBOD (lbs/day)	SOD (lbs/day)
Headwater Watershed	7,514	2,711	--
Tributary Watershed	17	0	--
SOD	--	--	649
Total	**7,532**	**2,711**	**649**

TMDL Allowable Loads

Table 10 summarizes the TMDL allowable loads needed to meet or exceed the 5 mg/L (daily minimum) DO concentration for each of the streams. In many of the scenarios, large watershed reductions alone do not fully mitigate the DO impairment. Therefore, to achieve the TMDL, simultaneous improvements to headwater conditions and reductions in watershed loads and wetland SOD are required to provide an implicit MOS.

Table 10. TMDL allowable loads for the modeled streams

Stream	CBOD (lbs/day)	NBOD (lbs/day)	SOD (lbs/day)
Battle Brook (AUID 07010203-535)[1]	2.6	40.9	21.1
Rice Creek (AUID 07010203-512)[2]	141	342	169
Clearwater River (AUID 07010203-511)[2]	7,532	2,711	649

[1] In addition to these allowable loads, changes in channel morphometry are necessary.

[2] In addition to these allowable loads, changes in headwater conditions are necessary.