May 2021

Watershed

Upper/Lower Red Lake Watershed Total Maximum Daily Load Study

This report quantifies the total amount of phosphorus, total suspended solids, and bacteria that can be received by the streams and lakes in the Upper/Lower Red Lake Watershed and maintain their ability to support swimming, fishing, and healthy biological communities.

MINNESOTA POLLUTION CONTROL AGENCY

EOR water ecology community

RED LAKE NATION

CLEAN WATER LAND & LEGACY AMENDMENT

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Document Number: wq-iw5-22e

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Acronyms

Ac	acre
ac-ft/yr	acre feet per year
AF	anoxic factor
AU	animal unit
AUID	assessment unit ID
BD-P	bicarbonate dithionite extractable phosphorus
BMP	best management practice
BWSR	Minnesota Board of Water and Soil Resources
CAFO	concentrated animal feeding operation
cfs	cubic feet per second
cfu	colony-forming unit
Chl-*a*	chlorophyll-*a*
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CV	coefficient of variation
DO	dissolved oxygen
DNR	Minnesota Department of Natural Resources
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
EQuIS	Environmental Quality Information System
F-IBI	fish index of biotic integrity
HSPF	Hydrologic Simulation Program-Fortran
HUC	Hydrologic Unit Code
IBI	index of biological integrity
ISTS	individual sewage treatment system
IPHT	imminent public health threat
IWM	Intensive Watershed Monitoring
km^2	square kilometer
LA	load allocation
Lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LC	loading capacity
LGU	local government unit
m	meter
mg/L	milligrams per liter
M-IBI	macroinvertebrate index of biotic integrity
mL	milliliter
MLCCS	Minnesota Land Cover Classification System
MOS	margin of safety
MPCA	Minnesota Pollution Control Agency

MPN	most probable number
MS4	Municipal Separate Storm Sewer Systems
MST	microbial source tracking
NA	North American
NF-GP	Northern Forest Streams-Glide/Pool
NF-RR	Northern Forest Streams-Riffle/Run
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
org/100mL	organisms per 100 mL
OHW	ordinary high water
PWP	Permanent Wetland Preserve
RIM	Reinvest in Minnesota
RL DNR	Red Lake Department of Natural Resources
RLWD	Red Lake Watershed District
RNR	River Nutrient Region
RR	release rate
SDS	State Disposal System
SFIA	Sustainable Forestry Incentives Act
SID	Stressor Identification
SIETF	SSTSs Implementation and Enforcement Task Force
SONAR	Statement of Need and Reasonableness
Sq km	square kilometer
SSTS	subsurface sewage treatment systems
STORET	EPA STORage and RETrieval database
SWCD	Soil and Water Conservation District
TAC	Technical Advisory Committee
TAS	Treatment as a State
TMDL	Total Maximum Daily Load
TP	total phosphorus
TSS	total suspended solids
ULRLW	Upper/Lower Red Lake Watershed
USGS	United States Geological Survey
UV	ultraviolet
WLA	wasteload allocation
WQX	EPA Water Quality Exchange database
WRAPS	Watershed Restoration and Protection Strategies
WRP	Wetland Reserve Program
WWTF	wastewater treatment facility

Executive Summary

The Clean Water Act (1972) requires that each state develop a report to identify and inform restoration of any waterbody that is deemed impaired by state regulations through a Total Maximum Daily Load (TMDL) Study. A TMDL identifies the pollutant that is causing the impairment and how much of that pollutant can enter the waterbody and still meet water quality standards.

There are 31 total impairments in 5 lakes and 16 stream reaches within the Upper/Lower Red Lake Watershed (ULRLW) that are on Minnesota's 2018 303(d) list of impaired waters. This TMDL study developed nine TMDLs for bacteria in the form of *Escherichia coli* (*E. coli*) for impairments in nine stream reaches, one TMDL for total suspended solids (TSS) impairment in one stream reach, and five TMDLs for total phosphorus (TP) for nutrient impairments in five lakes located in the ULRLW, Hydrologic Unit Code (HUC) 09020302. The remaining 16 impairments are either deferred or reclassified. The waterways of the ULRLW are tributaries to Upper and Lower Red Lake, which then flows to the Red River of the North via the Red Lake River, in northwestern Minnesota. Three impaired streams for which a TMDL was developed are located partially within the Red Lake Reservation. As a result, this TMDL was completed through a partnership between the Minnesota Pollution Control Agency (MPCA) and the Red Lake Nation through the Red Lake Department of Natural Resources (RL DNR). While the MPCA does not have jurisdiction on the Red Lake Nation lands, the Red Lake DNR and the MPCA cooperated on this watershed-wide project due to the benefits that would be realized by both the tribe and the State of Minnesota as a result of this project. The RL DNR accompanied MPCA staff during biological sampling in tribal waters, assisted with water quality sampling, participated in assessment activities, conducted public participation events within the Reservation and in other areas of the watershed outside their jurisdiction, provided a wealth of local knowledge of the watershed, and wrote significant sections of this TMDL report. This TMDL study was completed by the RL DNR and their subcontractor under a contract with the MPCA, who provided funding through the Clean Water Legacy Act.

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

- All available water quality data from the TMDL 10-year time period (2007 through 2016)
- ULRLW Hydrologic Simulation Program – FORTRAN (HSPF) model
- Lake sediment phosphorus concentrations
- Fisheries and aquatic plant surveys
- Stressor identification (SID) investigations
- Stakeholder input

The following pollutant sources were evaluated for each lake or stream as appropriate: watershed runoff, loading from upstream waterbodies, atmospheric deposition, lake internal loading, point sources, feedlots, septic systems, and wildlife. This TMDL study used an inventory of pollutant sources to develop a lake response model for each impaired lake and a load duration curve (LDC) model for each impaired stream. These models were then used to determine the pollutant reductions needed for the impaired waterbodies to meet water quality standards. A summary of existing conditions, pollutant sources, and reductions needed to meet water quality standards for each impaired waterbody addressed in this TMDL study is provided below.

Blackduck Lake (04-0069-00) TP TMDL:

- Blackduck Lake was listed as impaired in 2010.
- The current 10-year (2007 through 2016) growing season average TP concentration is 34 µg/L with a water quality standard goal of <30 µg/L.
- Blackduck Lake is 2,685 acres with a maximum depth of 28 feet and a shallow lake zone (<15 feet) that covers 50% of the lake surface area.
- The lake watershed (including the lake) 15,598 acres, or 6 times the lake surface area.
- The shoreline is well developed with seasonal conversion of cabins to year-round homes. At the time the TMDL was developed, there were 79 year-round homes and 132 seasonal cabins.
- The watershed is 8% impervious, 12% row crops, and 21% wetlands.
- The majority of unknown/internal load is likely coming from the near shore area (such as shoreline septic and erosion sources), Coburn Creek, and in-lake sediment phosphorus release.

Crane Lake (04-0165-00) TP TMDL:

- Crane Lake was listed as impaired in 2018.
- The current 10-year (2007 through 2016) growing season average TP concentration is 38 µg/L with a water quality standard goal of <30 µg/L.
- Crane Lake is 108 acres with a maximum depth of 30 feet and a shallow lake zone (<15 feet) that covers 76% of the lake surface area.
- Crane Lake receives drainage from Strand Lake, and discharges to Julia and Puposky Lakes.
- The total watershed (including the lake) is 2,510 acres, or 23 times the lake surface area. The direct drainage area is 248 acres, and the Strand Lake Watershed is 2,154 acres.
- The shoreline is mostly undeveloped.
- The watershed is 3% impervious, 8% row crops, and 22% wetlands.
- The majority of unknown/internal load is likely coming from in-lake sediment phosphorus release or shallow lake biology impacts on water quality.

Strand Lake, North Basin (04-0178-00) TP TMDL:

- Strand Lake was listed as impaired in 2018.
- The current 10-year (2007 through 2016) growing season average TP concentration is 36 µg/L with a water quality standard goal of <30 µg/L.
- Strand Lake is comprised of two distinct basins. The north basin is 69 acres with a maximum depth of 18 feet and a shallow lake zone (<15 feet) that covers 91% of the basin surface area. The south basin is 69 acres with a maximum depth of 62 feet and a shallow lake zone (<15 feet) that covers 56% of the basin surface area.

- The north basin of Strand Lake flows into the south basin of Strand Lake and then to Crane Lake.
- The lake watershed is 1,711 acres, or 25 times the lake surface area.
- The shoreline is mostly undeveloped.
- The watershed is 3% impervious, 7% row crops, and 22% wetlands.
- The majority of unknown/internal load is likely coming from in-lake sediment phosphorus release or shallow lake biology impacts on water quality.

Whitefish Lake, South Basin (04-0309-00) TP TMDL:

- Whitefish Lake was listed as impaired in 2018.
- The current 10-year (2007 through 2016) growing season average TP concentration is 86 µg/L with a water quality standard goal of <30 µg/L.
- Whitefish Lake is comprised of two distinct basins. The north basin is 41 acres with a maximum depth of 4 feet and a shallow lake zone (<15 feet) that covers 100% of the basin surface area. The south basin is 82 acres with a maximum depth of 14 feet and a shallow lake zone (<15 feet) that covers 100% of the basin surface area.
- The lake watershed (including the lake) is 4,985 acres, or 60 times the lake surface area.
- The shoreline is mostly undeveloped.
- The watershed is 5% impervious, 34% row crops (mostly in the upper reaches of the lakeshed), and 18% wetlands.
- The majority of unknown/internal load is likely coming from in-lake sediment phosphorus release.

Bartlett Lake (36-0018-00) TP TMDL:

- Bartlett Lake was listed as impaired in 2018.
- The current 10-year (2007 through 2016) growing season average TP concentration is 32 µg/L with a water quality standard goal of <30 µg/L.
- Bartlett Lake is 332 acres with a maximum depth of 16 feet and a shallow lake zone (<15 feet) that covers 96% of the lake surface area.
- The lake watershed (including the lake) is 2,033 acres, or 6 times the lake surface area.
- The shoreline is mostly undeveloped.
- The watershed is 7% impervious, <1% row crops, and 36% wetlands.
- The majority of unknown/internal load is likely coming from shallow lake biology impacts on water quality. Much of the internal load is from historical inputs from an old creamery, sawmill waste, and wastewater, as well as current and historical storm water from the city of Northome. The EOR 2018 Bartlett Lake In-Lake Management Alternatives report discuss the relationship between shallow lake biology and water quality in Bartlett Lake and discusses management recommendations for improving water quality.

***E. coli* TMDLs**:

Desktop data and Microbial Source Tracking (MST) evidence were used to determine the sources of bacteria to the impaired streams. Two impaired streams had low concentration of a human biomarker but no desktop data evidence for an Imminent Public Health Threat (IPHT) in the impaired stream subwatershed. A septic survey should be considered in this subwatershed or additional MST data collection to verify the low biomarker detection from this TMDL study. Five impaired streams had low to high concentrations of the ruminant biomarker and evidence for cattle in the drainage area. The livestock facilities should be reviewed for proper manure management to address the bacteria impairments in these streams. All but two of the impaired streams had low concentrations of one or both of the beaver and bird biomarkers, suggesting a watershed-wide low level of natural background sources of bacteria to streams in the ULRLW. Three impairments are being deferred due to a potential recategorization. *E. coli* TMDLs were developed for:

- Battle River, North Branch (09020302-503)
- North Cormorant River (09020302-506)
- South Cormorant River (09020302-507)
- Darrigans Creek (09020302-508)
- Blackduck River (09020302-510)
- Sandy River (09020302-522)
- Mud River (09020302-541)
- O'Brien Creek (09020302-544)
- Unnamed Creek (09020302-600)

TSS TMDLs:

There are three TSS impairments in the ULRLW. High TSS levels result in low clarity and poor habitat for aquatic organisms. High TSS levels are likely due to channel instability, bank erosion, hydrologic alterations and land use changes in the impaired stream subwatersheds. There are no major point sources of TSS in the impaired stream subwatersheds. Key strategies for reducing TSS in the impaired streams include the following: forest protection programs, conservation easements, drainage water management, stream restoration projects, culvert replacements, riparian buffers, livestock exclusion from streambanks, and pasture management. Two impairments are being deferred due to a potential recagetorization. A TSS TMDL was developed for the following:

- Mud River (09020302-541)

DO FIBI and MIBI Impairments:

There are four DO, three MIBI, and four FIBI impairments in the ULRLW. These impairments were found to not be caused by a pollutant and are being deferred due to potential recategorization.

The TMDL study's results aided in the selection of implementation activities during the ULRL Watershed Restoration and Protection Strategy (WRAPS) process. The purpose of the WRAPS process is to support local working groups in developing ecologically sound restoration and protection strategies for subsequent implementation planning. Following completion of the WRAPS process, the Upper/Lower Red Lake WRAPS Report will be publicly available on the MPCA ULRLW website:

https://www.pca.state.mn.us/water/watersheds/upperlower-red-lake

1 Project Overview

1.1 Purpose

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

The State of Minnesota has determined that 16 stream reaches and 5 lakes in the ULRLW (HUC 09020302) are impaired because they exceed established state water quality standards and, in accordance with the Clean Water Act, must conduct TMDL studies on the impaired waters. The goals of this TMDL are to provide WLA and LA for pollutant sources within Minnesota and to quantify the pollutant reductions needed to meet Minnesota water quality standards. TMDLs for 16 of the impairments (4 DO, 3 MIBI, 4 FIBI, 3 *E. coli*, and 2 TSS) have been deferred, and some impairments may be recategorized and do not need a TMDL. This TMDL study addresses the following impairments within the ULRLW (Figure 1-1) that are included in Minnesota’s 2018 303(d) list:

- aquatic recreation use impairments due to eutrophication based on TP in 5 lakes,
- aquatic recreation use impairments due to *E. coli* in 12 stream reaches,
- aquatic life use impairments due to TSS, fish/macroinvertebrate bioassessments, and/or dissolved oxygen (DO) in 10 stream reaches (14 total aquatic life use impairments).

Fifteen total TMDLs have been developed for five lakes and nine stream reaches.

Other ULRLW studies referenced in the development of this TMDL include:

- ULRLW SID Study (MPCA 2018)
- ULRLW Monitoring and Assessment Report (MPCA 2017)
- Bartlett Lake In-Lake Management Alternatives Report (EOR 2018)

The TMDL study’s results aided in the selection of implementation activities during the ULRL WRAPS process. The purpose of the WRAPS process is to support local working groups in developing scientifically-supported restoration and protection strategies for subsequent implementation planning. Following completion of the WRAPS process, the Upper/Lower Red Lake WRAPS Report will be publicly available on the MPCA ULRLW website:

https://www.pca.state.mn.us/water/watersheds/upperlower-red-lake

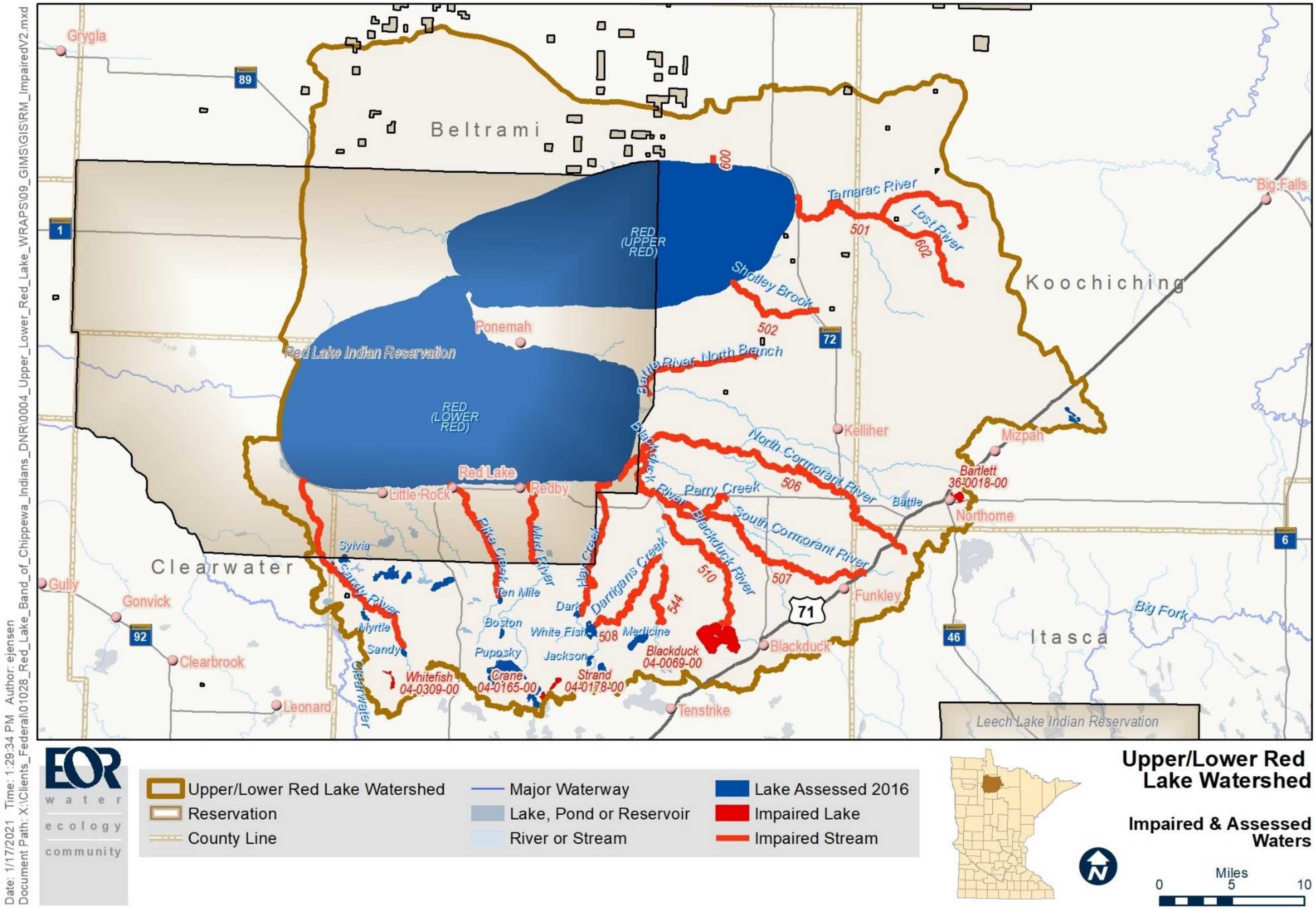


Figure 1-1. Impaired streams and lakes in the ULRLW addressed by this TMDL

1.2 Identification of Waterbodies

Table 1-1. Aquatic Life and Aquatic Recreation Use impairments in the ULRLW

Affected Use: Pollutant/Stressor	Stream AUID/ Lake ID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion	Impairment addressed by:
Aquatic Recreation: Nutrient/ Eutrophication Biological Indicators (Phosphorus)	36-0018-00	Bartlett Lake	0.5 Miles Northeast of Northome	2B, 3C	2018	2019	TP TMDL
	04-0069-00	Blackduck Lake	2 Miles West of Blackduck	2B, 3C	2010	2019	
	04-0165-00	Crane Lake	2 Miles Southeast of Puposky	2B, 3C	2018	2019	
	04-0178-00	Strand Lake	2 Miles East of Puposky	2B, 3C	2018	2019	
	04-0309-00	Whitefish Lake	6 Miles North of Pinewood	2B, 3C	2018	2019	
Aquatic Recreation: Escherichia coli	09020302-503^	Battle River, North Branch	Headwaters (Unnamed ditch) to S Br Battle R	2B, 3C	2018	2019	*E. coli* TMDL
	09020302-510	Blackduck River	Blackduck Lk to O'Brien Cr	2B, 3C	2018	2019	
	09020302-508	Darrigans Creek	Headwaters (Whitefish Lk 04-0137-00) to O'Brien Cr	2B, 3C	2018	2019	
	09020302-541^	Mud River	T150 R33W S16, south line to Lower Red Lk	2B, 3C	2018	2019	
	09020302-506	North Cormorant River	Headwaters to Blackduck R	2B, 3C	2018	2019	
	09020302-544	O'Brien Creek	T149 R32W S2, south line to T150 R32W S23, north line	1B, 2A, 3B	2018	2019	
	09020302-522^	Sandy River	Headwaters (Sandy Lk 04-0307-00) to Lower Red Lk	2B, 3C	2018	2019	
	09020302-507	South Cormorant River	Headwaters to Blackduck R	2B, 3C	2018	2019	
	09020302-600	Unnamed creek	Headwaters to Upper Red Lk (04-0035-01)	2B, 3C	2018	2019	
	09020302-512^	Blackduck River	South Cormorant R to North Cormorant R	2B, 3C	2018	2019	*E. coli* TMDL deferred**
	09020302-518^	Hay Creek	Headwaters (Dark Lk 04-0167-00) to Lower Red Lk	2B, 3C	2018	2019	
	09020302-502	Shotley Brook	Headwaters to Upper Red Lk	2B, 3C	2018	2019	

Affected Use: Pollutant/Stressor	Stream AUID/ Lake ID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion	Impairment addressed by:
Aquatic Life: Dissolved oxygen	09020302-503^	Battle River, North Branch	Headwaters (Unnamed ditch) to S Br Battle R	2B, 3C	2018	2019	Nonpollutant based stressor
	09020302-506	North Cormorant River	Headwaters to Blackduck R	2B, 3C	2018	2019	
	09020302-544	O'Brien Creek	T149 R32W S2, south line to T150 R32W S23, north line	1B, 2A, 3B	2018	2019	
	09020302-521^	Pike Creek	Headwaters (Ten Mile Lk 04-0267-00) to Lower Red Lk	2B, 3C	2018	2019	
Aquatic Life: Macroinvertebrate Bioassessments	09020302-508	Darrigans Creek*	Headwaters (Whitefish Lk 04-0137-00) to O'Brien Cr	2B, 3C	2018	2019	Nonpollutant based stressor
	09020302-521^	Pike Creek	Headwaters (Ten Mile Lk 04-0267-00) to Lower Red Lk	2B, 3C	2018	2019	
	09020302-502	Shotley Brook*	Headwaters to Upper Red Lk	2B, 3C	2018	2019	
Aquatic Life: Fish Bioassessments	09020302-503^	Battle River, North Branch*	Headwaters (Unnamed ditch) to S Br Battle R	2B, 3C	2018	2019	Nonpollutant based stressor
	09020302-602	Lost River*	Unnamed cr to Tamarac R	2B, 3C	2018	2019	
	09020302-605	Perry Creek*	Unnamed cr to Cormorant R	2B, 3C	2018	2019	
	09020302-501	Tamarac River*	Headwaters to Upper Red Lk	2B, 3C	2018	2019	
Aquatic Life: Turbidity/TSS	09020302-541^	Mud River	T150 R33W S16, south line to Lower Red Lk	2B, 3C	2018	2019	TSS TMDL
	09020302-506	North Cormorant River	Headwaters to Blackduck R	2B, 3C	2018	2019	TSS TMDL deferred***
	09020302-521^	Pike Creek	Headwaters (Ten Mile Lk 04-0267-00) to Lower Red Lk	2B, 3C	2018	2019	

^ Stream reach is partially located within the Red Lake Nation.

* Impairment identified from Stressor Identification Study (MPCA 2018a)

** Microbial source tracking indicated bacterial sources from nonanthropogenic sources only (beaver or birds) and no other human or livestock sources are present in the drainage area; TMDLs deferred while *E. coli* impairments considered for recategorization to 4D

*** Pike Creek and North Cormorant River are being considered for recategorization to 4B and potential future de-listing due to recent water quality data that meets the TSS water quality standards (see Section 3.5.4.1 and 3.5.4.2); TMDL deferred

1.3 Priority Ranking

The MPCA's schedule for TMDL completions, as indicated on Minnesota's Section 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned TMDL priorities with the watershed approach. The schedule for TMDL completion corresponds to the WRAPS report completion on the 10-year cycle. The MPCA developed a state plan Minnesota's TMDL Priority Framework Report to meet the needs of the EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration, and Protection under the CWA Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments to be addressed by TMDLs through the watershed approach.

2 Applicable Water Quality Standards and Numeric Water Quality Targets

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

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

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

2.1 Beneficial uses

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

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

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

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

2.2 Narrative and numeric criteria and state standards

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

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

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

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

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

2.3 Antidegradation policies and procedures

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

- Existing uses and the level of water quality necessary to protect existing uses are maintained and protected.
- Degradation of high water quality is minimized and allowed only to the extent necessary to accommodate important economic or social development.

- Water quality necessary to preserve the exceptional characteristics of outstanding resource value waters is maintained and protected.
- Proposed activities with the potential for water quality impairments associated with thermal discharges are consistent with section 316 of the Clean Water Act, United States Code, title 33, section 1326.

2.4 ULRLW water quality standards

The lakes and streams addressed by this TMDL study fall into one of the following two designated use classifications (identified in Table 1-1):

1B, 2A, 3B – domestic consumption requiring moderate treatment; a healthy cold water aquatic community; industrial consumption with a medium level of treatment

2B, 3C – a healthy warm water aquatic community; industrial consumption with a high level of treatment

Class 1 waters are protected for domestic consumption, Class 2 waters are protected for aquatic life and aquatic recreation, and Class 3 waters are protected for industrial consumption as defined by Minn. R. ch. 7050.0140. The most protective of these classes is 2B, for which water quality standards are provided below.

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

2.4.1 Lakes

2.4.1.1 Lake Eutrophication

TP is often the limiting factor controlling primary production in freshwater lakes: as in-lake TP concentrations increase, algal growth increases resulting in higher Chl-*a* concentrations and lower water transparency. In addition to meeting phosphorus limits, Chl-*a* and Secchi transparency standards must be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson 2005). Clear relationships were established between the causal factor (TP) and the response variables (Chl-*a* and Secchi transparency). Based on these relationships, it is expected that by meeting the phosphorus target in each lake, the Chl-*a* and Secchi standards will, likewise, be met.

The impaired lakes within the ULRLW were assessed against the Northern Lakes and Forests water quality standards (Table 2-1). To be listed as impaired (Minn. R. 7050.0150, subp. 5), the summer growing season (June through September) monitoring data must show that the standards for both TP (the causal factor) and either Chl-*a* or Secchi transparency (the response variables) were exceeded. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if it will be listed as impaired. For more details regarding the listing process, see the *Guidance Manual for*

Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List (MPCA 2018b).

Table 2-1. Lake Eutrophication Standards

Ecoregion	TP (µg/L)	Chl-*a* (µg/L)	Secchi (m)
Northern Lakes and Forest	< 30	< 9	> 2.0

2.4.2 Streams

2.4.2.1 Bacteria

The State of Minnesota has developed numeric water quality standards for bacteria (Minn. R. 7050.0222), in this case *E. coli*, which are protective concentrations for short- (acute) and long-term (chronic) exposure to pathogens in water. Although often harmless, fecal indicator bacteria, such as *E. coli*, are used as an easy-to-measure parameter to evaluate the suitability of recreational waters for the presence of pathogens and probability of illness. Pathogenic bacteria, viruses, and protozoa pose a health risk to humans, potentially causing illnesses with gastrointestinal symptoms (nausea, vomiting, fever, headache, and diarrhea), skin irritations, or other symptoms. Pathogen types and quantities vary among fecal sources; therefore, human health risk varies based on the source of fecal contamination.

E. coli concentrations are not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31.

Table 2-2. *E. coli* Standards

Standard Type	*E. coli* (organisms/100 ml) as a Geometric Mean	Effective Period
Acute	<1,260	April through October
Chronic	<126	April through October

Geometric mean is used in place of an arithmetic average in order to measure the central tendency of the data, dampening the effect that very high or very low values have on arithmetic averages. *E. coli* can reproduce rapidly (hours to days) when waters become nutrient rich or very warm, and some individual readings can be orders of magnitude greater than the majority of all readings. The MPCA's *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* provides details regarding how waters are assessed for conformance to the *E. coli* standard (MPCA 2018b). See also the MPCA website on bacteria: https://www.pca.state.mn.us/water/bacteria.

The *E. coli* concentration standard of 126 organisms (org) per 100 milliliters (mL) was considered reasonably equivalent to the previous fecal coliform standard of 200 org/100 mL from a public health protection standpoint. Figure III-7 in the July 2007 MPCA SONAR (Statement of Need and Reasonableness) Book III supports this rationale using a log plot that shows a good relationship between these two parameters. The following regression equation was deemed reasonable to convert any data reported in fecal coliform to *E. coli* equivalents:

E. coli concentration (equivalents) = 1.80 x (Fecal Coliform Concentration)

It should also be noted that most analytical laboratories report *E. coli* in terms of either colony forming units (CFU)/100 mL or most probable number (MPN)/100 mL. Both are equivalent to org/100 mL. This TMDL report will present *E. coli* data in MPN/100 mL since all of the monitored data collected for this TMDL was reported in these units. The *E. coli* TMDL was written to achieve the bacteria water quality standard of 126 org/100 mL.

Red Lake Nation is in the process of gaining Treatment as a State (TAS) approval and their draft standards are under development. Their intention is to adopt the state's criteria for bacteria so there should be no conflicts at this time for the bacteria TMDLs that have been developed in this study.

2.4.2.2 TSS

Although sediment delivery and transport are important natural processes for all stream systems, sediment imbalance (either excess sediment or lack of sediment) can result in the loss of habitat in addition to the direct harm to aquatic organisms. As described in a review by Waters (1995), excess suspended sediments cause harm to aquatic life through two major pathways: (1) direct, physical effects on biota (i.e. abrasion of gills, suppression of photosynthesis, avoidance behaviors); and (2) indirect effects (i.e. loss of visibility, increase in sediment oxygen demand). Elevated turbidity levels and TSS concentrations can reduce the penetration of sunlight, and thus impede photosynthetic activity and limit primary production (Munawar et al. 1991; Murphy et al. 1981).

TSS criteria for Minnesota are stratified by geographic region and stream class, due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. The assessment window for these samples is April-September, so any TSS data collected outside of this period is not be considered for assessment purposes. The TSS standard for cool or warm water streams (2B) in the Northern River Nutrient Region (RNR) is 15 mg/L. For assessment, the standard concentration is not to be exceeded in more than 10% of samples within a 10-year data window.

Table 2-3. TSS Standards

River Nutrient Region	Water Class	TSS (mg/l)
Northern	2B	< 15

For more information, refer to the *Aquatic Life Water Quality Standards Draft Technical Support Document for Total Suspended Solids* (Markus 2011) and the *Minnesota Nutrient Criteria Development for Rivers* (Heiskary et al. 2013) report.

Red Lake Nation is in the process of gaining TAS approval and their draft standards are under development. Their intention is to adopt the state's criteria for TSS, so there should be no conflicts with the TSS TMDLs that have been developed in this study.

2.4.2.3 Fish Index of Biotic Integrity

The aquatic life impairments in Battle River, North Branch (-503), Lost River (-602), Perry Creek (-605), and Tamarac River (-501) were each characterized by low Fish Index of Biotic Integrity (F-IBI) scores. Degradation of surface waters can lead to changes in biological communities as pollutant intolerant species are replaced by pollutant tolerant species. The F-IBI and other indices of biological integrity are biological monitoring frameworks used to quantify changes in the composition of biological communities. The development of an F-IBI framework for Minnesota is described in MPCA 2014a.

Narrative language within Minnesota Administrative Rule identifies an IBI calculation as the primary determinant for evaluating impairment of aquatic biota (Minn. R. 7050.0150, subp. 6, Impairment of biological community and aquatic habitat). The F-IBI threshold for impaired streams in the ULRLW are listed in Table 2-4.

Table 2-4. State of Minnesota F-IBI score impairment thresholds for streams in the ULRLW.

State of Minnesota F-IBI Score Impairment Thresholds		
Impaired Reach Name (AUID)	F-IBI Class[§] /(Use)	F-IBI Score Threshold
Battle River, North Branch (-503)	NH	42
Lost River (-602)	NS	47
Perry Creek (-605)	NH	42
Tamarac River (-501)	NS	47

[§]F-IBI Classes: Northern Stream (NS) and Northern Headwaters (NH)

2.4.2.4 Macroinvertebrate Index of Biotic Integrity

The aquatic life impairments in Darrigans Creek (-508), Pike Creek (-521), and Shotley Brook (-502) were each characterized by low macroinvertebrate index of biotic integrity (M-IBI) scores. Degradation of surface waters can lead to changes in biological communities as pollutant intolerant species are replaced by pollutant tolerant species. The M-IBI and other indices of biological integrity are biological monitoring frameworks used to quantify changes in the composition of biological communities. The development of an M-IBI framework for Minnesota is described in MPCA 2014b.

Narrative language within Minnesota Administrative Rule identifies an IBI calculation as the primary determinant for evaluating impairment of aquatic biota (Minn. R. 7050.0150, subp. 6, Impairment of biological community and aquatic habitat). The M-IBI threshold for impaired streams in the ULRLW are listed in Table 2-5.

Table 2-5. State of Minnesota M-IBI score impairment thresholds for streams in the ULRLW

State of Minnesota M-IBI Score Impairment Thresholds		
Impaired Reach Name (AUID)	M-IBI Class[§] /(Use)	M-IBI Score Threshold
Darrigans Creek (-508)	NF-RR	53
Pike Creek (-521)	NF-GP	51
Shotley Brook (-502)	NF-GP	51

[§]M-IBI Classes: Northern Forest Streams Riffle/Run Habitat (NF-RR) and Northern Forest Streams-Glide/Pool Habitats (NF-GP)

2.4.2.5 Dissolved Oxygen

DO is essential to life for all aquatic organisms. When DO drops below acceptable levels, desirable aquatic organisms, such as fish, can be killed or harmed. A stream is considered impaired if there are at least three total violations and more than 10% of samples are below the water quality standard in one of these three data sets over 10 years:

- suitable pre-9 a.m. May through September measurements,
- all May through September measurements, or
- all October through April measurements.

A total of 20 independent observations are required for a DO assessment. Compliance for DO is required for 50% of the days at which flow of the receiving water is equal to the 7Q10.

Table 2-2. Stream dissolved oxygen standards (Minn. R. 7050.0220)

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

3 Watershed and Waterbody Characterization

The impaired streams and lakes included in this study are located within the ULRLW (HUC 09020302) of Northern Minnesota (Figure 1-1). The ULRLW drains approximately 1,974 square miles (1,263,678 acres) in Beltrami, Koochiching, Itasca, and Clearwater counties, with a majority of the watershed located in Beltrami County. Upper and Lower Red Lake are located in North Central Minnesota and are about 40 miles north of Bemidji. The predominant land use in the watershed is wetlands (41.3%) and forests (34.8%), and drainage ditch networks are a prominent feature of the landscape.

Tribal lands in the ULRLW

The Red Lake Nation Reservation, a federally recognized reservation, is located in the western portion of the watershed (Figure 1-1). Six impaired stream reaches flow from within the State of Minnesota to within the federally recognized Indian reservation. These stream reaches do not serve as a border between the State of Minnesota and the Red Lake Nation (for example, as the Red River of the North serves as the border between the states of Minnesota and North Dakota). The state and the RL DNR have worked cooperatively on this water quality assessment and the development of the TMDLs for these waters and agree that these waters should be included on the state's impaired waters list, while recognizing that the inclusion of tribal waters is advisory only as the state does not have jurisdiction over these waters. The RL DNR manage tribal lands and resources for the benefit of tribal members. While the MPCA does not have jurisdiction on the Red Lake Nation lands, the Red Lake Nation and the MPCA cooperated on this watershed-wide project due to the benefits that would be realized by both the tribe and the State of Minnesota as a result of this project. The Red Lake Reservation is a closed reservation and permission is needed by nontribal members to enter their tribal lands. The RL DNR accompanied the MPCA staff during biological sampling in tribal waters, assisted with water quality sampling, participated in assessment activities, conducted public participation events within the Reservation and in other areas of the watershed outside their jurisdiction, provided a wealth of local knowledge of the watershed, and wrote significant sections of this TMDL report. This TMDL study was completed by the RL DNR and their subcontractor under a contract with the MPCA who provided funding through the Clean Water Legacy Act.

For the purposes of the 303(d) list, the assessment of the portion of the water body within the Reservation is advisory to EPA only, because EPA has stated that it does not approve the state's impaired waters listings or TMDLs for waters within the boundaries of an Indian reservation. Note that the MPCA includes parcels held in trust (tribal trust lands) in the definition of Indian reservation.

3.1 Lakes

The physical characteristics of the impaired lakes within the ULRLW are listed in Table 3-1. Lake surface areas, lake volumes, mean depths, and littoral areas (less than 15 feet) were calculated using Minnesota Department of Natural Resources (DNR) bathymetry data, supplemented by EOR survey data; maximum depths were reported from the DNR Lake Finder website, where available; and watershed areas and watershed to surface area ratios were calculated using the U.S. Geological Survey (USGS) Stream Stats tool.

Blackduck Lake (04-0069-00), Crane Lake (04-0165-00), Strand Lake (04-0178-00), and Whitefish Lake (04-0309-00) and their watersheds, are located in Beltrami County. Bartlett Lake (36-0018-00) and its watershed are located in Koochiching County.

Table 3-1. Impaired lake physical characteristics

Impaired Lake or Upstream Lake (DNR Lake ID)	Surface area (ac)	Littoral area (% total area)	Volume (acre-feet)	Mean depth (feet)	Maximum depth (feet)	Watershed area* (incl. lake area) (ac)	Watershed area (ac) : Surface area (ac)
Blackduck Lake 04-0069-00	2,685	50%	37,276	14	28	15,598	6
Crane Lake 04-0165-00	108	76%	1,088	10	30	2,510	23
Strand Lake (North Basin) 04-0178-00	69	91%	610	9	18	1,711	25
Whitefish Lake (South Basin) 04-0309-00	82	100%	584	7	14	4,985	60
Bartlett Lake 36-0018-00	332	96%	2,409	7	16	2,033	6

*Note that the watershed area includes the surface area of the lake

3.2 Streams

Direct and total drainage area for the impaired stream reaches are listed in Table 3-2. Direct drainage areas were delineated using USGS Stream Stats, in conjunction with the DNR Level 8 Subwatersheds. The direct drainage areas include only the area downstream of any monitored upstream lake or stream.

Table 3-2. Impaired stream reach direct drainage and total watershed areas

Impaired Stream Reach Direct Drainage and Total Watershed Areas				
Impaired Lake DNR ID/ Stream AUID 09020302-	Name/Description	Direct Drainage Area (ac)	Impaired Upstream AUID (last 3 digits)/Lake ID	Total Drainage Area (ac)
501	Tamarac River/Headwaters to Upper Red Lk	144,545	602	195,442
502	Shotley Brook/Headwaters to Upper Red Lk	29,495	-	29,495
503	Battle River, North Branch/Headwaters (Unnamed ditch) to S Br Battle R	19,288	-	19,288
506	North Cormorant River/Headwaters to Blackduck R	44,390	-	44,390
507	South Cormorant River/Headwaters to Blackduck R	44,982	605	57,788
508	Darrigans Creek/Headwaters (Whitefish Lk 04-0137-00) to O'Brien Cr	16,460	-	16,460
510	Blackduck River/Blackduck Lk to O'Brien Cr	19,610	04-0069-00	35,208
512	Blackduck River/South Cormorant R to North Cormorant R	15,928	507, 508, 510, 544	145,080
518	Hay Creek/Headwaters (Dark Lk 04-0167-00) to Lower Red Lk	13,893	-	13,893
521	Pike Creek/Headwaters (Ten Mile Lk 04-0267-00) to Lower Red Lk	15,698	-	15,698
522	Sandy River/Headwaters (Sandy Lk 04-0307-00) to Lower Red Lk	49,015	04-0309-00	54,000
541	Mud River/T150 R33W S16, south line to Lower Red Lk	30,601	04-0165-00	33,111
544	O'Brien Creek/T149 R32W S2, south line to T150 R32W S23, north line	19,696	-	19,696
600	Unnamed creek/Headwaters to Upper Red Lk (04-0035-01)	568	-	568
602	Lost River/Unnamed cr to Tamarac R	50,897	-	50,897
605	Perry Creek/Unnamed cr to Cormorant R	12,805	-	12,805
04-0069-00	Blackduck Lake	15,598	-	15,598
04-0165-00	Crane Lake	799	04-0178-00	2,510
04-0178-00	Strand Lake (North Basin)	1,711	-	1,711
04-0309-00	Whitefish Lake (South Basin)	4,985	-	4,985
36-0018-00	Bartlett Lake	2,033	-	2,033

3.3 Subwatersheds

The impaired stream and lake subwatersheds referenced in this TMDL are illustrated in Figure 3-1 and Figure 3-2 below.

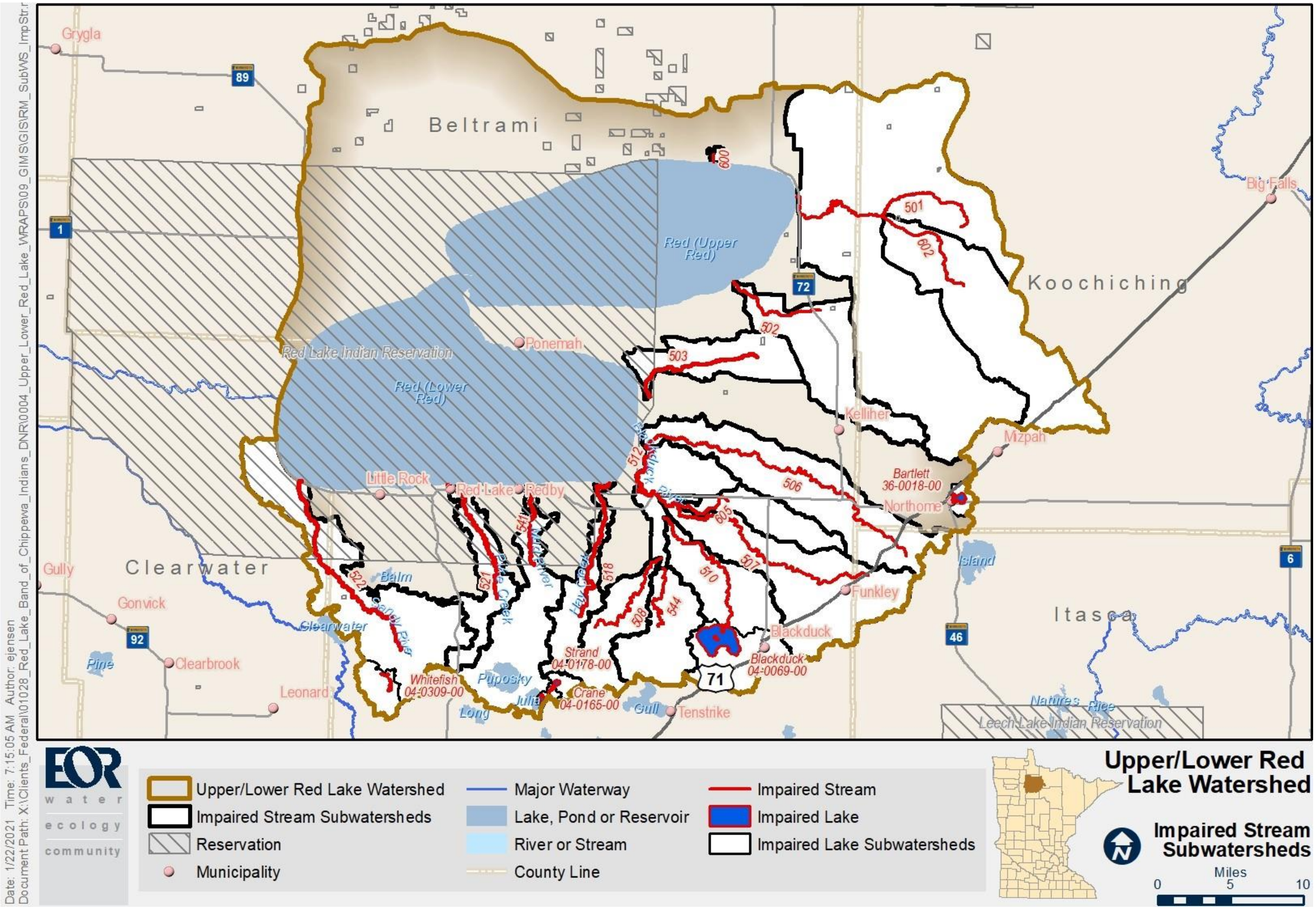


Figure 3-1. Impaired stream subwatersheds referenced in this TMDL

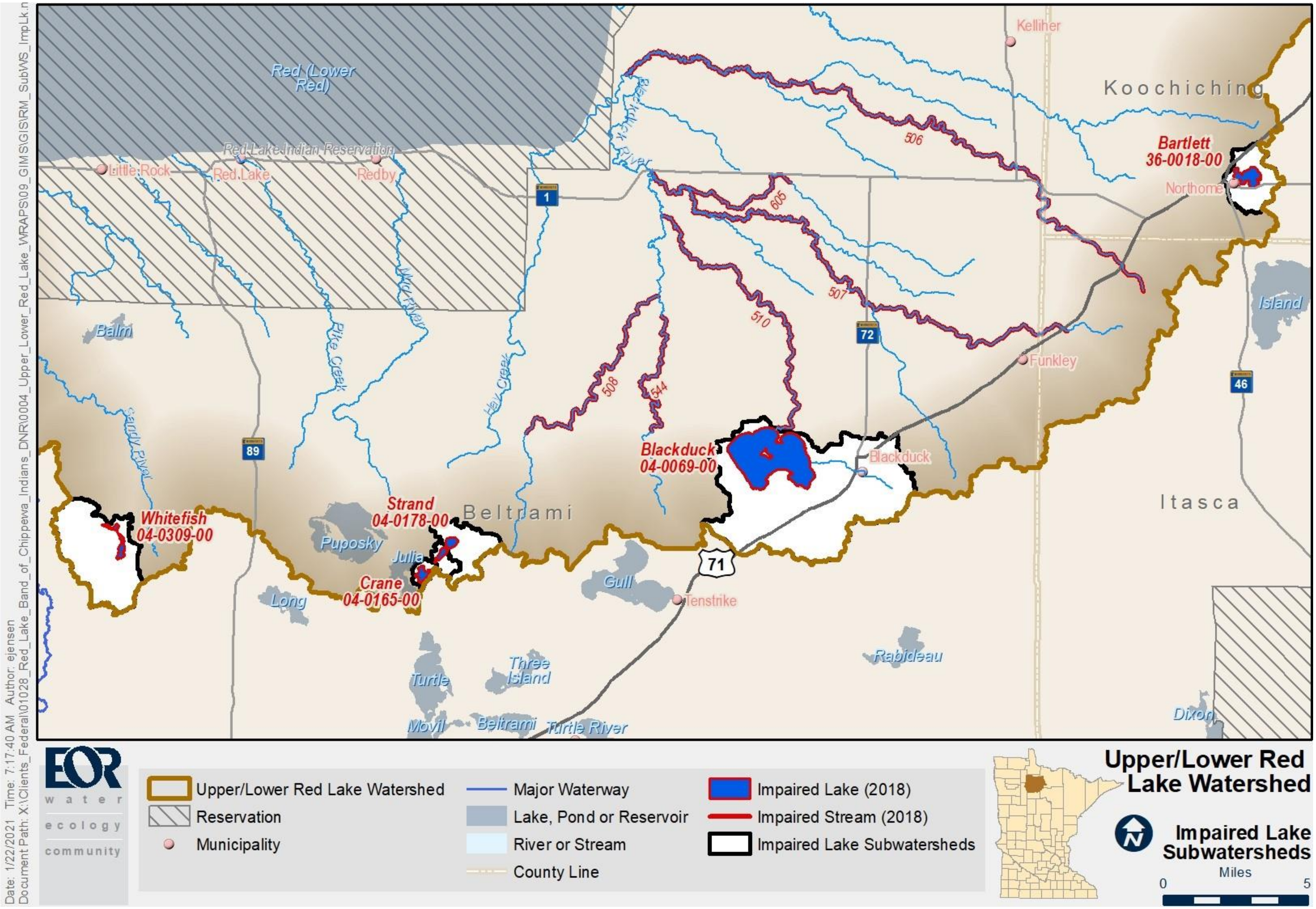


Figure 3-2. Impaired lake subwatersheds referenced in this TMDL

3.4 Land Use

Land cover in the ULRLW was assessed using the 2013 Minnesota Land Cover Classification and Impervious Surface Area by Landsat (MLCCS; https://gisdata.mn.gov/dataset/base-landcover-minnesota). This information is necessary to draw conclusions about pollutant sources and best management practices (BMPs) that may be applicable within each subwatershed.

The land cover distribution within impaired stream watersheds is summarized in Table 3-3 and Figure 3-3. This data was simplified to reduce the overall number of categories. Wetlands includes emergent wetlands and forested/shrub wetlands. Open Water includes all lakes and rivers. Extraction includes pits, quarries, and mines. Forest includes conifer forest, deciduous forest, and mixed forest. Grassland and managed grass includes native grass stands, alfalfa, and clover. Row crops include all annually planted row crops (corn, soybeans, wheat, oats, barley, etc.), and fallow crop fields. Impervious includes developed open space, and low, medium, and high density developed areas.

The primary land cover within the ULRLW is wetlands (41.3%) and forests (34.8%). The impaired stream subwatersheds have land cover distributions very similar to the ULRLW as a whole.

Table 3-3. ULRLW and impaired lake and stream subwatershed land cover (MLCCS 2013)

ULRLW Land Cover Summary								
Waterbody Name – AUID (last 3 digits)/Lake ID	**Impervious**	**Wetlands**	**Open Water**	**Extraction**	**Forest**	**Grassland**	**Hay & Pasture**	**Row Crops**
Tamarac River (-501)	1.2%	75.7%	0.5%	<0.1%	20.3%	1.3%	0.5%	0.5%
Shotley Brook (-502)	2.3%	52.7%	0.3%	<0.1%	38.9%	3.1%	2.3%	0.3%
Battle River, North Branch (-503)	2.8%	31.6%	1.7%	<0.1%	48.3%	6.2%	7.8%	1.5%
North Cormorant River (-506)	3.0%	24.0%	0.5%	<0.1%	37.7%	11.5%	15.8%	7.5%
South Cormorant River (-507)	2.7%	26.1%	0.5	<0.1%	40.9%	11.2%	11.0%	7.6%
Darrigans Creek (-508)	2.5%	19.9%	7.1%	<0.1%	44.2%	9.0%	7.3%	10.0%
Blackduck River (-510)	5.7%	18.4%	8.5%	<0.1%	34.5%	9.9%	14.5%	8.6%
Blackduck River (-512)	3.7%	23.4%	3.6%	<0.1%	39.0%	10.3%	11.6%	8.4%
Hay Creek (-518)	3.0%	23.4%	2.6%	<0.1%	45.3%	8.6%	5.7%	11.5%
Pike Creek (-521)	4.5%	29.7%	3.1%	<0.1%	46.0%	4.6%	1.8%	10.3%
Sandy River (-522)	3.2%	30.7%	3.4%	<0.1%	50.5%	5.9%	0.6%	5.6%
Mud River (-541)	3.7%	28.4%	11.7%	<0.1%	38.1%	7.0%	1.6%	9.6%
O'Brien Creek (-544)	5.1%	14.0%	3.8%	<0.1%	34.9%	9.5%	17.7%	14.9%
Unnamed Creek (-600)	2.1%	72.0%	0.1%	<0.1%	16.0%	7.8%	<0.1%	2.0%
Lost River (-602)	1.2%	76.0%	1.2%	<0.1%	19.9%	1.0%	0.6%	0.1%
Perry Creek (-605)	2.6%	27.7%	0.1%	<0.1%	29.7%	13.8%	16.1%	10.1%
Blackduck Lake (04-0069-00)	8.3%	21.4%	18.8%	<0.1%	31.8%	4.7%	2.7%	12.3%
Crane Lake (04-0165-00)	3.6%	22.2%	9.5%	<0.1%	50.0%	6.9%	<0.1%	7.7%
Strand Lake (04-0178-00)	3.1%	22.4%	6.3%	<0.1%	53.5%	7.7%	<0.1%	7.1%
Whitefish Lake (04-0309-00)	5.1%	17.5%	3.1%	<0.1%	33.1%	7.2%	<0.1%	34.0%
Bartlett Lake (36-0018-00)	7.4%	36.2%	16.0%	<0.1%	30.3%	5.8%	3.8%	0.5%
ULRLW	**2.9%**	**41.3%**	**2.9%**	**<0.1%**	**34.8%**	**6.4%**	**6.3%**	**5.4%**

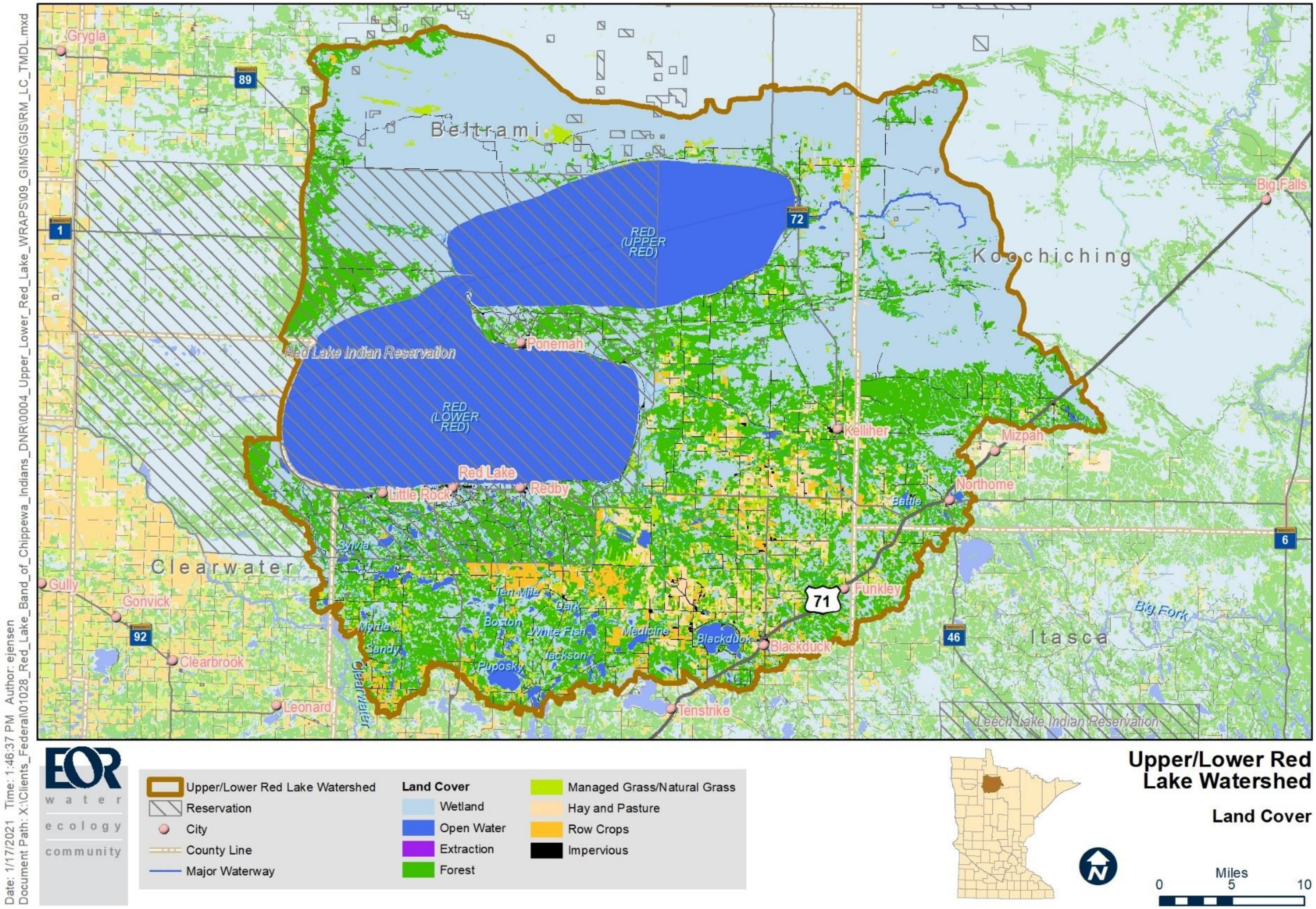


Figure 3-3. Land cover in the ULRLW (MLCCS 2013)

3.5 Current/Historical Water Quality

The existing in-stream water quality conditions were quantified using data downloaded from the MPCA Environmental Quality Information System (EQuIS) database and the EPA STORage and RETrieval (STORET)/Water Quality Exchange (WQX) database. Data from the most recent 10 year time period (2007-2016) and overlapping with the MPCA's most recent intensive monitoring conducted in the watershed from 2014-2015 were used to assess the water quality of the impaired water bodies.

3.5.1 Lake Eutrophication (Phosphorus)

The existing in-lake water quality conditions were quantified using data downloaded from the MPCA EQuIS database and available for the most recent 10-year time period (2007 through 2016). Data for TP, Chl-*a* and Secchi were available from one monitoring station (04-0069-00-205) collected in 2008 and 2013 through 2016 for Blackduck Lake. There were a small number of additional Secchi depth measurements collected at other stations but these were not included in the analysis. Data were available from one monitoring station collected during 2011 and 2012 for Crane, Strand, and Whitefish Lakes (Table 3-4). Data were available from two monitoring stations in Bartlett Lake during 2007 through 2016. However, only data from monitoring station 36-0018-00-202 was used to calibrate the steady state lake water quality response model BATHTUB used to determine the lake loading capacity (LC; see Section 4.1.1.1), because this station is located in near the deepest point of the lake in the main open water basin and better represents the steady state, mixed conditions of the whole lake. Monitoring station 36-0018-00-201 is located in shallow water between an island and the city of Northome. Water quality in shallow or sheltered bays tend to have much poorer water quality than the open, well-mixed portions of the lake and are not representative of the whole lake.

Growing season means of TP, Chl-*a*, and Secchi transparency depth were calculated using monitoring data from the growing season (June through September) and for surface collected samples (sample depth between 0 to 2 meters). Information on the species and abundance of aquatic plant and fish communities was compiled from DNR fisheries surveys, if available. Year-to-year water quality trends and descriptions of the aquatic plant and fish communities for each impaired lake are included in Appendix A. The 10-year growing season mean TP, Chl-*a*, and Secchi data used to calibrate the lake water quality response models for each impaired lake are listed in Table 3-4 below.

Table 3-4. Ten-year growing season mean TP, Chl-*a*, and Secchi (2007-2016)

Lake Name (Monitoring Station ID)	Years of Data	Ten-year (2007-2016) Growing Season Mean (June – Sept)								
		TP			Chl-*a*			Secchi		
		(µg/L)	#	CV	(µg/L)	#	CV	(m)	#	CV
Northern Lakes and Forests		**< 30**		--	**< 9**		--	**> 2.0**		--
Blackduck (04-0069-00-205)	2008, 2013-2016	**34**	24	11%	**20**	24	17%	**2.3**	20	5%
Crane (04-0165-00-201)	2011-2012	**38**	10	9%	**16**	10	19%	**2.0**	10	9%
Strand (04-0178-00-201)	2011-2012	**36**	10	8%	**11**	10	12%	**1.9**	10	5%
Whitefish (04-0309-00-201)	2011-2012	**86**	10	6%	**39**	10	11%	**1.2**	10	14%
Bartlett (36-0018-00-201)	2007	**68**	7	7%	**16**	7	16%	**1.0**	7	10%
Bartlett (36-0018-00-202)	2014-2015	**32**	8	6%	**21**	4	14%	**1.0**	4	7%

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

3.5.1.1 Shallow Lakes

The relationship between TP concentration and the response variables (Chl-*a* and Secchi depth transparency) is often different in shallow lakes as compared to deeper lakes. In deeper lakes, algae abundance is often controlled by physical and chemical factors such as light availability, temperature, and nutrient concentrations. The biological components of the lake (such as microbes, algae, aquatic plants, zooplankton and other invertebrates, and fish) are distributed throughout the lake, along the shoreline, and on the bottom sediments. In shallow lakes, the biological components are more concentrated into less volume and consequently exert a stronger influence on the ecological interactions within the lake. There is a more dense biological community at the bottom of shallow lakes than in deeper lakes, because of the fact that oxygen is replenished in the bottom waters and light can often penetrate to the bottom. These biological components can control the relationship between TP and the response variables algae and water clarity.

The result of biological components' impact on water clarity is that shallow lakes normally exhibit one of two ecologically alternative stable states (Figure 3-4): the turbid water, algae-dominated state, and the clear water, aquatic plant-dominated state (Scheffer *et al.* 1993). The clear state is the most ecologically preferred, since algae communities are held in check by diverse and healthy zooplankton and fish communities. Fewer nutrients are released from the sediments in this state. This is because roots of aquatic plants stabilize the sediments, lessening the amount of sediment stirred up by wind-driven mixing.

Nutrient reduction or addition in a shallow lake does not lead to linear improvement or degradation in water quality (indicated by algal biomass in Figure 3-5). As external nutrient loads are decreased in a lake in the turbid water, algae-dominated state, no improvements in water quality may occur at first. Drastic reductions in nutrient loads or a change in the biological community will cause the lake to abruptly shift from the turbid water, algae-dominated state to the clear water, aquatic plant-dominated state. Conversely, as external nutrient loads are increased in a shallow lake in the clear water, aquatic plant-dominated state, only slight degradations in water quality may occur at first. At some point, further increase in nutrient loads will cause the shallow lake to abruptly shift from the clear water, aquatic plant-dominated state to the turbid water, algae-dominated state. The general pattern in Figure 3-5 is often referred to as "hysteresis," meaning that when forces are applied to a system, it does not return completely to its original state nor does it follow the same trajectory on the way back.

The biological response of the lake to TP inputs will depend on the state that the lake is in. For example, if the lake is in the clear state, the aquatic plants may be able to take up P instead of the algae. However, if enough stressors are present in the lake, increased TP inputs may lead to a shift to the turbid state with an increase in algal density and decreased transparency. The two main categories of stressors that can shift the lake to the turbid state are the following:

- Disturbance to the aquatic plant community, for example from wind-driven mixing, bottom feeding fish (such as carp), boat motors, or light availability (influenced by algal density or water depth); and
- A decrease in the number of zooplankton can result in an increase in algae. A decrease in the number of zooplankton is usually caused by an increase in the number of fish that feed directly on zooplankton due to a decrease in or absence of piscivorous (predator) fish.

One implication of the alternative stable states in shallow lakes is that different management approaches are used for shallow lake restoration than those used for restoration of deeper lakes. Shallow lake restoration often focuses on restoring the macrophyte, zooplankton, and fish communities to the lake. This is commonly achieved through a whole lake drawdown.

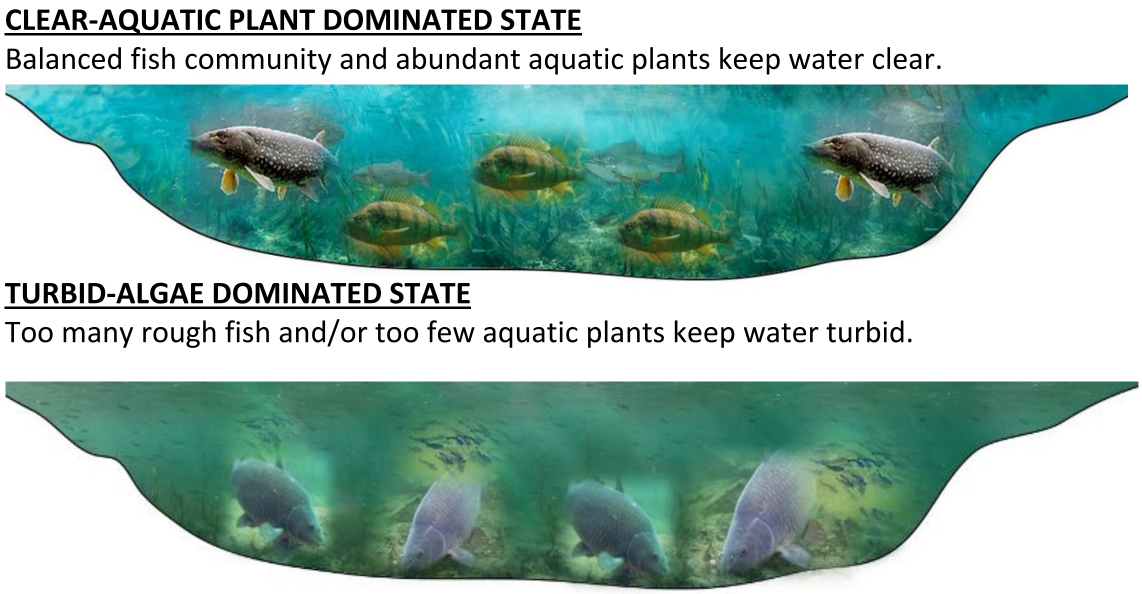


Figure 3-4. Clear and turbid water states in shallow lakes (EOR)

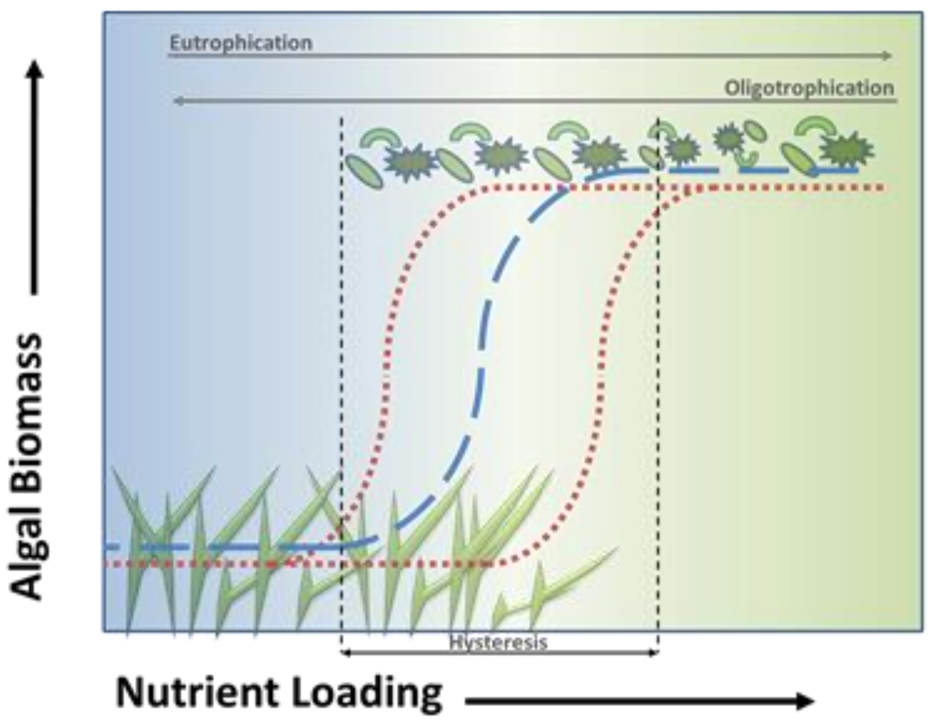


Figure 3-5. Nutrient loading and algae biomass hysteresis of alternative stable states in shallow lakes (Scheffer *et al.* 1993). The red dotted lines represent the two relationships between nutrient loading and the amount of algae in shallow lakes (hysteresis) as they become more eutrophic (delayed growth of algae as nutrient loading increases, and delayed loss of algae as nutrient loading decreases). In other words, there is a delay in shallow lake water quality changes in response to increases or decreases in nutrient loading.

3.5.2 Stream Monitoring Stations

Figure 3-6 displays the stream monitoring stations where water quality data, summarized in the following sections, were collected and assessed within the 10-year timeframe of the TMDL study (2007 through 2016) to identify impairments and determine existing water quality conditions. All stream water quality data were downloaded from the MPCA EQuIS database and EPA STORET/WQX for the most recent 10-year time period (2007 through 2016).

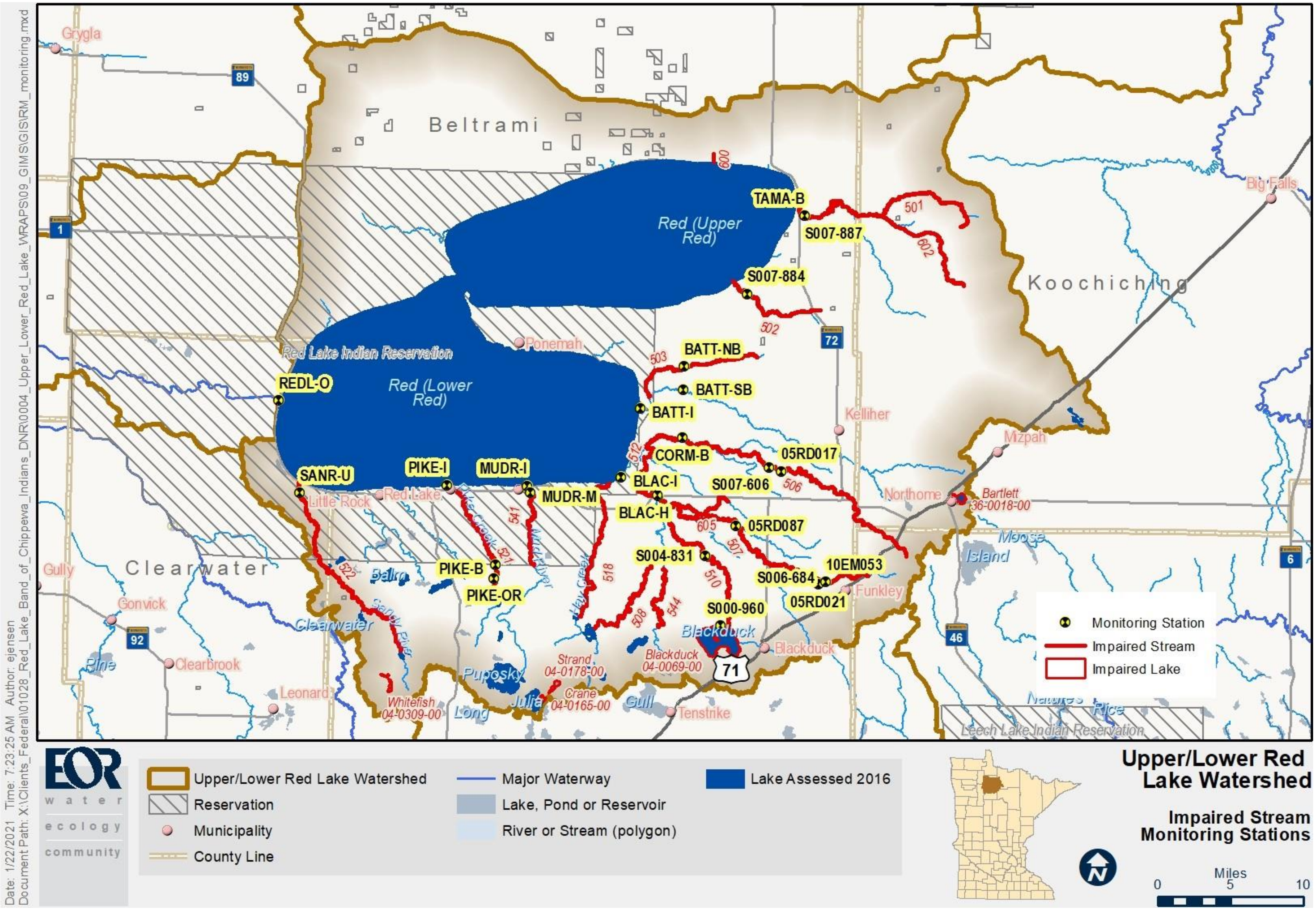


Figure 3-6. Monitoring Locations along Impaired Stream Reaches

3.5.3 Stream *Escherichia coli*

Twelve streams in the ULRLW have impaired aquatic recreation due to high *E. coli* concentrations. Using data from the most recent 10-year period (2007 through 2016), geometric mean *E. coli* concentrations were calculated by month for each impaired stream. Few *E. coli* monitoring data were available for the assessment; therefore, additional monitoring is recommended to verify the impairments.

3.5.3.1 Shotley Brook (-502)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for Shotley Brook (09020302-502) are reported in Table 3-5. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in August at Station S007-884.

Table 3-5. Ten-year geometric mean *E. coli* concentrations by month in Shotley Brook (09020302-502), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
S007-884	June	5	26.1	10.9	71.7	0
	July	5	73.5	19.9	770.1	0
	August	**5**	**128.7**	**52.0**	**186.0**	0

3.5.3.2 Battle River, North Branch (-503)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for Battle River, North Branch (09020302-503) are reported in Table 3-6. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in June through August, as well as greater than 10% of samples exceeding 1,260 org/100 mL in September, at Station BATT-NB (S003-962). Three instantaneous samples exceeded 1,260 org/100 mL on this reach.

Table 3-6. Ten-year geometric mean *E. coli* concentrations by month in Battle River, North Branch (09020302-503), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
BATT-NB (S003-962)	April	3	16.0	4.1	90.9	0
	May	6	37.0	5.2	88.4	0
	June	**12**	**128.1**	**28.8**	**461.1**	**0**
	July	**11**	**139.3**	**6.3**	**2500.0**	**1**
	August	**10**	**320.8**	**77.6**	**816.4**	**0**
	September	**6**	**40.6**	**1.0**	**1553.1**	**2**
	October	3	19.2	11.0	41.4	0

3.5.3.3 North Cormorant River (-506)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for North Cormorant River (09020302-506) are reported in Table 3-7. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in August at Station CORM_36 (S007-606), as well as greater than 10% of samples exceeding 1,260 org/100 mL in multiple months for multiple stations. Seven instantaneous samples exceeded 1,260 org/100 mL on this reach. More monitoring data was needed to confirm high *E. coli* at stations CORM_72 and CORM_102.

Table 3-7. Ten-year geometric mean *E. coli* concentrations by month in North Cormorant River (09020302-506) (upstream to downstream), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
CORM_72	May	2	72.7	20.3	260.3	0
	June	2	185.6	160.7	214.3	0
	July	2	114.2	104.3	125.0	0
	August	2	71.4	62.4	81.6	0
	September	2	45.3	36.4	56.3	0
CORM_36 (S007-606)	April	1	6.3	6.3	6.3	0
	May	**6**	**379.9**	**110**	**2419.6**	**1**
	June	**6**	**410.3**	**86.2**	**1299.7**	**1**
	July	4	347.7	191.8	866.4	0
	August	**5**	**677.3**	**186**	**2419.6**	**2**
	September	4	350.4	199	816.4	0
	October	3	411.2	117.8	980.4	0
CORM_102	May	2	47.3	44.3	50.4	0
	June	2	150.7	43.9	517.2	0
	July	2	57.2	34.1	96.0	0
	August	2	21.1	14.6	30.5	0
	September	2	56.5	49.6	64.4	0
CORM-B (S003-961)	April	3	25.0	21.8	29.8	0
	May	**8**	**62.0**	**6.3**	**1986.3**	**1**
	June	15	82.5	11.8	365.4	0
	July	**14**	**89.6**	**1.0**	**2500.0**	**2**
	August	11	108.4	20.0	987.0	0
	September	7	40	1	556.0	0
	October	1	42.0	42.0	42.0	0

3.5.3.4 South Cormorant River (-507)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for South Cormorant River (09020302-507) are reported in Table 3-8. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in June, July, and September, and instantaneous samples exceeding 1,260 org/100 mL in July and September at Station S004-834. The geometric mean standard was also exceeded in July at Station S007-883. Three instantaneous samples exceeded 1,260 org/100 mL on this reach.

Table 3-8. Ten-year geometric mean *E. coli* concentrations by month in South Cormorant River (09020302-507) (upstream to downstream), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
S004-834	April	3	19.5	10.8	62.4	0
	May	6	34.6	8.6	101.7	0
	June	**10**	**233.9**	**41.0**	**866.4**	**0**
	July	**8**	**209.7**	**34.5**	**1413.6**	**1**
	August	**9**	**114.2**	**25.6**	**980.4**	**0**
	September	**7**	**248.1**	**88.2**	**1413.6**	**1**
	October	5	92.3	16.6	727.0	0
S007-883	June	5	54.2	32.7	142.1	0
	July	**5**	**126.8**	**41.4**	**2419.6**	**1**
	August	5	123.8	30.5	740.0	0

3.5.3.5 Darrigans Creek (-508)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for Darrigans Creek (09020302-508) are reported in Table 3-9. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in May through October at Station S004-832. Ten instantaneous samples exceeded 1,260 org/100 mL on this reach.

Table 3-9. Ten-year geometric mean *E. coli* concentrations by month in Darrigans Creek (09020302-508), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
S004-832	April	3	32.8	15.0	118.7	0
	May	**7**	**149.6**	**26.5**	**435.2**	**0**
	June	**10**	**677.0**	**150.0**	**2419.6**	**2**
	July	**9**	**511.0**	**143.9**	**2419.6**	**1**
	August	**10**	**607.1**	**127.4**	**2489.0**	**3**
	September	**7**	**356.4**	**88.4**	**1986.3**	**2**
	October	**5**	**879.3**	**214.3**	**1732.9**	**2**

3.5.3.6 Blackduck River (-510)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for Blackduck River (09020302-510) are reported in Table 3-10. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in July and September at Station S004-831. One instantaneous sample exceeded 1,260 org/100 mL on this reach.

Table 3-10. Ten-year geometric mean *E. coli* concentrations by month in Blackduck River (09020302-510), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
S004-831	April	3	34.5	9.7	155.3	0
	May	6	26.7	5.2	57.6	0
	June	9	122.7	52.1	727.0	0
	July	**8**	**199.5**	**33.6**	**1553.1**	**1**
	August	11	91.7	30.1	285.1	0
	September	**6**	**158.9**	**53.8**	**344.8**	**0**
	October	4	62.5	37.3	104.6	0

3.5.3.7 Blackduck River (-512)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for Blackduck River (09020302-512) are reported in Table 3-11. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in August at Station BLAC-H. Three instantaneous samples exceeded 1,260 org/100 mL on this reach. More monitoring data was needed to confirm high *E. coli* levels at station BLAC-B.

Table 3-11. Ten-year geometric mean *E. coli* concentrations by month in Blackduck River (09020302-512) (upstream to downstream), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
BLAC-H	April	3	27.0	9.7	184.2	0
	May	**7**	**77.6**	**20.9**	**2419.6**	**1**
	June	**8**	**108.8**	**40.8**	**5000.0**	**1**
	July	**6**	**122.3**	**41.0**	**2500.0**	**1**
	August	**5**	**187.6**	**97.0**	**1203.3**	**0**
	September	5	86.7	17.1	517.2	0
	October	1	62.0	62.0	62.0	0
BLAC-B	May	1	24.9	24.9	24.9	0
	June	1	50.4	50.4	50.4	0
	July	2	69.2	36.4	131.4	0
	August	2	55.1	23.1	131.4	0
S007-882	June	5	23.6	9.7	48.1	0
	July	5	28.3	11.0	249.5	0
	August	5	21.2	16.1	33.6	0
BLAC-I	April	3	14.6	1.0	155.3	0
	May	6	9.7	1.0	42.6	0
	June	7	10.9	2.0	109.5	0
	July	6	16.0	4.1	35.0	0
	August	5	17.0	3.1	41.4	0
	September	5	20.0	8.6	38.9	0
	October	1	56.5	56.5	56.5	0

3.5.3.8 Hay Creek (-518)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for Hay Creek (09020302-518) are reported in Table 3-12. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in July and August at Station 10RD011 (S007-880). One instantaneous sample exceeded 1,260 org/100 mL on this reach.

Table 3-12. Ten-year geometric mean *E. coli* concentrations by month in Hay Creek (09020302-518), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100
10RD011 (S007-880)	June	5	34.9	12.1	95.9	0
	July	**5**	**151.1**	**52.1**	**1299.7**	**1**
	August	**5**	**159.9**	**101.2**	**365.4**	**0**

3.5.3.9 Sandy River (-522)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for Sandy River (09020302-522) are reported in Table 3-13. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in June and July at Station SANR-U. One instantaneous sample exceeded 1,260 org/100 mL on this reach. More monitoring data was needed to confirm high *E. coli* levels at monitoring station SANDY_32.

Table 3-13. Ten-year geometric mean *E. coli* concentrations by month in Sandy River (09020302-522) (upstream to downstram), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
SANDY_32	May	2	47.5	37.3	60.5	0
	June	2	41.9	27.2	64.4	0
	July	2	57.1	48.7	67.0	0
	August	2	86.9	85.7	88.2	0
	September	2	54.9	41.4	72.7	0
09RD003 (S007-877)	June	5	109.3	50.4	290.9	0
	July	6	98.1	63.8	166.4	0
	August	5	104.9	69.1	209.8	0
SANR-U	April	3	32.9	14.8	67.7	0
	May	6	39.4	16.0	93.3	0
	June	**7**	**160.0**	**60.5**	**410.6**	**0**
	July	**6**	**236.6**	**101.7**	**1299.7**	**1**
	August	4	201.7	77.6	410.6	0
	September	4	170.3	78.9	410.6	0
	October	1	21.6	21.6	21.6	0

3.5.3.10 Mud River (-541)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for Mud River (09020302-541) are reported in Table 3-14. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in June and July at Station MUDR-M (S007-881), and in June through September at Station MUDR-I. Four instantaneous samples exceeded 1,260 org/100 mL on this reach. More monitoring data was needed to confirm high *E. coli* levels at monitoring station MUDR-U.

Table 3-14. Ten-year geometric mean *E. coli* concentrations by month in Mud River (09020302-541) (upstream to downstream), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
MUDR-U	May	1	3.0	3.0	3.0	0
	June	2	176.0	75.4	410.6	0
	July	1	27.5	27.5	27.5	0
MUDR-M (S007-881)	April	3	5.4	4.1	7.3	0
	May	5	38.0	14.8	410.6	0
	June	**11**	**145.8**	**38.8**	**721.5**	**0**
	July	**10**	**114.3**	**25.9**	**2500.0**	**1**
	August	**10**	**81.7**	**25.6**	**1413.6**	**1**
	September	**5**	**128.8**	**38.6**	**344.8**	**0**
	October	1	30.5	30.5	30.5	0
MUDR-I	April	3	14.2	8.5	21.1	0
	May	5	38.3	17.5	228.2	0
	June	**7**	**230.0**	**43.5**	**1203.3**	**0**
	July	**6**	**178.6**	**21.6**	**2500.0**	**1**
	August	**5**	**132.1**	**27.5**	**1986.3**	**1**
	September	**5**	**256.8**	**145.0**	**435.2**	**0**
	October	1	36.8	36.8	36.8	0

3.5.3.11 O'Brien Creek (-544)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for O'Brien Creek (09020302-544) are reported in Table 3-15. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in June, July, September, and October at Station S004-833. Two instantaneous samples exceeded 1,260 org/100 mL on this reach.

Table 3-15. Ten-year geometric mean *E. coli* concentrations by month in O'Brien Creek (09020302-544), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100
S004-833	April	3	47.5	5.2	435.2	0
	May	6	77.7	43.5	160.7	0
	June	**10**	**181.8**	**24.3**	**1299.7**	**1**
	July	**8**	**254.1**	**63.8**	**686.7**	**0**
	August	7	89.8	1.0	579.4	0
	September	**7**	**171.8**	**33.1**	**579.4**	**0**
	October	**5**	**148.7**	**37.4**	**2419.6**	**1**

3.5.3.12 Unnamed creek (-600)

The 10-year (2007 through 2016) April through October monthly geometric mean *E. coli* concentrations for unnamed creek (09020302-600) are reported in Table 3-16. The *E. coli* impairment for this reach was due to a monthly geometric mean exceeding 126 org/100 mL in August at Station S007-888.

Table 3-16. Ten-year geometric mean *E. coli* concentrations by month in unnamed creek (09020302-600), 2007-2016. Bold values indicate a monthly geometric mean that exceeded the water quality standard of 126 org/100 mL for which there were at least 5 samples, or at least one sample that exceeded 1,260 org/100 mL.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100 mL)	Minimum (org/100 mL)	Maximum (org/100 mL)	No. of samples > 1,260 org/100 mL
S007-888	June	5	16.0	5.2	58.3	0
	July	5	80.4	23.1	365.4	0
	August	**5**	**169.6**	**93.3**	**579.4**	**0**

3.5.4 Stream Total Suspended Solids

Using data from the most recent 10-year period (2007 through 2016), the percent of TSS samples exceeding the North RNR standard of 15 mg/L, from April through September, were calculated for the following three stream reaches: North Cormorant River (09020302-506), Pike Creek (09020302-521), and Mud River (092020302-541).

3.5.4.1 North Cormorant River (09020302-506)

The 10-year (2007 through 2016) TSS water quality exceedances for the North Cormorant River (09020302-506) are reported in Table 3-17. The original TSS impairment listing for this reach was due to slightly greater than 10% of all samples collected between April and September exceeding the standard at stations CORM_102. However, the percent of samples exceeding 15 mg/L across all four monitoring stations is below 10%. Consequently, a TSS TMDL for this impaired reach is deferred and being considered for recategorization. To illustrate the seasonal variability in TSS concentration at each station, TSS data are shown by month for each monitoring station in Figure 3-7.

Table 3-17. Ten-year total suspended solids water quality exceedances by station in North Cormorant River (09020302-506), 2007-2016 (April – September). Bold values indicated a TSS water quality standard exceedance.

Monitoring Station (upstream to downstream)	No. of Samples	No. of Samples > 15 mg/L	% of Samples > 15 mg/L	90^{th} Percentile TSS Concentration (mg/L)*
CORM_72	10	0	0.0%	12.3
CORM_36 (S007-606)	26	1	3.8%	6.0
CORM_102	**10**	**1**	**10%**	**5.3**
CORM-B (S003-961)	94	9	9.6%	13.7
All Stations	140	11	7.9%	n/a

* TSS Samples below the detection limit were set to 0.5 mg/L, half the detection limit.

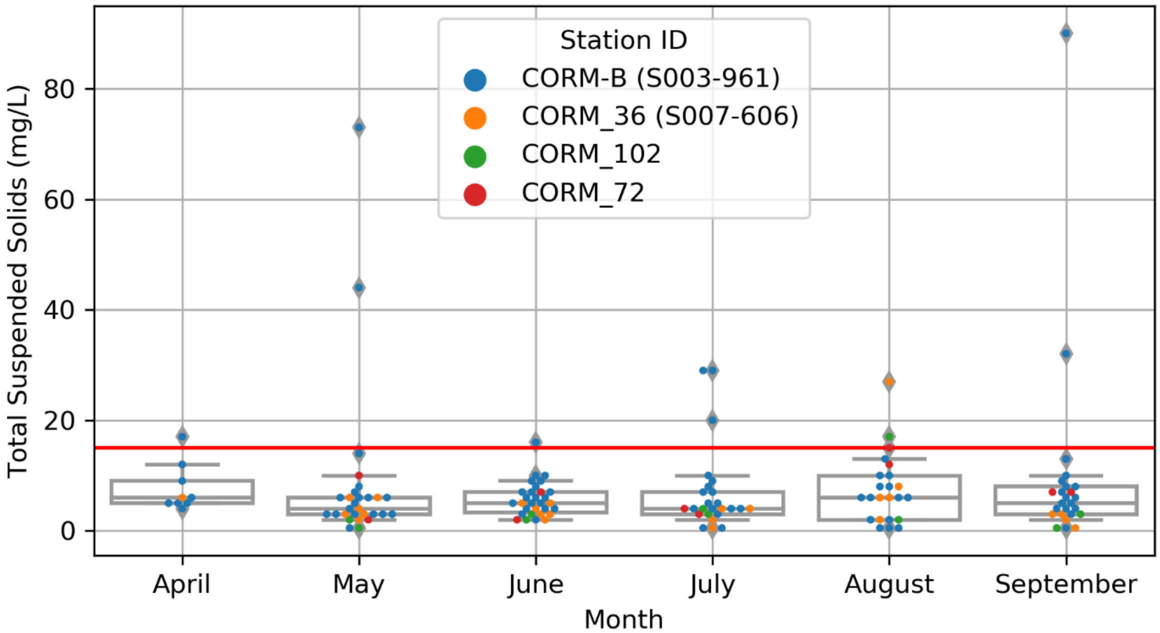


Figure 3-7. Total suspended solids (mg/L) by month in North Cormorant River (09020302-506).
The red line represents the TSS water quality standard for Northern Region Streams (15 mg/L).

3.5.4.2 Pike Creek (09020302-521)

The 10-year (2007 through 2016) TSS water quality exceedances for the Pike Creek (09020302-521) are reported in Table 3-18. The original TSS impairment listing for this reach was based on 10% of all samples collected between April and September exceeding the standard at monitoring station PIKE-B. However, the percent of samples exceeding 15 mg/L across all six monitoring stations is below 10%. To illustrate the seasonal variability in TSS concentration at each station, TSS data are shown by month for each monitoring station in Figure 3-8. The TSS exceedances at PIKE-B were due to erosion that occurred as a result of an incorrectly sized culvert upstream of the PIKE-B sampling station. The culvert was replaced in 2017 with a correctly sized culvert that is adequate for the flow of the stream without causing further erosion. This TMDL has been deferred while the reach is under consideration for recategorization.

Table 3-18. Ten-year total suspended solids water quality exceedances by station in Pike Creek (09020302-521), 2007-2016 (April – September). Bold values indicated a TSS water quality standard exceedance.

* TSS Samples below the detection limit were set to 0.5 mg/L, half the detection limit.

Monitoring Station (upstream to downstream)	No. of Samples	No. of Samples > 15 mg/L	% of Samples > 15 mg/L	90th Percentile TSS Concentration (mg/L)
PIKE-OR	67	1	1.5%	5.4
PIKE-B	65	5	7.7%	8.2
PIKE_FIRELINE	10	0	0%	2.8
PIKE_BARTONS	10	0	0%	0.65
S007-879	20	0	0%	5.6
PIKE-I (S002-970)	67	5	7.5%	11.4
All Stations	239	11	4.6%	n/a

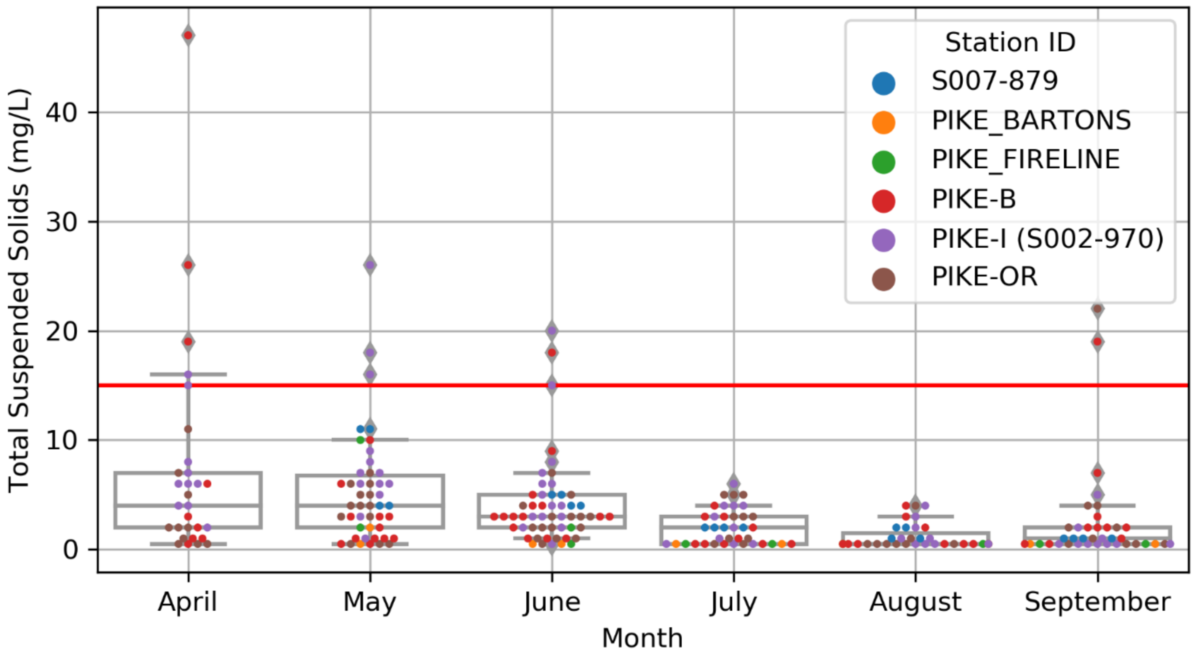


Figure 3-8. Total suspended solids (mg/L) by month in Pike Creek (09020302-521).
The red line represents the TSS water quality standard for Northern Region Streams (15 mg/L).

3.5.4.3 Mud River (09020302-541)

The 10-year (2007 through 2016) TSS water quality exceedances for the Mud River (09020302-541) are reported in Table 3-19. The TSS impairment for this reach was due to greater than 10% of all samples collected between April and September exceeding the standard at stations MUDR-M (S007-881) and MUDR-I. To illustrate the seasonal variability in TSS concentration at each station, TSS data are shown by month in Figure 3-9.

Table 3-19. Ten-year total suspended solids water quality exceedances by station in Mud River (09020302-541), 2007-2016 (April – September). Bold values indicated a TSS water quality standard exceedance.

Monitoring Station (upstream to downstream)	No. of Samples	No. of Samples > 15 mg/L	% of Samples > 15 mg/L	90th Percentile TSS Concentration (mg/L)
MUDR-M (S007-881)	**47**	**10**	**21%**	**20.4**
MUDR-I	**69**	**17**	**25%**	**28.4**
All Stations	116	27	23%	27.5

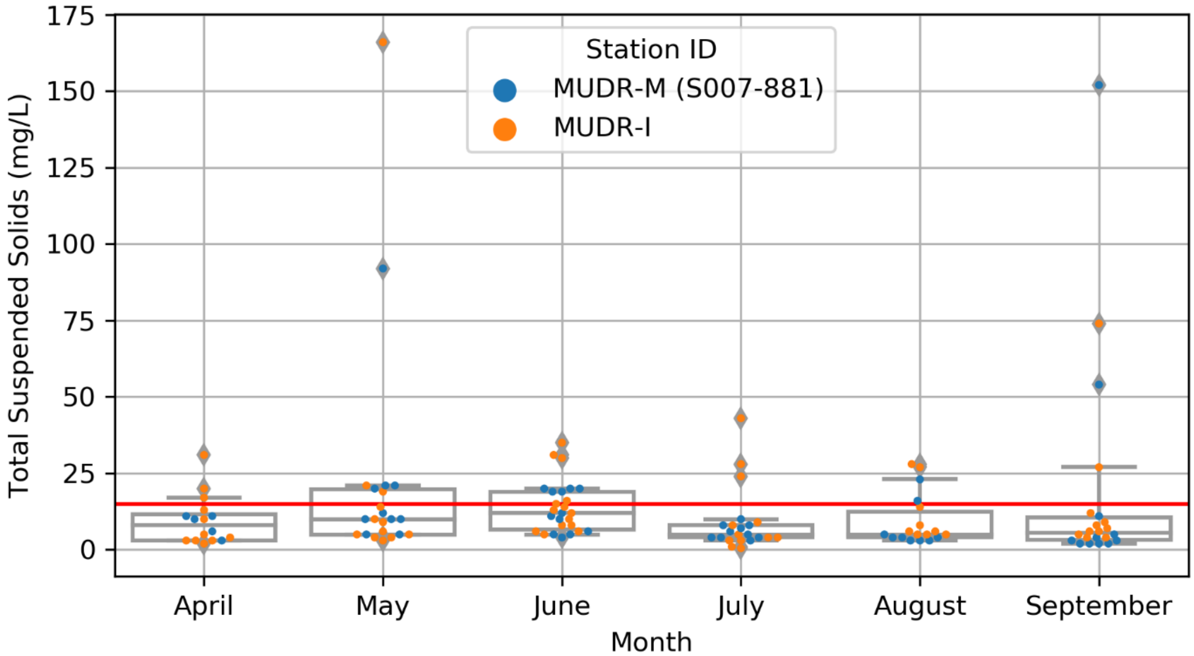


Figure 3-9. Total suspended solids (mg/L) by month in Mud River (09020302-544), 2007-2016.
The dashed red line represents the TSS water quality standard for Northern Region Streams (15 mg/L).

3.5.5 Stream Dissolved Oxygen

Ten-year (2007 through 2016) assessment statistics and instantaneous DO concentrations were summarized for the following four stream reaches impaired by low DO concentrations addressed in this TMDL study: Battle River, North Branch (09020302-503), North Cormorant River (09020302-506), Pike Creek (09020302-521), and O'Brien Creek (090203020-544).

3.5.5.1 Battle River, North Branch (09020302-503)

The 10-year (2007 through 2016) DO water quality standard exceedances for the Battle River, North Branch (09020302-503) are summarized by station and all stations on the assessment unit ID (AUID) in Table 3-20. The DO impairment for this reach was due to greater than 10% of all samples measuring less than 5 mg/L collected between May and September at both station BATT-NB (S003-962) and BATT-I. Instantaneous DO measurements are shown by month for each monitoring station in Figure 3-10.

Table 3-20. Ten-year DO water quality standard exceedances in Battle River, North Branch (09020302-503), 2007-2016. Bold values indicate a DO water quality standard exceedance (at least 20 independent samples are needed to assess for DO).

Monitoring Station (upstream to downstream)	Criteria	No. of Samples (N)	No. of Samples < 5 mg/L	% Samples < 5 mg/L (If N>19)
BATT-NB (S003-962)	Before 9 AM May - Sept.	**58**	**9**	**15%**
	All May - Sept.	**162**	**22**	**14%**
	Oct. - April	61	4	7%
BATT-I	Before 9 AM May - Sept.	**86**	**22**	**26%**
	All May - Sept.	**142**	**41**	**29%**
	Oct. - April	53	0	0%

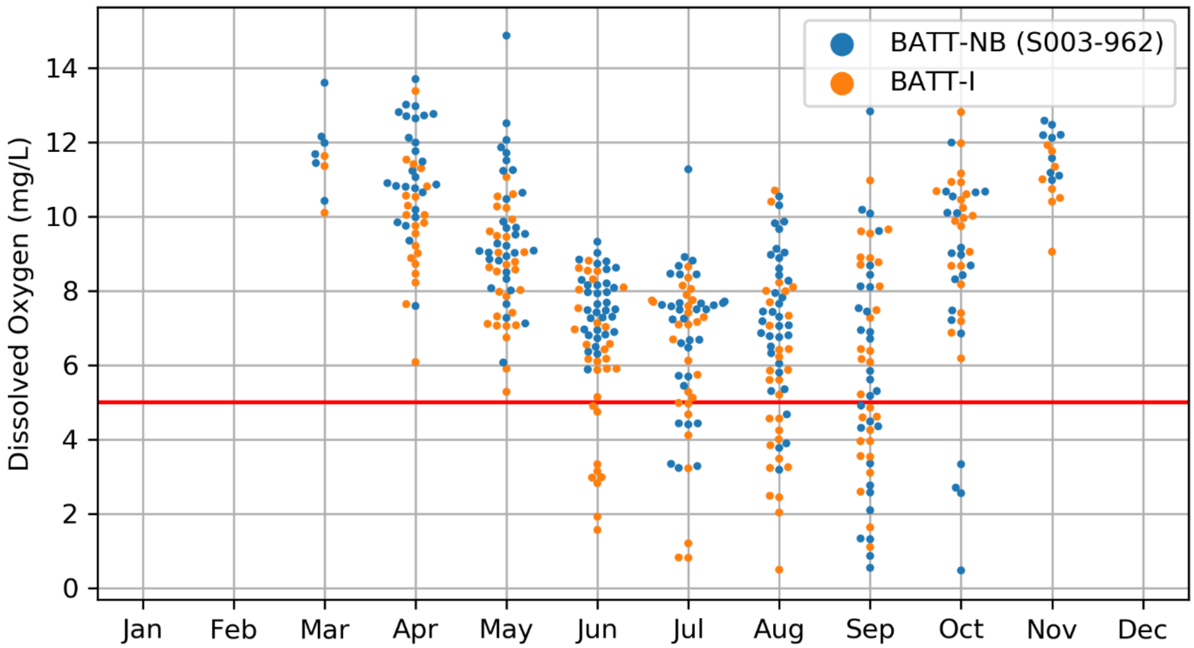


Figure 3-10. Dissolved oxygen (mg/L) by month in Battle River, North Branch (09020302-503) at monitoring station BATT-I, 2007-2016. The red line represents the DO standard for class 2B streams.

3.5.5.2 North Cormorant River (09020302-506)

The 10-year (2007 through 2016) DO water quality standard exceedances for the North Cormorant River (09020302-506) are summarized by station and all stations on the AUID in Table 3-21. The DO impairment for this reach was due to greater than 10% of all samples measuring less than 5 mg/L collected between May and September at both station CORM_72 and CORM-B (S003-961). Instantaneous DO measurements are shown by month for each monitoring station in Figure 3-11.

Table 3-21. Ten-year DO water quality standard exceedances in North Cormorant River (09020302-506), 2007-2016. Bold values indicate a DO water quality standard exceedance (at least 20 independent samples are needed to assess for DO).

Monitoring Station (upstream to downstream)	Criteria	No. of Samples (N)	No. of Samples < 5 mg/L	% Samples < 5 mg/L (If N>19)
CORM_72	Before 9 AM May - Sept.	0	0	IF
	All May - Sept.	10	3	IF
	Oct. - April	0	0	IF
CORM_36 (S007-606)	Before 9 AM May - Sept.	0	0	IF
	All May - Sept.	24	0	0%
	Oct. - April	4	0	IF
CORM_102	Before 9 AM May - Sept.	0	0	IF
	All May - Sept.	10	0	IF
	Oct. - April	0	0	IF
	Before 9 AM May - Sept.	**73**	**9**	**12%**

Monitoring Station (upstream to downstream)	Criteria	No. of Samples (N)	No. of Samples < 5 mg/L	% Samples < 5 mg/L (If N>19)
CORM-B (S003-961)	All May - Sept.	**162**	**29**	**18%**
	Oct. - April	61	3	5%

IF = insufficient data to assess for DO impairment (<20 independent samples)

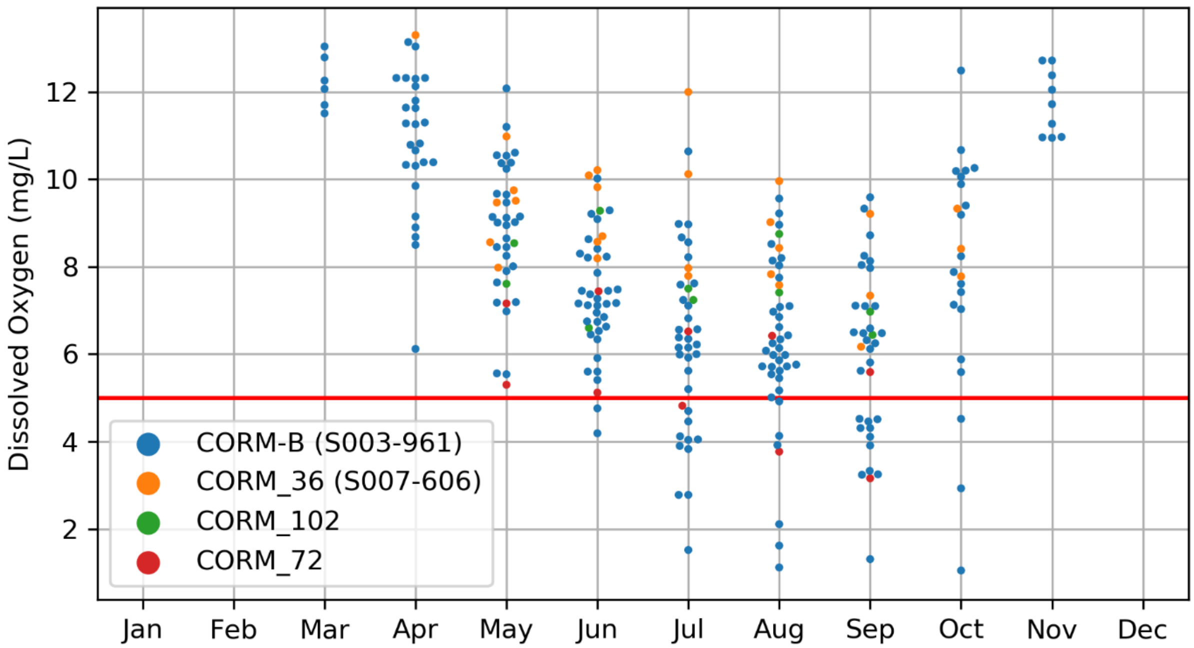


Figure 3-11. Dissolved oxygen (mg/L) by month in North Cormorant River (09020302-506) at monitoring station CORM-B (S003-961), 2007-2016. The dashed line represents the DO standard for class 2B streams.

3.5.5.3 Pike Creek (09020302-521)

The 10-year (2007 through 2016) DO water quality standard exceedances for Pike Creek (09020302-521) are summarized by station and all stations on the AUID in Table 3-22. The DO impairment for this reach was due to greater than 10% of all samples measuring less than 5 mg/L collected between May and September at stations PIKE-OR and PIKE-B. Instantaneous DO measurements are shown by month for each monitoring station in Figure 3-12.

Table 3-22. Ten-year DO water quality standard exceedances in Pike Creek (09020302-521), 2007-2016. Bold values indicate a DO water quality standard exceedance (at least 20 independent samples are needed to assess for DO).

Monitoring Station (upstream to downstream)	Criteria	No. of Samples (N)	No. of Samples < 5 mg/L	% Samples < 5 mg/L (If N>19)
PIKE-OR	Before 9 AM May - Sept.	**58**	**13**	**22%**
	All May - Sept.	**152**	**25**	**16%**
	Oct. - April	66	0	0%
PIKE-B	Before 9 AM May - Sept.	**53**	**25**	**47%**

Monitoring Station (upstream to downstream)	Criteria	No. of Samples (N)	No. of Samples < 5 mg/L	% Samples < 5 mg/L (If N>19)
	All May - Sept.	**146**	**58**	**39%**
	Oct. - April	**57**	**6**	**11%**
PIKE_FIRELINE	Before 9 AM May - Sept.	0	0	IF
	All May - Sept.	10	5	IF
	Oct. - April	0	0	IF
PIKE_BARTONS	Before 9 AM May - Sept.	0	0	IF
	All May - Sept.	10	0	IF
	Oct. - April	0	0	IF
S007-879	Before 9 AM May - Sept.	2	0	IF
	All May - Sept.	21	0	0%
	Oct. - April	0	0	IF
PIKE-I (S002-970)	Before 9 AM May - Sept.	37	0	0%
	All May - Sept.	159	0	0%
	Oct. - April	72	0	0%

IF = insufficient data to assess for DO impairment (<20 independent samples)

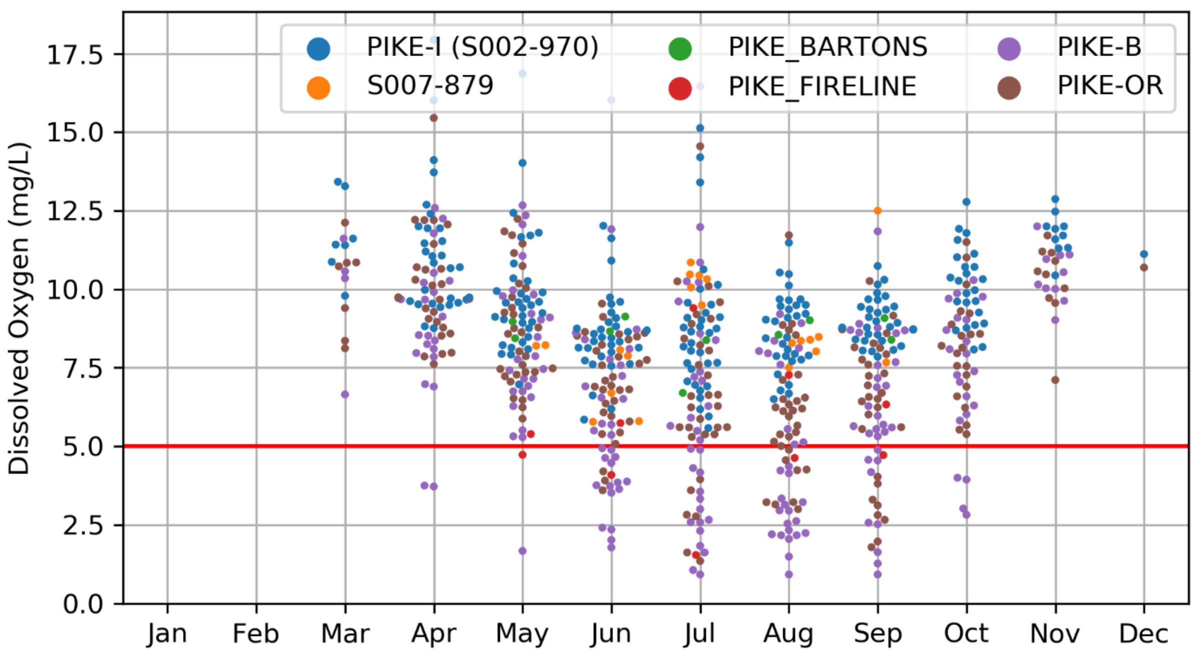


Figure 3-12. Dissolved oxygen (mg/L) by month in Pike Creek (09020302-521) at monitoring station PIKE-I, 2007-2016. The dashed line represents the DO standard for class 2B streams.

3.5.5.4 O'Brien Creek (09020302-544)

The 10-year (2007 through 2016) DO water quality standard exceedances for O'Brien Creek (09020302-544) are summarized by station in Table 3-23. The DO impairment for this reach was due to greater than 10% of all samples measuring less than 7 mg/L collected between May and September at station S004-833. Instantaneous DO measurements are shown by month for monitoring station S004-833 in Figure 3-13.

Table 3-23. Ten-year DO water quality standard exceedances in O'Brien Creek (09020302-544), 2007-2016. Bold values indicate a DO water quality standard exceedance (at least 20 independent samples are needed to assess for DO).

Monitoring Station (upstream to downstream)	Criteria	No. of Samples (N)	No. of Samples < 7 mg/L	% Samples < 7 mg/L (If N>19)
S004-833	Before 9 AM May - Sept.	0	0	IF
	All May - Sept.	**38**	**7**	**18%**
	Oct. - April	9	0	IF

IF = insufficient data to assess for DO impairment (<20 independent samples)

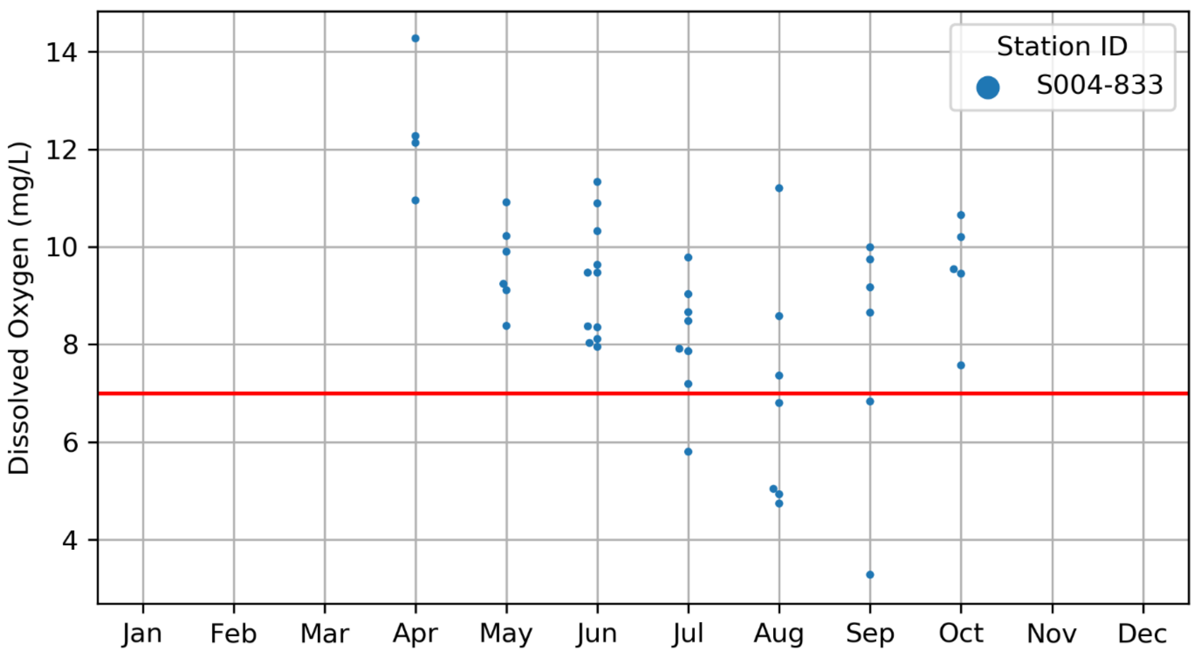


Figure 3-13. Dissolved oxygen (mg/L) by month in O'Brien Creek (09020302-544) at monitoring station S004-833, 2007-2016. The dashed line represents the DO standard for class 2A streams.

3.6 Pollutant Sources and Stressors Summary

Sources of pollutants in the ULRLW include permitted and nonpermitted sources. The phrase 'nonpermitted' does not indicate that the pollutants are illegal, but rather that they do not require a permit. Likewise, the term "permitted" indicates that these sources are regulated and limited by a federal and/or state permit. Some nonpermitted sources are unregulated, and some nonpermitted sources are regulated through instruments other than state permits, such as state and local regulations.

3.6.1 Permitted Sources

Regulated sources of pollutants include wastewater treatment facility (WWTF) effluent, National Pollutant Discharge Elimination System (NPDES) and State Disposal System (SDS) permitted and nonpermitted feedlots, regulated construction stormwater, and regulated industrial stormwater. Pollutant loads from NPDES-permitted wastewater and stormwater sources were accounted for using the methods described in subsequent sections.

Regulated Stormwater

Regulated stormwater delivers and transports pollutants to surface waters and is generated in the watershed during precipitation events. The sources of pollutants in stormwater are many, including decaying vegetation (leaves, grass clippings, etc.), domestic and wild animal waste, soil, deposited particulates from air, road salt, and oil and grease from vehicles. There are three potential types of regulated stormwater in the watershed:

Regulated Construction Stormwater

Construction stormwater is regulated by NPDES/SDS permits (MNR100001) for any construction activity disturbing: (a) one acre or more of soil, (b) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre, or (c) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The WLA for stormwater discharges, from sites where there are construction activities, reflects the number of construction sites greater than one acre in size that are expected to be active in the impaired lake or stream subwatershed at any one time.

Regulated Industrial Stormwater

Industrial stormwater is regulated by NPDES/SDS permits (MNR050000) if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in an impaired lake or stream subwatershed for which NPDES/SDS industrial stormwater permit coverage is required.

Municipal MS4 Permitted Communities

There are no Municipal Separate Storm Sewer Systems (MS4) permitted communities or communities that will require MS4 permits in the next 10 years within the ULRLW. The largest unregulated communities are Blackduck, Funkley, Northome, and Kelliher, and also the Reservation communities of Little Rock, Red Lake, Ponemah and Redby. Unregulated discharges from the nonreservation communities are included in the nonpermitted source estimate of watershed runoff as described in Section 3.6.2.

Municipal and Industrial Wastewater

Municipal wastewater is the domestic sewage and wastewater collected and treated by municipalities before being discharged to waterbodies as municipal wastewater effluent. Industrial wastewater is wastewater produced as a result of industrial processes that is collected and treated by the industry before being discharged to waterbodies as industrial wastewater effluent.

Municipal Wastewater

There are two WWTFs located within the drainage area of *E. coli* impaired streams in the ULRLW. The Blackduck WWTF, SDS permit MN0052302, is a stabilization pond system that discharges treated water through spray irrigation on land within the Blackduck River (-510) Subwatershed. The Kelliher WWTF, NPDES/SDS permit MNG585068, discharges to Bullhead Creek within the Battle River, North Branch (-503) Subwatershed.

The Kelliher WWTF is a relatively small stabilization pond system that is designed to treat 36,500 gallons per day of wastewater. Stabilization ponds are only allowed to discharge during certain discharge windows in the spring and fall of each year when stream flows tend to be at their greatest, as long as the receiving waters are not ice covered. The discharge windows for the Kelliher WWTF are March 1 through June 30 and September 1 through December 31. The permitted discharge from the Kelliher WWTF is limited to 6 inches per day from their secondary pond cell. The facility's secondary cell is 2.17 acres which limits the total daily discharge to a maximum of 353,710 gallons per day.

The Kelliher WWTF discharges to Bullhead Creek (-618) which flows to an unnamed creek (-523) that is over 4.5 miles long. It then joins the Battle River, South Branch (-539) about 20 miles upstream of its confluence with the Battle River, North Branch. Battle River, South Branch (-539) was assessed in 2016 and it was determined to be fully supporting its aquatic life and recreation uses, indicating that this stream reach assimilates the upstream discharge from the Kelliher WWTF without a detrimental effect on its water quality or designated uses.

There is one SDS-permitted WWTF whose surface discharge stations fall within a phosphorus impaired lake subwatershed (Blackduck WWTF). This WWTF is a stabilization pond system that discharges treated water through spray irrigation within the Blackduck Lake (04-0069) Subwatershed. No surface discharge is included in the permit for this facility, and irrigation on saturated soil or at rates that could cause overland run-off are prohibited in the permit.

Industrial Wastewater

There are two permitted industrial wastewater facilities located within the ULRLW. Both facilities hold nonmetallic mining general permits (MNG490000) for construction sand and gravel mining. These permits cover both industrial stormwater and wastewater, and allow discharges to waters of the state resulting from stormwater and uncontaminated groundwater produced by gravel pit dewatering.

Feedlots Requiring NPDES or SDS Permit Coverage

Of the approximately 47 animal feeding operations (AFOs) in the ULRLW (see Table 3-33 in Section 3.6.2.2), there are zero concentrated animal feeding operations (CAFOs). CAFOs are defined by the EPA based on the number and type of animals. The MPCA currently uses the federal definition of a CAFO in its permit requirements of animal feedlots along with the definition of an animal unit (AU). In Minnesota, the following types of livestock facilities are required to operate under an NPDES permit or a state issued SDS permit: a) all federally defined CAFOs that have had a discharge, some of which are under 1,000 AUs in size; and b) all CAFOs and nonCAFOs that have 1,000 or more AUs.

3.6.2 Nonpermitted Sources

3.6.2.1 Lake Phosphorus

This section provides a brief description of the potential sources in the ULRLW that contribute to excess nutrients in the impaired lakes. TP in lakes often originates on land. TP from sources such as phosphorus-containing fertilizer, manure, and the decay of organic matter can adsorb to soil particles. Wind and water action erode the soil, detaching particles and conveying them via stormwater runoff to nearby waterbodies where the TP becomes available for algal growth. Organic material, such as leaves and grass clippings, can leach dissolved TP into standing water and runoff, or be conveyed directly to waterbodies where biological action breaks down the organic matter and releases TP.

The following sources of TP that do not require an NPDES permit were evaluated:

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

Watershed runoff

The MPCA HSPF model for the ULRLW was used to estimate watershed runoff volumes (Figure 3-14) and TP loads (Figure 3-15) from the direct drainage area of impaired lakes. The HSPF model estimates the amount of daily overland runoff and stream flow, based on unique land cover and soil type combinations, and precipitation data. The HSPF model was calibrated for the time period 1996 through 2014. The HSPF model was used to estimate the eight-year (2007 through 2014) average annual flow and phosphorus load from the drainage area of each impaired lake, and daily streamflow estimates from 2007 through 2014 in the impaired streams. The HSPF TP loads for each lake in Table 3-24 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

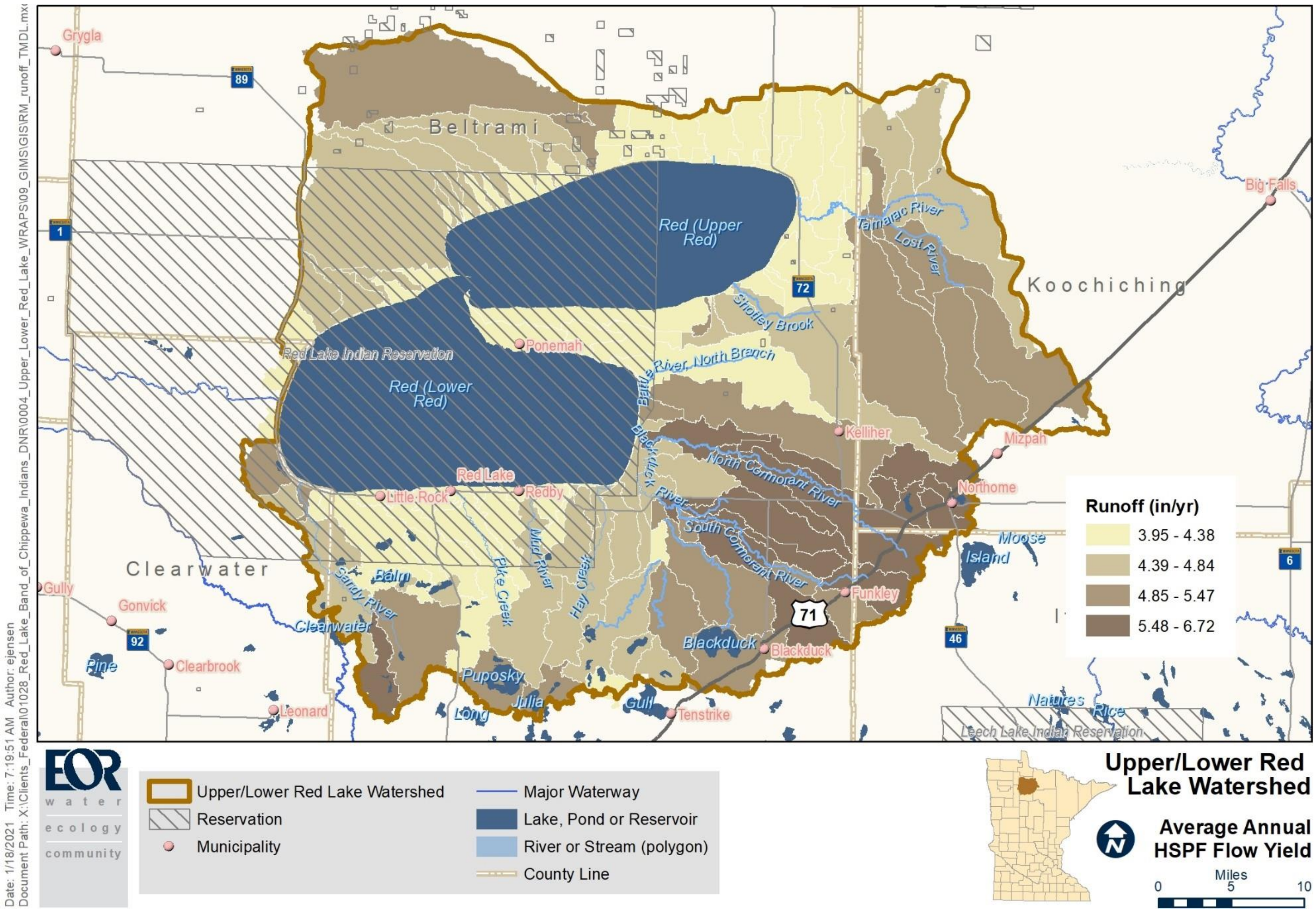


Figure 3-14. HSPF 2007-2014 average annual runoff flow yields by subbasin

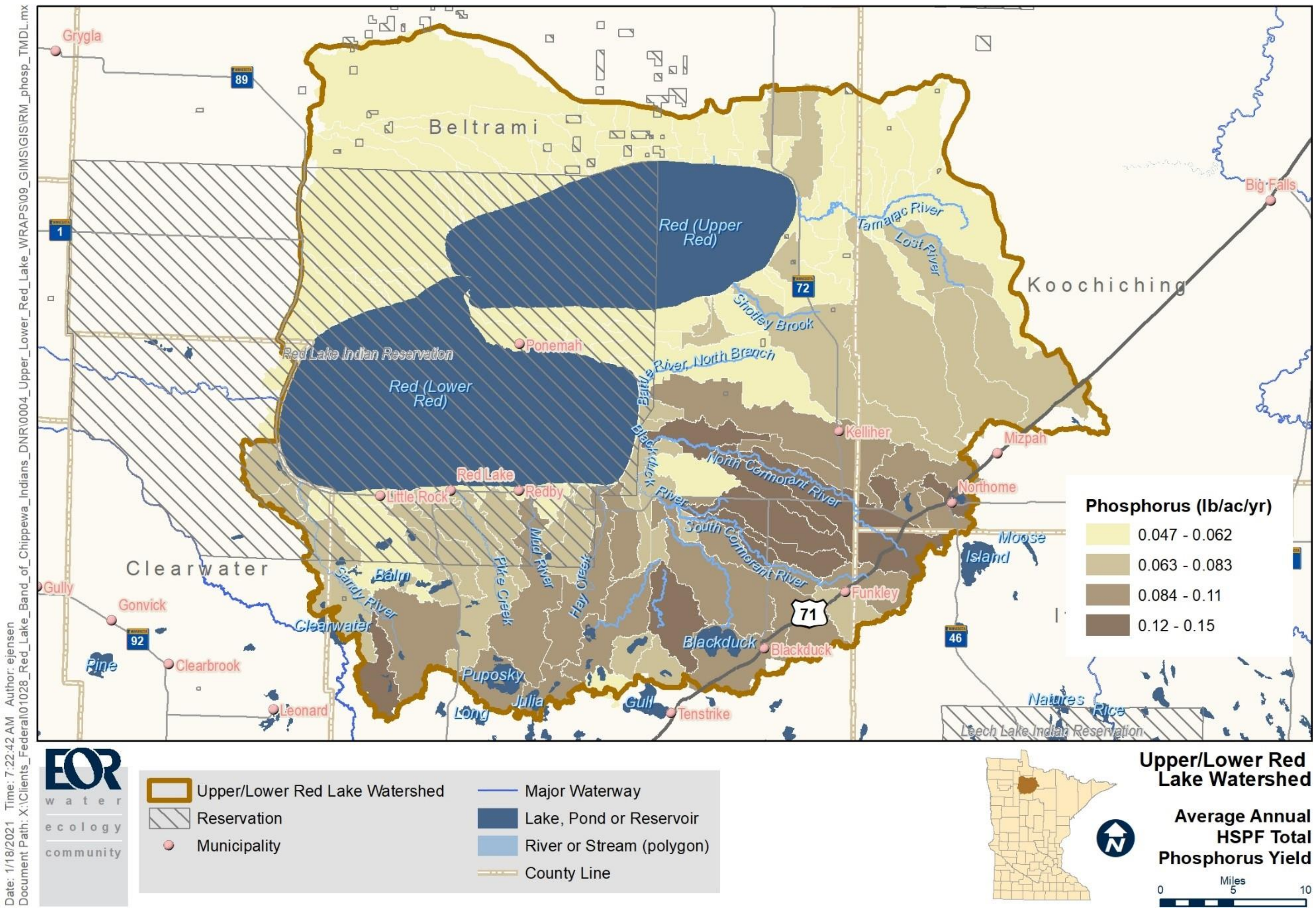


Figure 3-15. HSPF 2007-2014 average annual phosphorus yields by subbasin

Table 3-24. HSPF eight-year (2007-2014) average annual flow volumes and TP loads for lake direct drainage areas

Impaired lake or Upstream Lake	Direct drainage area (ac)	TP Conc. (µg/L)	Flow (ac-ft/yr)	TP Load (lb/yr)
Blackduck	12,913	25.8	5,922	416
Crane	248	30.3	135	11
Strand (North)	1,642	30.3	666	55
Whitefish (South)	4,903	74.6	2,020	410
Bartlett	1,701	33.0	994	89
Strand (South)*	374	30.3	172	14

* An uncalibrated BATHTUB model was developed to estimate the in-lake phosphorus concentration of Strand Lake (South Basin), which is upstream of Crane Lake.

Upstream lakes and streams

Upstream lakes and streams can contribute significant TP loads to downstream impaired lakes and streams. Water quality monitoring data and flow from upstream lakes and streams, summarized in Table 3-25, and were used to estimate the TP loads to downstream impaired waters. The total upstream lake loads in Table 3-25 were used to determine existing conditions in the TMDL Summary tables in Section 4.1.6.

No surface phosphorus concentration data has been collected from the Strand Lake South Basin from which to calculate the upstream lake phosphorus load from Strand Lake South Basin to Crane Lake. Therefore, watershed and upstream lake phosphorus loads and flows from HSPF (Table 3-24 and Table 3-25) were input into the BATHTUB model to predict the average in-lake phosphorus concentration of Strand Lake South Basin. This lake concentration was applied to the HSPF predicted flow to determine the upstream lake load to Crane Lake.

Table 3-25. Existing upstream phosphorus loads to impaired lakes and streams

Impaired Lake	Upstream Lake (Lake ID)	TP (µg/L)	Flow (ac-ft/yr)	TP Load (lb/yr)
Crane Lake	Strand Lake (South)*	29.7	795	64
Strand Lake (South)*	Strand Lake (North)	35.9	644	63

* An uncalibrated BATHTUB model was developed to estimate the in-lake phosphorus concentration of Strand Lake (South Basin), which is upstream of Crane Lake.

Nonpermitted feedlots

AFOs under 1,000 AUs and those that are not federally defined as CAFOs are not required to operate under NPDES or SDS permits. In Minnesota, feedlots with greater than 50 AUs, or greater than 10 AUs in shoreland areas, are required to register with the state. Facilities with AUs below these thresholds are not required to register with the state.

The animals raised in AFOs produce manure that is stored in piles, pits, lagoons, tanks, and other storage devices. The manure is then applied or injected to area fields as fertilizer. When stored and applied properly, this beneficial re-use of manure provides a natural source for crop nutrition. It also lessens the need for fuel and other natural resources that are used in the production of fertilizer. AFOs, however, can pose environmental concerns. Inadequately managed manure runoff from open lot feedlot facilities and improper application of manure can contaminate surface or groundwater.

Livestock are potential sources of fecal bacteria and nutrients to streams in the ULRLW, particularly when direct access to surface waters is not restricted and/or where feeding structures are located adjacent to riparian areas.

Animal waste from nonpermitted AFOs can be delivered to surface waters from failure of manure containment, runoff from the AFO itself, or runoff from nearby fields where the manure is applied. While a full accounting of the fate and transport of manure was not conducted for this project, a large portion of it is ultimately applied to the land surface and, therefore, this source is of possible concern. Minn. R. 7020.2225 contains several requirements for land application of manure; however, there are no explicit requirements for *E. coli* treatment prior to land application. Manure practices that inject or incorporate manure pose lower risk to surface waters than surface application with little or no incorporation. In addition, manure application on frozen/snow covered ground in late winter months presents a high risk for runoff.

Runoff during precipitation and snow melt can carry P from uncovered feedlots to nearby surface waters. For the purpose of this TMDL study, nonpermitted feedlots are defined as being all registered feedlots without an NPDES or SDS Permit that house under 1,000 AUs. While these feedlots do not fall under NPDES or SDS requirements, other regulations still apply. Phosphorus loads to impaired lakes, listed in Table 3-26 from nonpermitted, registered feedlots were estimated based on the estimate of phosphorus generated by AU type, the fraction of feedlots contributing to waters, and the phosphorus fraction lost to surface waters from the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004). The total annual feedlot loads for each lake in Table 3-26 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

Table 3-26. Feedlot assumptions and phosphorus loads to impaired lakes

Impaired Lake or Upstream Lake	Beef Cattle		Total P generated	Fraction of feedlots contributing to waters	P fraction lost to surface waters (average flow)	Total Annual Feedlot Load
	AU	lb/ AU-yr	lb/yr	%	%	lb/yr
Whitefish Lake	36.5	33.5	1,223	35	0.2	**0.9**

Subsurface sewage treatment systems

Phosphorus loads from SSTS were estimated based on assumptions described in the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004) and county specific estimates of failing septic systems rates based on the MPCA 2012 SSTS Annual Report, Appendix C. The total shoreline SSTS loads due to failing systems for each lake in Table 3-27 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

Table 3-27. SSTS assumptions and phosphorus loads to impaired lakes

Impaired Lake	Shoreline SSTS[a]	Seasonal residence (4 mo/yr)	Permanent Residence	Conforming Systems	Failing Systems[b]	Capita per Residence[c]	P Production per Capita	Conforming SSTS %P "passing"	Failing ISTS %P "passing"	Conforming Systems	Failing Systems	P Load Conforming SSTS	P Load Failing SSTS	Total Shoreline SSTS P Load	Total Shoreline SSTS P Load due to Failing
	#	%	%	%	%	#	lb/yr	%	%	#	#	lb/yr	lb/yr	lb/yr	lb/yr
Blackduck	297	0%	100%	93%	7%	2.57	1.95	20%	43%	276	21	277	45	321.9	24.2
Crane	9	0%	100%	93%	7%	2.57	1.95	20%	43%	8	1	8	2	10.2	1.2
Strand (North)	8	0%	100%	93%	7%	2.57	1.95	20%	43%	7	1	7	2	9.2	1.2
Whitefish (South)	13	0%	100%	93%	7%	2.57	1.95	20%	43%	12	1	12	2	14.2	1.2
Bartlett	2	0%	100%	50%	50%	2.20	1.95	20%	43%	1	1	1	2	2.7	**1.0**

[a] Based on counts of shoreline residences from current aerial imagery.

[b] Based on the estimate of percent of failing septic systems by County in the MPCA 2012 SSTS Annual Report Appendix C. https://www.pca.state.mn.us/sites/default/files/wq-wwists1-51.pdf.

[c] Based on the estimated number of people per household by County from the 2010 Census.

Atmospheric Deposition

Atmospheric deposition represents the TP that is bound to particulates in the atmosphere and is deposited directly onto surface waters. Average TP atmospheric deposition loading rates were approximately 0.233 pounds per acre (lb/ac) of TP per year for an average rainfall year for the Red River Basin (Barr 2007 addendum to MPCA 2004). This rate was applied to the lake surface area to determine the total atmospheric deposition load per year to the impaired lakes and streams. The total annual atmospheric deposition load for each lake in Table 3-28 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

Table 3-28. Atmospheric deposition phosphorus loads to impaired lakes (MPCA 2004)

Impaired Lake or Upstream Lake	Atmospheric Deposition Phosphorus Load (lb/yr)
Blackduck	625.3
Crane	25.1
Strand (North)	16.1
Whitefish (South)	19.2
Bartlett	77.4
Strand (South)*	16.1

* An uncalibrated BATHTUB model was used to estimate the in-lake phosphorus concentration of Strand Lake (South Basin), which is upstream of Crane Lake.

Internal Loading

Internal loading in lakes refers to the phosphorus within a lake's bottom sediments or aquatic plants that is released back into the water column. Internal loading can occur via the following:

1. *Chemical release from bottom sediments:* Caused by anoxic (lack of oxygen) conditions in the overlying water column layers or high pH (greater than nine). If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be distributed throughout the water column during fall mixing. In shallow lakes, the periods of anoxia can last for short periods of time and occur frequently.

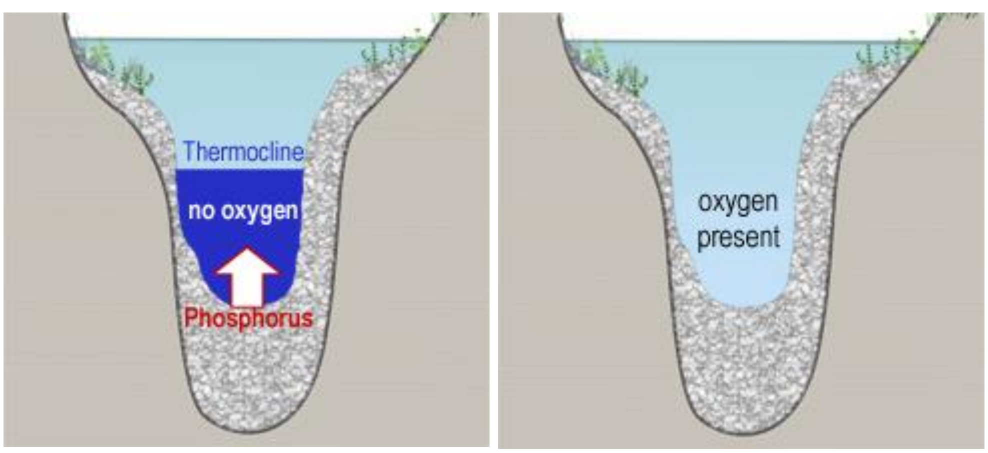


Figure 3-16. Sediment phosphorus release under anoxic (no oxygen) conditions in lakes (From: RMBEL https://www.rmbel.info/primer/total-phosphorus/)

2. *Physical disturbance of bottom sediments*: Caused by bottom-feeding fish bioturbation (such as carp and bullhead), motorized boat activity, and wind-driven mixing/wave action. This is more common in shallow lakes than in deeper lakes.
3. *Fish feeding and excretion*: Benthivorous (bottom feeding) fish move phosphorus from the sediment to the water by feeding on lake bottom food items, providing new phosphorus for algae growth. Some studies have shown that release of phosphorus from fish feeding can release more phosphorus than all other lake organisms combined, and can be on the same order of magnitude as external, watershed loading (Persson 1997; Brabrand et al. 1990).

Internal loading due to the anoxic release from the sediments of each lake was estimated based on the expected release rate of P from the lakebed sediment, the lake anoxic factor (AF), and the lake area. Lake sediment samples were collected and tested for concentration of TP and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound P. Phosphorus release rates were calculated using statistical regression equations and developed using measured release rates and sediment P concentrations from a large set of North American lakes (Nürnberg 1988; Nürnberg 1996). Internal loading due to physical disturbance is difficult to reliably estimate and was therefore not included in the lake P analyses. In lakes where internal loading is believed to be substantial, the internal load estimates derived from lake sediment data shown in Table 3-29 are likely an underestimate of the actual internal load. For example, the Nurnberg dataset tends to underpredict internal loading in shallow lakes due to the lack of shallow lakes included in the North American dataset used to develop the regression equations.

Some amount of internal loading is implicit in the BATHTUB lake water quality model; therefore, internal loading rates added to the BATHTUB model during calibration represents the excess sediment release rate beyond the average background release rate, accounted for by the model development lake dataset. The implicit amount of internal loading in BATHTUB is typically smaller than the calibrated BATHTUB rates for shallow lakes because the BATHTUB model development lake dataset is less representative of this lake type, and therefore accounts for less implicit internal loading in shallow lakes. Shallow lake sediments can easily be disturbed by wind-driven mixing of the water column or physical disturbance from boats and bottom-feeding fish.

Sediment samples were collected in December 2018 from three of the five impaired lakes (Crane, Strand North, and Whitefish). The Nurnberg internal loading estimates and the excess internal load estimates used to calibrate the BATHTUB models (see Section 4.1.1.1 Calibration) for the three lakes are shown in Table 3-29. The Nurnberg sediment TP release rates were similar to the BATHTUB excess internal load rates for all three lakes, suggesting that the BATHTUB excess internal load rates were reasonable for these impaired lakes. Therefore, the BATHTUB excess internal load rates were used to estimate the existing internal load in all five impaired lakes. The BATHTUB calibrated excess internal loads for each lake in Table 3-29 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

The 2018 Bartlett Lake In-Lake Management Alternatives Study (Appendix D) identified a diverse and health aquatic plant community and desirable game fish community that has been periodically unbalanced following periodic winterkill events. Given the low BATHTUB calibrated excess release rates in Bartlett Lake, the unbalanced fish community following periodic winterkills is likely contributing to internal loading in Bartlett Lake.

Table 3-29. Internal phosphorus load assumptions and summary

Impaired Lake	Lake Type	Monitored Sediment P Concentration (mg/kg dry)		Nurnberg Predicted Anoxic Factor	Nurnberg Estimated Total Sediment P Release Rate NA Lakes Dataset (mg/m^2-anoxic day)			Nurnberg Average Estimated Total Sediment P Release Rate NA Lakes Dataset	BATHTUB Calibrated Excess Release Rate	BATHTUB Calibrated Excess Internal Load
		Iron P (BD-P)	Total P (TP)	(days)	BD-P	TP	Average	(mg/m^2-calendar day)	(mg/m^2-calendar day)	(lb/yr)
Blackduck	Deep								0.204	**1,765**
Crane	Shallow	381	1600	47	4.65	1.85	3.25	0.41	0.328	**115**
Strand (North)	Shallow	524	1200	46	6.61	0.34	3.48	0.43	0.245	**55**
Whitefish (South)	Shallow	359	1200	63	4.35	0.34	2.34	0.41	1.34	**511**
Bartlett	Shallow								0.09	**97**

3.6.2.2 Stream *E. coli*

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

Microbial Source Tracking

The RL DNR collected water samples for MST and were filtered for microbial DNA from bacteria impaired streams during the months of August and September in 2017. These data were analyzed using five microbial biomarkers to identify potential source animals of the fecal pollution. For streams where pollution was detected, the source and concentration (low, moderate, or high) are listed in Table 3-30.

Table 3-30. Detected sources of *E. coli* by stream (August-September 2017)

Stream AUID	Stream Name	Anthropogenic Sources			Wildlife Sources	
		Ruminant	Human: Dorei	Human: EPA	Bird	Beaver
09020302-502	Shotley Brook				Low	
09020302-503	Battle River, North Branch	Moderate				Low
09020302-506	North Cormorant River	Moderate				Low
09020302-507	South Cormorant River					Low
09020302-508	Darrigans Creek	High		Low		
09020302-510	Blackduck River	Low				
09020302-512	Blackduck River					Low
09020302-518	Hay Creek				Low	Low
09020302-522	Sandy River				Low	Low
09020302-541	Mud River					Low
09020302-544	O'Brien Creek	Low			Low	Low
09020302-600	Unnamed creek		Low		Low	Low

Subsurface Sewage Treatment Systems

"Failing" SSTS are specifically defined as systems that are failing to protect groundwater from contamination. Failing SSTS were not considered a source of fecal pollution to surface water. However, systems which discharge partially treated sewage to the ground surface, road ditches, tile lines, and directly into streams, rivers and lakes are considered an IPHT. IPHT systems also include illicit discharges from unsewered communities (sometimes called "straight-pipes"). Straight pipes are illegal and pose an IPHT as they convey raw sewage from homes and businesses directly to surface water. Community straight pipes are more commonly found in small rural communities.

IPHT data are derived from surveys of county staff and county level SSTS status inventories. The MPCA's 2012 SSTS Annual Report provides the percentage of systems in unsewered communities that are IPHT for each county in Minnesota (Table 3-31). The number of IPHT within each impaired reach subwatershed was estimated based on the county IPHT percentages and the county population estimates from 2010 US Census data (U.S. Census Bureau 2011, Table 3-32). Most of the population within the impaired stream drainage areas resides within Beltrami County, which does not have data on failing SSTS systems. Instead, estimates were made based on the data for the greater Bemidji area. The greater Bemidji area Joint Powers Board lists no known IPHT, and therefore, IPHT systems are not expected to be a significant source of *E. coli* within the drainage areas of the impaired streams. The North Branch Battle River has a significant area of its watershed located in Koochiching County, which lists 10% of its SSTS systems as IPHT. Therefore, IPHT systems may be a significant source of *E. coli* within the drainage area of the Battle River.

Table 3-31. Estimate of %IPHT as reported by each county

County IPHT Estimates:	
County	**IPHT (as % of all septics)**
Beltrami	No Data
Clearwater	1%
Itasca	3%
Koochiching	10%

Table 3-32. Estimated IPHT within each impaired stream drainage area

Estimated IPHT within each impaired stream drainage area:			
Impaired Reach (09020302-XXX)	**2010 US Census Counts**		**Estimated number of IPHT**
	Population	**Households**	
-502	76	30	0 or 1
-503	814	336	13 or 14
-506	283	113	1 or 2
-507	457	179	0 or 1
-508	106	41	0
-510	1,531	596	0
-512	2388	931	0 or 1
-518	147	57	0
-522	305	119	1 or 2
-541	596	232	0
-544	214	83	0
-600	1	1	0

Livestock

Livestock have the potential to contribute bacteria to surface water through grazing activities or if their manure is not properly managed or stored. With the exception of pasture situations, livestock manure is typically collected and applied to nearby fields through injection, which significantly reduces the transport of bacteria contained in manure to surface waters. Pastures are not regulated in Minnesota, and therefore, pastured livestock in riparian areas can be a significant source of bacteria in streams and lakes. The population estimates provided in this study are meant to identify areas where livestock are located (Table 3-33). These areas should be monitored closely by each county to ensure proper management and storage of manure.

Table 3-33. MPCA registered active feedlots and animals by impaired stream subwatershed

Stream Name (AUID)	Number of Feedlots	Number of Animal Units (AU)
Shotley Brook (-502)	0	0
Battle River, North Branch (-503)	0	0
North Cormorant River (-506)	14	1,577
South Cormorant River (-507)	6	417
Darrigans Creek (-508)	6	1,108
Blackduck River (-510)	5	501
Blackduck River (-512)	0	0
Hay Creek (-518)	0	0
Sandy River (-522)	4	124
Mud River (-541)	8	572
O'Brien Creek (-544)	4	220
Unnamed Creel (-600)	0	0
Total	**47**	**4,519**

Beaver

Beaver activities in streams act as sources of fecal contamination. Beaver activity was noted for the Battle River, North Branch (-503) in the ULRLW SID Report (MPCA 2018). Aerial imagery from 2016 through 2019 was used to further validate the MST data. Table 3-34 summarizes the available data on beaver activity and impaired reaches which tested positive for MST beaver biomarkers within the ULRLW.

Table 3-34. Observed beaver activity and beaver biomarkers for streams impaired for *E. coli*.

Impaired Stream Reach	Noted Beaver Activity	MST Beaver Biomarker
Battle River, North Branch (-503)	Yes	Low
North Cormorant River (-506)	Potential	Low
South Cormorant River (-507)	Potential	Low
Blackduck River (-512)		Low
Hay Creek (-518)		Low
Sandy River (-522)	Potential	Low
Mud River (-541)	Potential	Low
O'Brien Creek (-544)	Potential	Low
Unnamed creek (-600)		Low

Birds

The presence of large numbers of birds on or near surface waters can act as sources of fecal contamination. See Table 3-35 for impaired reaches that tested positive for MST bird biomarkers.

Table 3-35. Bird biomarkers for streams impaired for *E. coli*.

Impaired Stream Reach	MST Bird Biomarker
Shotley Brook (-502)	Low
Hay Creek (-518)	Low
Sandy River (-522)	Low
O'Brien Creek (-544)	Low
Unnamed creek (-600)	Low

Summary

Desktop data and MST evidence for sources of bacteria to the impaired streams are summarized in Table 3-36. Two impaired streams had low concentrationsof a human biomarker, but no desktop data evidence for an IPHT in the impaired stream subwatershed. A septic survey should be considered in this subwatershed or additional MST data collection to verify the low biomarker detection from this TMDL study. Five impaired streams had low to high concentrations of the livestock biomarker and evidence for cattle in the drainage area. The livestock facilities and associated pastures and livestock access to water should be reviewed for proper manure management to address the bacteria impairments in these streams. All but two of the impaired streams had low concentrations of one or both of the beaver and bird biomarkers, suggesting a watershed-wide low level of natural background source of bacteria to streams in the ULRLW.

Table 3-36. Bacteria source summary by impaired stream subwatershed.

Impaired Stream Reach	Humans		Livestock		Beaver	Birds
	Estimated Number of IPHT	MST Biomarker	Active Registered Feedlots (Animal Units, AUs)	MST Biomarker	MST Biomarker	MST Biomarker
Shotley Brook (-502)	0 or 1		0			Low
Battle River, North Branch (-503)	13 or 14		0	Moderate	Low	
North Cormorant River (-506)	1 or 2		14 (1,577 AUs)	Moderate	Low	
South Cormorant River (-507)	0 or 1		6 (417 AUs)		Low	
Darrigans Creek (-508)*	0	Low	6 (1,108 AUs)	High		
Blackduck River (-510)	0		5 (501 AUs)	Low		
Blackduck River (-512)*	0 or 1		0		Low	
Hay Creek (-518)*	0		0		Low	Low
Sandy River (-522)	1 or 2		4 (124 AUs)		Low	Low
Mud River (-541)	0		8 (572 AUs)		Low	
O'Brien Creek (-544)	0		4 (220 AUs)	Low	Low	Low
Unnamed creek (-600)	0	Low	0		Low	Low

*TMDLs were deferred for these reaches.

3.6.2.3 Stream Total Suspended Solids

The HSPF model was used to simulate nonpermitted sources of TSS in the ULRLW. HSPF has been used extensively in Minnesota and nationwide in support of TMDLs to simulate the complex nutrient cycling associated with P, nitrogen, DO, algal growth, and biological oxygen demand. The model splits a watershed into small segments based on unique combinations of homogenous soils, land slope, land cover, and climate. From these segments, daily landscape hydrology and water quality are simulated and routed through the channel network to the watershed outlet. The model was calibrated and run using data from 1996 to 2014. The predicted average annual total sediment yields from the HSPF model are summarized in Figure 3-17. Sediment yields are higher in the lower portions of the ULRLW where agriculture is more prevalent.

The HSPF model predicted the relative contribution of TSS sources to the three TSS impaired stream reaches: North Cormorant River, Pike Creek and Mud River (Figure 3-18). Shotley Brook and Darrigans Creek were also included in this analysis due to the sediment stressor to the macroinvertebrate community identified from the SID study (MPCA 2018a). Stream bed and bank erosion were the dominant sources of sediment to Shotley Brook, Mud River, and Pike Creek. Bank erosion and agricultural land uses were the dominant sediment sources to the North Cormorant River, and developed and agricultural land uses were the dominant sediment source to Darrigans Creek. These sources of sediment were similar to the findings of the SID study conducted by the MPCA (2018a). According to MPCA, high TSS levels in the impaired streams are due to channel instability, bank erosion from cattle access, hydrologic alterations through significant ditching, and land use changes from wetlands to open pasture and cropland. There are no major point sources of TSS in the impaired stream subwatersheds.

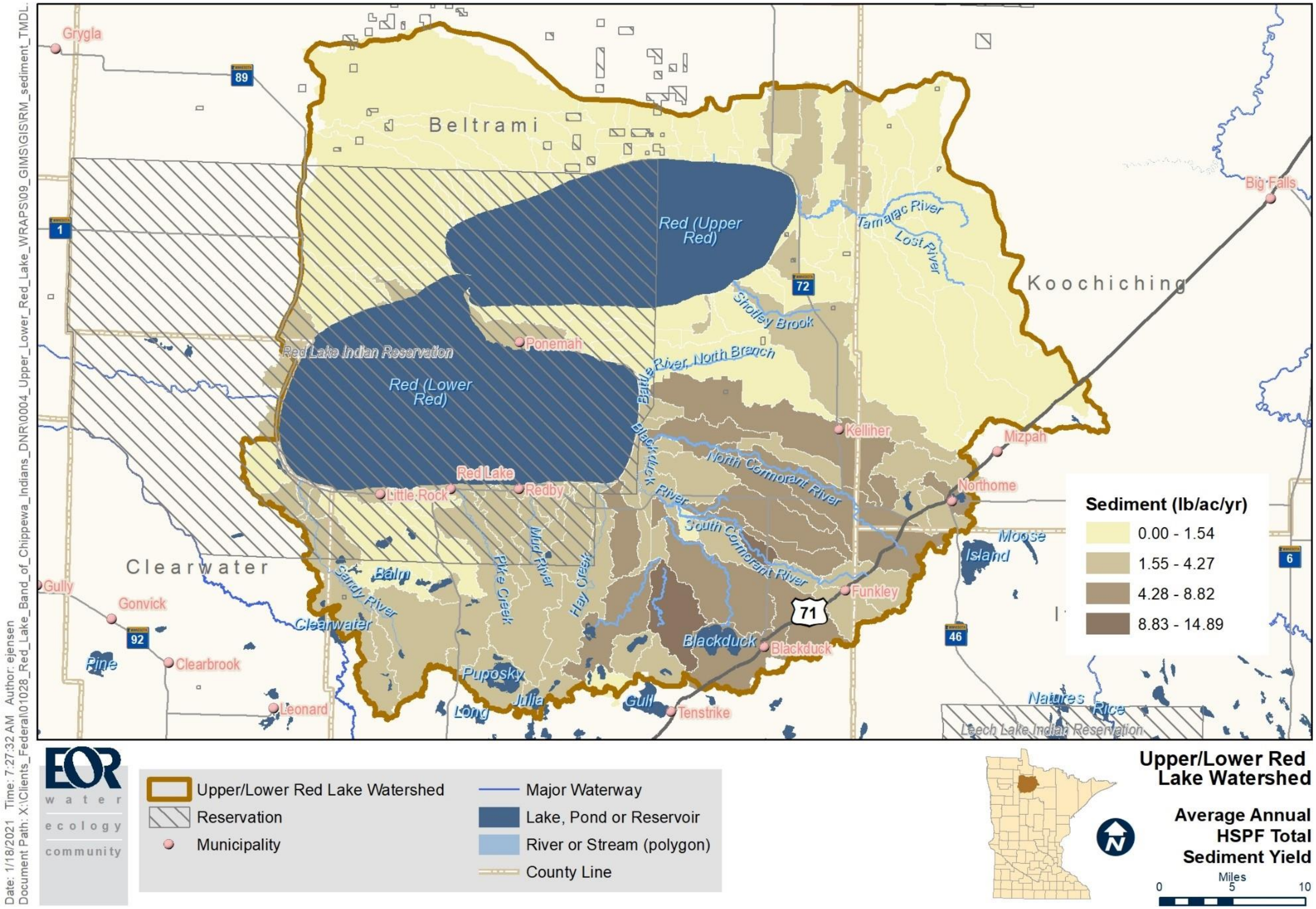


Figure 3-17. HSPF 2007-2014 average annual total sediment yields by subwatershed

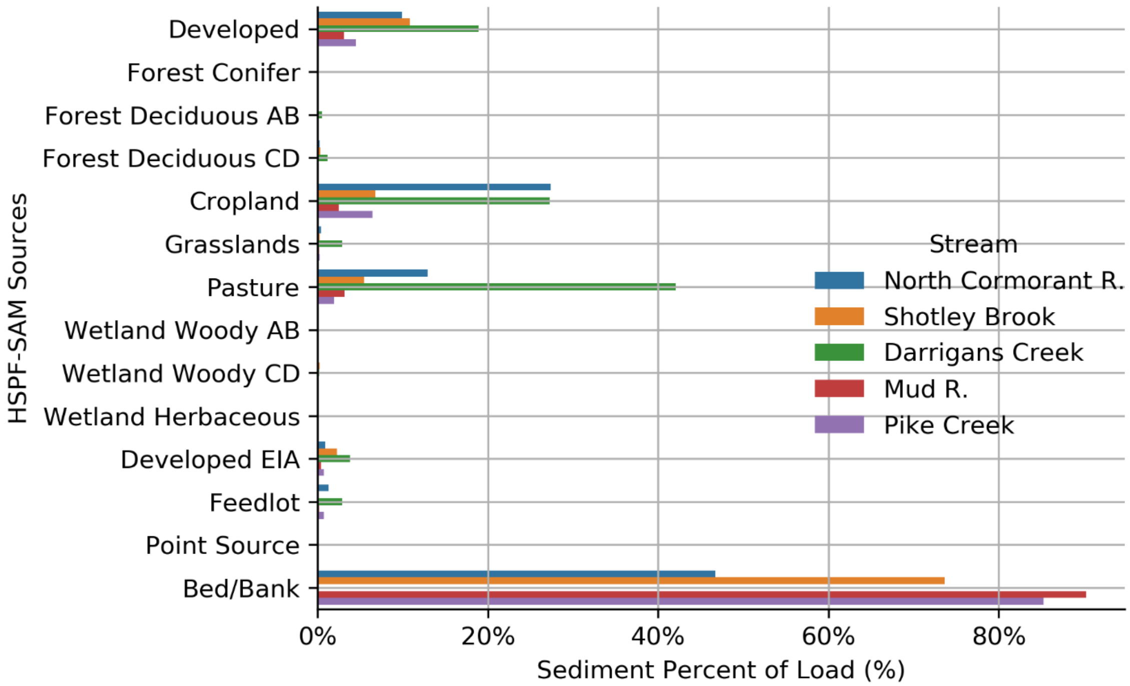


Figure 3-18. HSPF modeled sediment load percent of total by source and impaired stream

3.7 Linkage of the Impairments and Stressors

The following section provides the linkage between the lake and stream impairments in the ULRLW and the pollutant-based stressors that will be addressed by TMDLs in this study. Those links were not able to be made for 16 impairments in the ULRLW. These impairments will be addressed through restoration strategies identified in the WRAPS report.

3.7.1 Lake Eutrophication

The lake eutrophication impairments in the ULRLW were characterized by phosphorus and Chl-*a* concentrations, and Secchi transparency depths that failed to meet the state water quality standards. Excessive nutrient loads, in particular TP, lead to an increase in algal blooms and reduced transparency – both of which may significantly impair or prohibit the use of lakes for aquatic recreation. The TMDL study developed phosphorus lake response models and calculated phosphorus TMDLs for the five lake eutrophication impairments:

- 36-0018-00: Bartlett Lake
- 04-0069-00: Blackduck Lake
- 04-0165-00: Crane Lake
- 04-0178-00: Strand Lake
- 04-0309-00: Whitefish Lake

3.7.2 Stream *E. coli*

The stream bacteria impairments in the ULRLW were characterized by high *E. coli* concentrations during June through September. Minnesota *E. coli* water quality standards were developed to directly protect for primary (swimming and other recreation where immersion and inadvertently ingesting water is likely) and secondary (boating and wading where the likelihood of ingesting water is much less) body contact during the warm season months, as there is very little swimming in Minnesota during the cold season months. The TMDL study developed *E. coli* LDCs and TMDLs for the nine *E. coli* impairments that were linked to anthropogenic sources (human or ruminant) identified through MST (see Section 3.6.2.2):

- 09020302-503: Battle River, North Branch
- 09020302-506: North Cormorant River
- 09020302-507: South Cormorant River
- 09020302-508: Darrigans Creek
- 09020302-510: Blackduck River, Blackduck Lk to O'Brien Ck
- 09020302-522: Sandy River
- 09020302-541: Mud River
- 09020302-544: O'Brien Creek
- 09020302-600: Unnamed creek

A linkage to anthropogenic sources could not be made for three *E. coli* impairments. These impairments are being deferred while MPCA considers recategorization to category 4D, as indicated in Table 1-1. Evidence of wild bird and beaver sources of *E. coli* was from MST results (see Section 3.6.2.2).

- 09020302-502: Shotley Brook
- 09020302-512: Blackduck River, South Cormorant R to North Cormorant R
- 09020302-518: Hay Creek

3.7.3 Stream Total Suspended Solids

The stream aquatic life impairments due to TSS in the ULRLW were characterized by high TSS levels. TSS is a measure of suspended sediment in water and the primary cause of turbidity in the ULRLW. Turbidity is a physical characteristic of water that describes the degree to which light is scattered and absorbed in the water column (therefore reducing water clarity). Turbidity is caused by suspended sediment or impurities, such as clay, silt, fine organic matter, algae, and other organic and inorganic sources. This study developed a TSS LDC and TMDL for one TSS impaired reach where sediment stressors were linked to watershed or bed/bank sources:

- 09020302-541: Mud River

Two TSS impaired reaches are being considered for recategorization to 4B and potential future de-listing:

- 09020302-506: North Cormorant River - recent water quality data meets the TSS water quality standard (see Section 3.5.4.1). This reach is being considered for recategorization to 4B and potential future de-listing.
- 09020302-521: Pike Creek - The biological impairments on Pike Creek were largely due to a culvert sizing issue. This culvert has been replaced. Recent water quality data meets the TSS water quality standard (see Section 3.5.4.2). This reach is being considered for recategorization to 4B and potential future de-listing.

3.7.4 Stream Fish and Macroinvertebrate Bioassessments

The fish and/or macroinvertebrate bioassessment impairments in the ULRLW were characterized by low Index of Biological Integrity (IBI) scores for fish and/or macroinvertebrates. The presence of a diverse and reproducing aquatic community is a good indication that the aquatic life beneficial use is being supported by a lake or stream. The aquatic community integrates the cumulative impacts of pollutants, habitat alteration, and hydrologic modification on a waterbody over time. Characterization of an aquatic community is accomplished using IBI, which incorporates multiple attributes of the aquatic community, called “metrics”, to evaluate complex biological systems. For further information regarding the development of stream F-IBI and M-IBI, refer to MPCA 2014a and MPCA 2014b listed in the references at the end of this report.

In 2018, the MPCA completed a SID study to determine the cause of low fish and M-IBI scores in the ULRLW. The SID study results are summarized by AUID number in Table 3-37. While sediment/TSS was identified as a stressor for three aquatic life impairments, the root cause of the sediment stressor was altered hydrology or channel alterations. Because the linkage between the impairments and sediment/TSS was weak, TSS TMDLs were not developed for the following list of seven fish/macroinvertebrate impairments. The nonpollutant based stressors (connectivity, altered hydrology, channel alteration, and habitat) that are driving these impairments and identification of restoration strategies will be addressed through the WRAPS process:

- 09020302-501: Tamarac River (Fish bioassessments) - The primary stressors for fish impairment are low DO and altered hydrology. The subwatershed has a large wetland system that is likely contributing wetland-sourced (low DO) water to the river. The hydrology has been altered through historical bog ditching creating less stable conditions in the stream and more easily allow the wetland-sourced water a direct route to the stream.
- 09020302-502: Shotley Brook (Macroinvertebrate bioassessments) - Altered hydrology and sand-based TSS are the main stressors for the macroinvertebrate community. The altered hydrology mainly is the result of wetland ditches creating higher peak flows, which lead to an unstable habitat. Suspended sand traveling through the stream during periods of high flow degrades habitat and may also damage macroinvertebrate tissues from abrasion.

- 09020302-503: Battle River, North Branch (Fish bioassessments) - Available evidence supports lack of base flow and loss of physical connectivity (for fish) due to altered hydrology as a stressor. Trenches dug for drainage of headwater-area bogs contribute to flashy flows and a new beaver dam that was constructed between 2013 through 2015 created a physical barrier for connectivity.
- 09020302-508: Darrigans Creek (Macroinvertebrate bioassessments) - Excess of fine particulate sediment is the main stressor caused by cattle trampling the stream banks leading to bank erosion. A lack of a natural buffer along the stream is also contributing to erosion and habitat degradation.
- 09020302-521: Pike Creek (Macroinvertebrate bioassessments) - The biological impairments on Pike Creek were largely due to a culvert sizing issue. This culvert has been replaced.
- 09020302-602: Lost River (Fish bioassessments) - The primary stressors for fish impairment are low DO and channel alteration. The main source of water in the stream is from a large bog where seepage through peat soils removes a lot of oxygen from the water. Segments of the stream have been straightened in order to accommodate adjacent rice fields and could be contributing to habitat loss within the stream.
- 09020302-605: Perry Creek (Fish bioassessments) - Available evidence supports lack of base flow and loss of physical connectivity (for fish) as the main stressors. Beavers are very active in the area and have created physical barriers for migration, as well as some debris accumulation in culverts. This area of the watershed can experience droughts in late summer months that contribute to low flow volumes. There is no evidence that lower flows are caused by human influence.

Table 3-37. Summary of stressors causing biological impairment in ULRLW streams by location (AUID)

Stream	AUID Last 3 digits	Aquatic Life Impairment	Stressor								
			Dissolved Oxygen	Phosphorus	Sediment/ TSS	Connectivity	Altered Hydrology	Channel Alteration	Habitat	Temperature	Wetland Export
Tamarac River	-501	F-IBI	●				♦				
Shotley Brook	-502	M-IBI			●		♦	●	●		
Battle River, North Branch	-503	F-IBI	●			●	✧				
North Cormorant River	-506	DO, TSS			●		♦	●	●	●	?
Darrigans Creek	-508	M-IBI			●			♦			
Pike Creek	-521	DO, M-IBI, TSS					✧			●	?
O'Brien's Creek	-544	DO					✧			●	?
Lost River	-602	F-IBI	●		?			?	?		
Perry Creek	-605	F-IBI				○	○				

● Determined to be a direct stressor
♦ A "root cause" stressor, which causes other consequences that become the direct stressors.
✧ Possible contributing root cause
○ A stressor, but anthropogenic contribution, if any, not quantified. Includes beaver dam as a natural stressor
? Inconclusive

3.7.5 Dissolved Oxygen

Aquatic life impairments in Battle River, North Branch (09020302-503), North Cormorant River (09020302-506), Pike Creek (09020302-521), and O'Brien Creek (09020302-544) were triggered by low DO levels. The Pike Creek and O'Brien Creek DO impairments were not included in the MPCA SID study (2018a). An analysis was conducted as part of this TMDL study to determine the cause of low DO levels in each of these reaches. Potential causes of low DO in these reaches investigated include low or stagnant flow, high water temperatures, and nutrients (eutrophication). Because the potential causes of these DO impairments are nonpollutant based, these TMDLs will be deferred and the impairments may be recategorized.

Current DO conditions in these stream reaches are summarized in Section 3.5.5.

Stream Flow

DO levels can be greatly affected by water agitation; increased water agitation increases DO levels by causing more oxygen from the air to be dissolved into surface waters. Decreased stream flow and water movement may result in lower levels of DO due to lower rates of diffusion from the air. Flow conditions for each impaired reach based on HSPF modeled daily continuous flow records for 2007 through 2014 are summarized in Table 3-38. Median flows for the impaired reaches ranged from 3.6 to 7.4 cfs.

Paired DO and flow records can be used to assess if DO levels are influenced by certain flow conditions. Paired DO and flow records from these stream reaches are summarized in Figure 3-19 through Figure 3-22 below. Paired DO and flow records were also considered for DO levels that were less than the water quality standard (5 mg/L) during the impairment assessment period (May through September) and compared to the median flow for each impaired reach (Figure 3-23 through Figure 3-26). For paired DO and flow records across the entire range of stream flows modeled, there appears to be some relationship between increasing DO with increasing flows. However, DO records less than 5 mg/L occurred above and below median flows. Therefore, there is no strong evidence that low or stagnant flow conditions are a probable cause of low DO (< 5 mg/L) in the impaired reaches.

Table 3-38. Flow conditions for impaired reaches as a percent of time flow is exceeded

Impaired reach	Percent of time flow exceeded		
	10% (Very low flow)	25% (Low flow)	50% (Median flow)
Battle River, North Branch (-503)	1.1	2.0	3.6
North Cormorant River (-506)	1.8	3.7	7.4
Pike Creek (-521)	1.2	2.6	5
O'Brien Creek (-544)	1.4	2.9	5.8

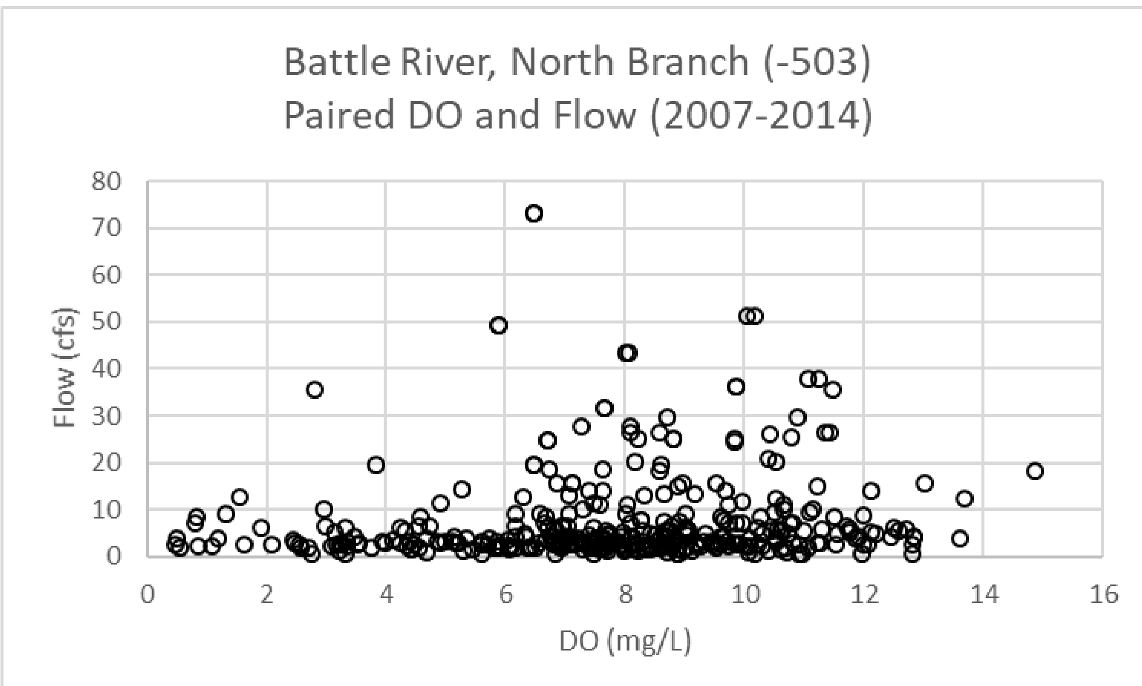


Figure 3-19. Battle River, North Branch (-503) paired DO and flow (2007-2014)

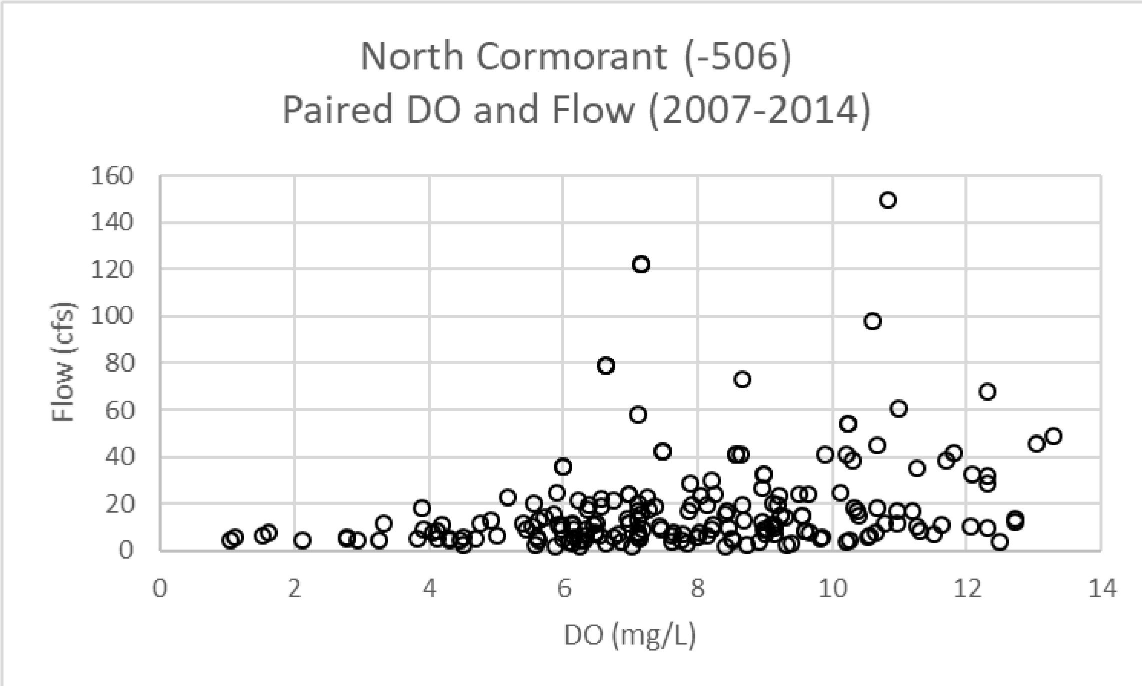


Figure 3-20. North Cormorant River (-506) paired DO and flow (2007-2014)

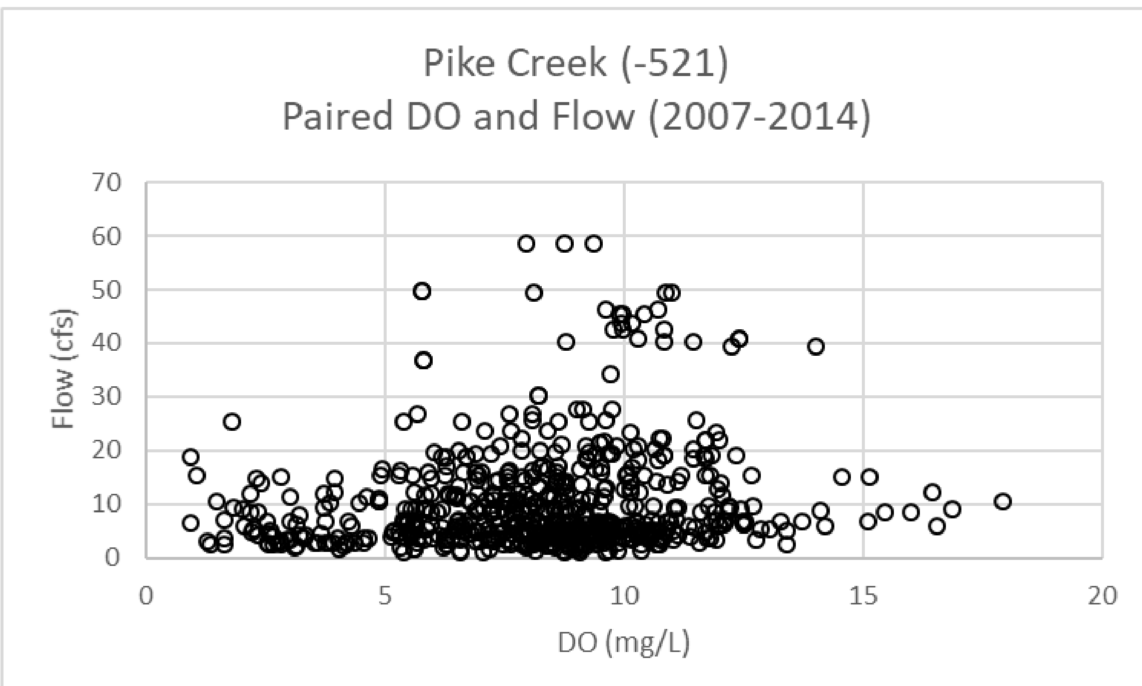


Figure 3-21. Pike Creek (-521) paired DO and flow (2007-2014)

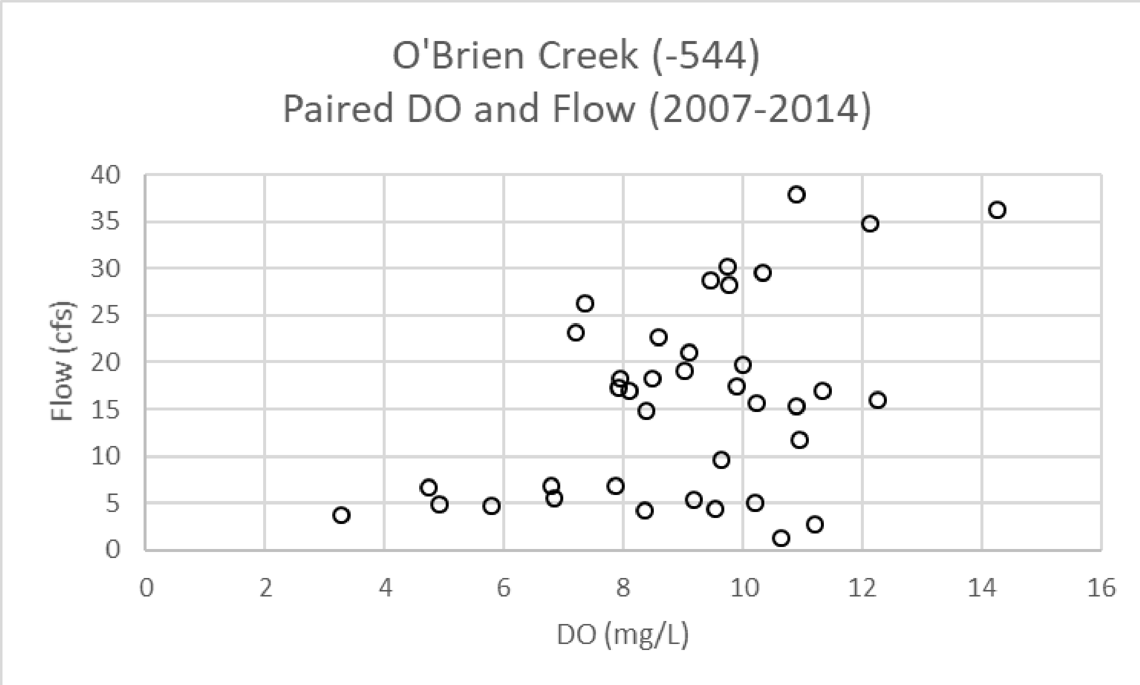


Figure 3-22. O'Brien Creek (-544) paired DO and flow (2007-2014)

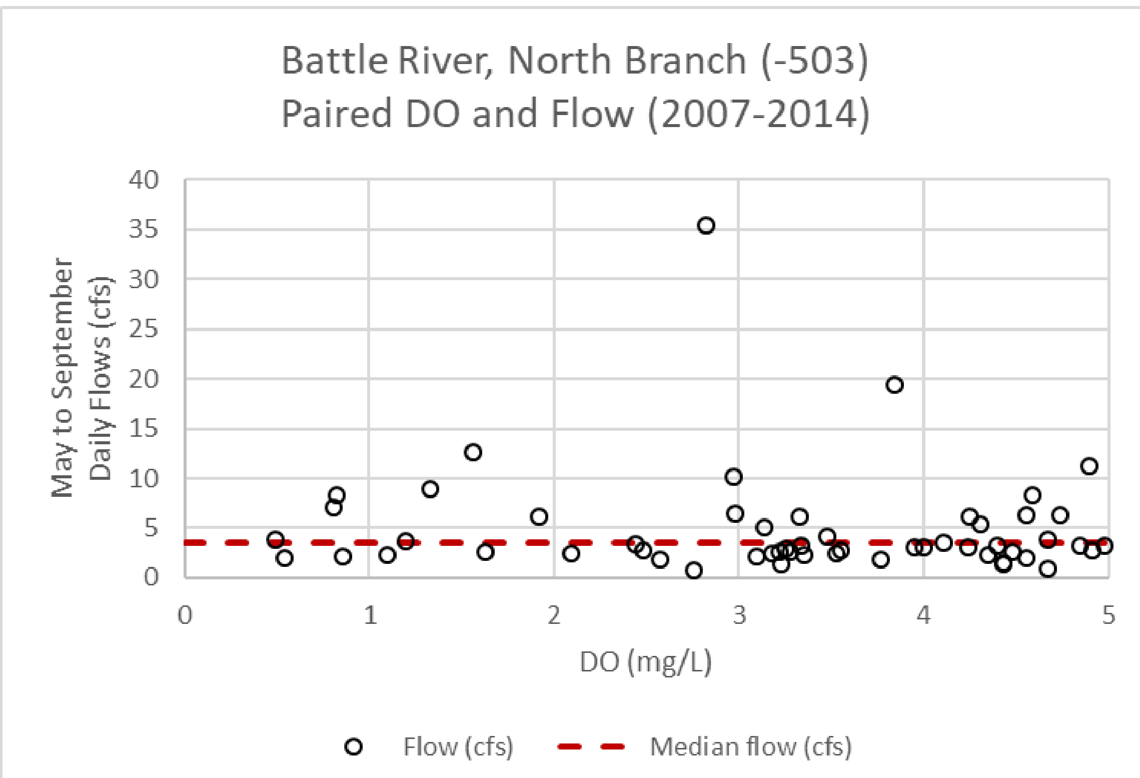


Figure 3-23. Battle River, North Branch (-503) paired DO (<5 mg/L) and May to September flows (2007-2014)

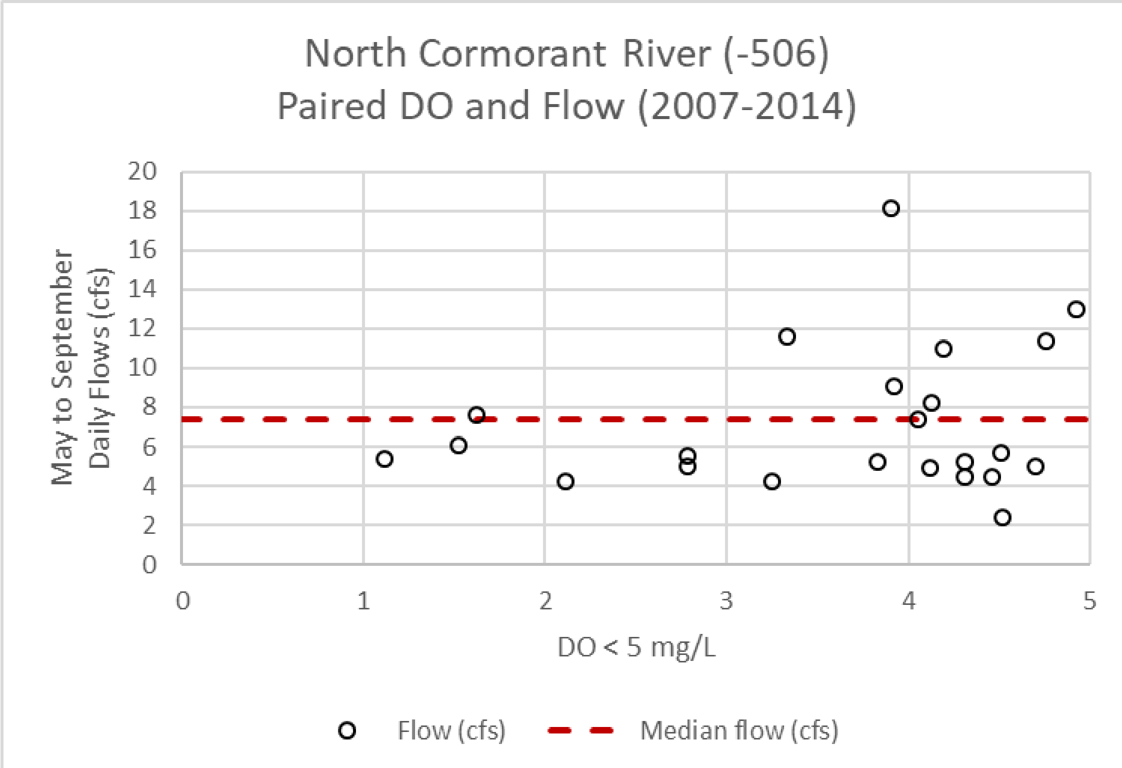


Figure 3-24. North Cormorant River (-506) paired DO (<5 mg/L) and May to September flows (2007-2014)

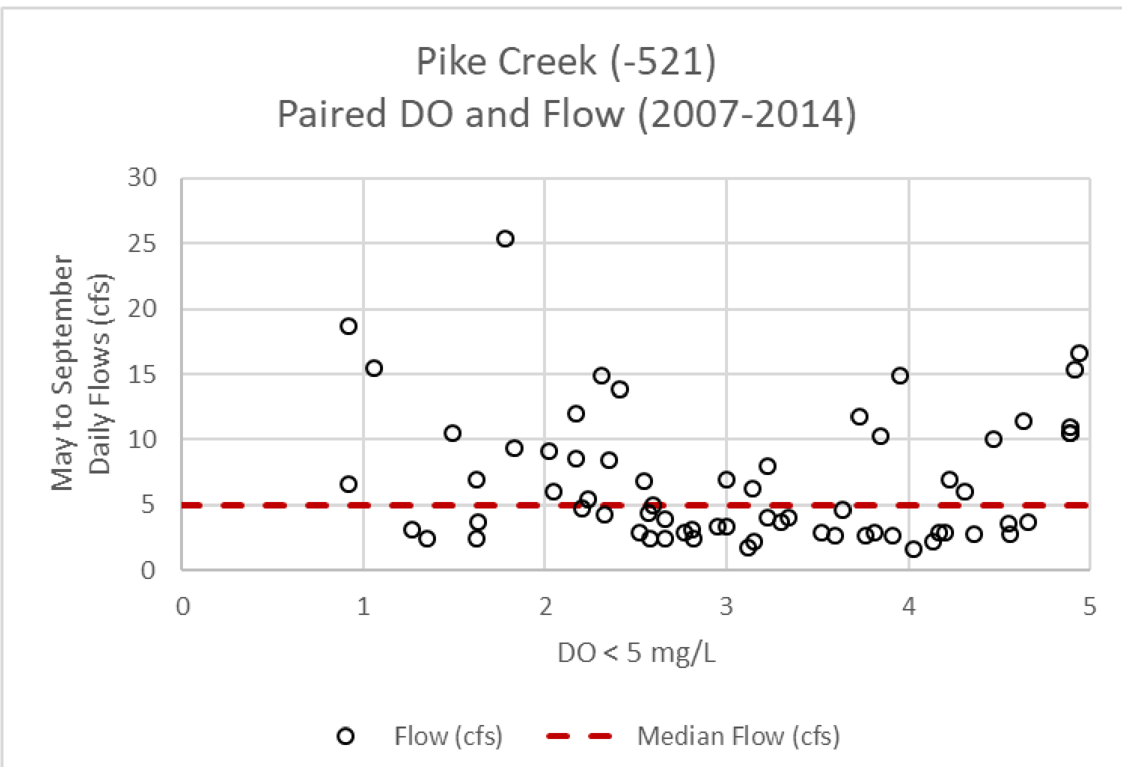


Figure 3-25. Pike Creek (-521) paired DO (<5 mg/L) and May to September flows (2007-2014)

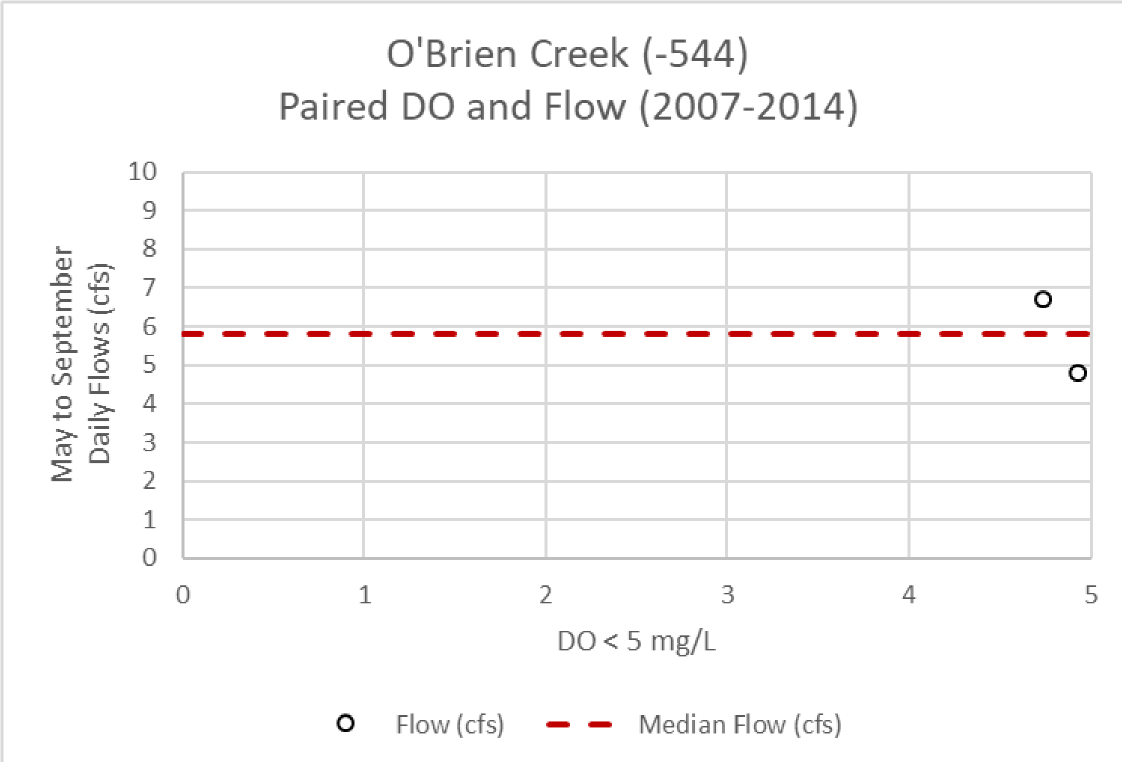


Figure 3-26. O'Brien Creek (-544) paired DO (<5 mg/L) and May to September flows (2007-2014)

__Stream Temperature__

Warmer waters hold less oxygen than cooler waters. In addition, warmer waters have increased rates of organic matter decomposition, which consumes oxygen. During the summer months, runoff and stream temperatures tend to increase in response to warming air and soil temperatures. No stream temperature data was available to compare with flow, therefore it was assumed that stream temperatures follow air temperate patterns, with temperatures warmest in July and August. The percent of DO samples that were below 5 mg/L are summarized by month for each impaired reach (Table 3-29). Average daily flows are also summarized by month for each impaired reach, with flows tending to be lowest in August and September (Table 3-40)

The percent of DO samples below 5 mg/L in Battle River, North Branch (-503) increased from May through September while average daily flows decreases. This suggests that stream flow had a stronger influence on DO than stream temperature in Battle River, North Branch (-503).

The percent of DO samples below 5 mg/L in North Cormorant River (-506) was highest in July and September while average daily flows decreased from May through September. This suggests that stream temperature has a stronger influence on DO in early to mid-summer, while stream flow has a stronger influence on DO in late summer in North Cormorant River (-506).

The percent of DO samples below 5 mg/L in Pike Creek (-521) was highest in August and similar in June, July, and September; average daily flows decreased from May through September.

O'Brien Creek only exhibited DO concentrations below 5 mg/L during the month of August, as flows were at late summer minimums. However, no DO samples were below the standard in September even though flows were similar to those in August.

Table 3-39. Percent of DO samples below 5 mg/L by month (May through September)

Impaired reach	Percent of DO samples below 5 mg/L				
	May	June	July	August	September
Battle River, North Branch (-503)	0%	13%	23%	24%	41%
North Cormorant River (-506)	0%	4%	24%	14%	31%
Pike Creek (-521)	2%	17%	19%	25%	18%
O'Brien Creek (-544)	0%	0%	0%	29%	0%

Table 3-40. Average daily flows by month (May through September)

Impaired reach	Average daily flow (cfs)				
	May	June	July	August	September
Battle River, North Branch (-503)	13.1	11.6	9.6	4.7	4.1
North Cormorant River (-506)	25.9	23.1	18.7	9.4	8.6
Pike Creek (-521)	15.2	14.2	10.3	6.0	6.1
O'Brien Creek (-544)	19.6	19.0	13.4	9.6	9.3

Wetland Influences

Minnesota's Intensive Watershed Monitoring (IWM) program, and follow-up monitoring efforts such as SID, have found many examples of low DO levels in small, northern Minnesota streams with large amounts of wetland acreage within their subwatersheds, often in the form of peatland bogs/fens, and often the immediate riparian landform. Land cover is summarized for each DO impaired stream reach in Table 3-41. Battle River, North Branch (-503) has the highest fraction of wetlands (32%) compared to the DO impaired stream reaches, but still less than the average fraction of wetlands in the entire ULRLW (41%). However, some impaired reaches addressed in this TMDL have much higher fractions of wetlands (up to 76%; Table 3-3). While wetlands may be contributing some low DO runoff to the DO impaired reaches, they are not likely the dominant cause of low DO.

Table 3-41. Land cover for the DO impaired stream reach subwatersheds (2013 MLCCS)

ULRLW Land Cover Summary								
DO Impaired Reach	Impervious	Wetlands	Open Water	Extraction	Forest	Grassland	Hay & Pasture	Row Crops
Battle River, North Branch (-503)	2.8%	31.6%	1.7%	<0.1%	48.3%	6.2%	7.8%	1.5%
North Cormorant River (-506)	3.0%	24.0%	0.5%	<0.1%	37.7%	11.5%	15.8%	7.5%
Pike Creek (-521)	4.5%	29.7%	3.1%	<0.1%	46.0%	4.6%	1.8%	10.3%

ULRLW Land Cover Summary								
DO Impaired Reach	Impervious	Wetlands	Open Water	Extraction	Forest	Grassland	Hay & Pasture	Row Crops
O'Brien Creek (-544)	5.1%	14.0%	3.8%	<0.1%	34.9%	9.5%	17.7%	14.9%
ULRLW	**2.9%**	**41.3%**	**2.9%**	**<0.1%**	**34.8%**	**6.4%**	**6.3%**	**5.4%**

Phosphorus (Eutrophication)

The RL DNR conducted continuous monitoring of DO levels for both North Cormorant River (-506) and O'Brien Creek (-544). These records are displayed in Figure 3-27 and Figure 3-28. The continuous DO profiles do not indicate large daily fluctuations in DO that would suggest stream eutrophication. In eutrophic streams, large amounts of algae produce high levels of DO during the day and very low levels of DO at night from respiration (consumption) of the DO produced during the day. Small daily fluctuations were observed with larger seasonal changes of DO levels, likely due to wetland and temperature influences. Similarly, phosphorus (eutrophication) were not found to be probable stressors to aquatic life in Battle River, North Branch (-503) and North Cormorant River (-506) as part of the SID study (MPCA 2018a). Phosphorus (eutrophication) is not likely a cause of low DO in streams in the ULRLW.

Summary

The interaction of stream flow and stream temperature is the most probable cause of low DO in the DO impaired reaches. Low DO runoff from wetlands may be contributing but is likely a minor cause. Phosphorus (eutrophication) is not likely a cause of low DO in the DO impaired reaches. No pollutant TMDLs are recommended to address the four DO impairments and they may be recategorized to categories that do not require TMDLs:

- 09020302-521: Pike Creek - The biological impairments on Pike Creek were largely due to a culvert sizing issue. This culvert has been replaced.
- 09020302-503: Battle River, North Branch - The primary stressor to low DO in Battle River, North Branch in this study is altered hydrology which results in low flow and stagnant conditions in late summer months. Wetland ditching upstream reduces the natural baseflow to the stream. Lower flows typically seen in the late summer months correlate with low DO, while DO rebounded after precipitation events.
- 09020302-506: North Cormorant River - The RL DNR conducted continuous monitoring of DO levels in North Cormorant River (Figure 3-27). The continuous DO profiles do not indicate large daily fluctuations in DO that would suggest stream eutrophication. In eutrophic streams, large amounts of algae produce high levels of DO during the day and very low levels of DO at night from respiration (consumption) of the DO produced during the day. Small daily fluctuations were observed with larger seasonal changes of DO levels, likely due to wetland and temperature influences.

- 09020302-544: O'Brien Creek - The RL DNR conducted continuous monitoring of DO levels in O'Brien Creek (Figure 3-28). The continuous DO profiles do not indicate large daily fluctuations in DO that would suggest stream eutrophication. In eutrophic streams, large amounts of algae produce high levels of DO during the day and very low levels of DO at night from respiration (consumption) of the DO produced during the day. Small daily fluctuations were observed with larger seasonal changes of DO levels, likely due to wetland and temperature influences. There are also beaver dam issues and stagnant flow conditions contributing to the DO impairment on O'Brien Creek.

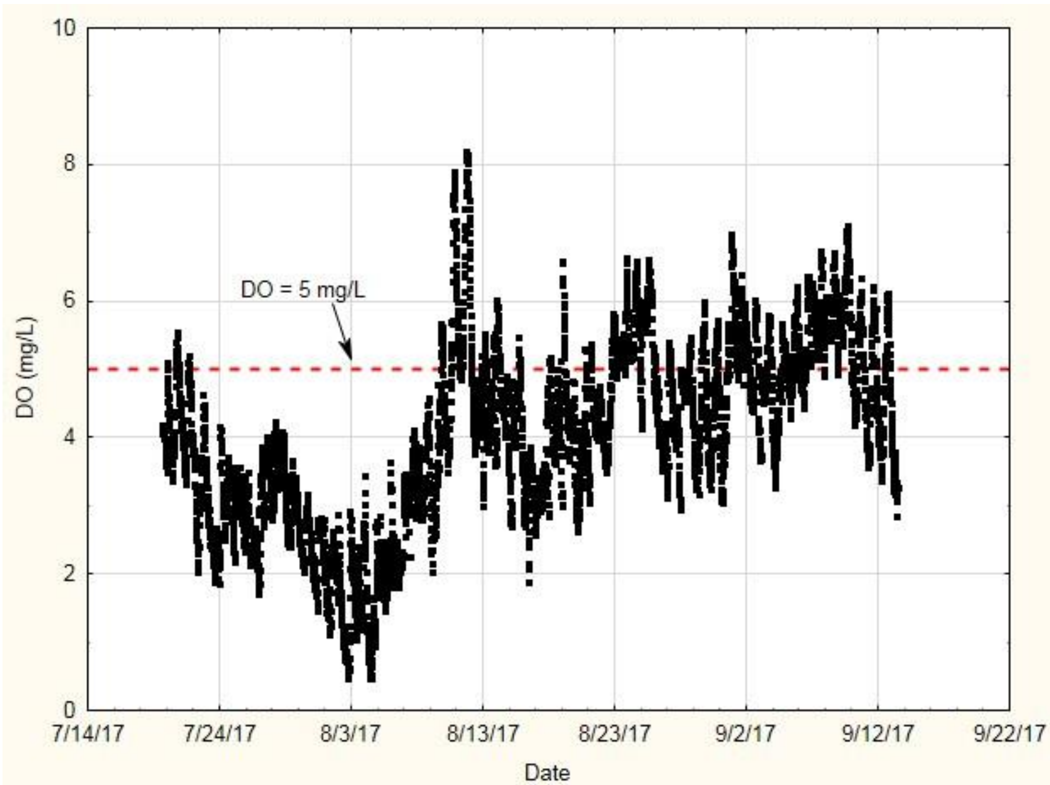


Figure 3-27. Continuous DO monitoring for North Cormorant River (09020302-506) at station CORM-B.

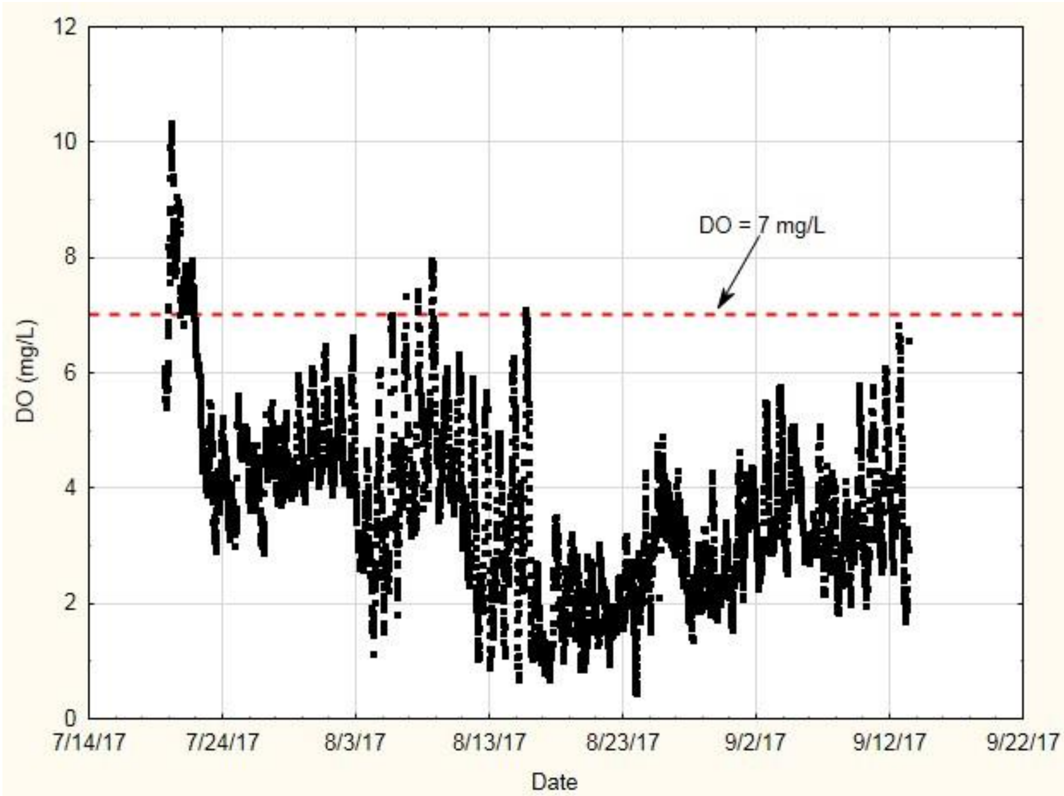


Figure 3-28. Continuous DO monitoring for O'Brien Creek (09020302-544) at station S004-833.

4 TMDL Development

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

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

Where:

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

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

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

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

Natural background consideration

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

Based on the MPCA's waterbody assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of the impairments this report developed TMDLs for. Natural background sources are implicitly included in the LA portion of the TMDL allocation tables, and TMDL reductions should focus on the major anthropogenic sources identified in the source assessment.

There were several streams impaired due to *E. coli* with evidence of natural background sources of *E. coli* from wild bird and beaver populations within the impaired stream subwatersheds. These impairments are being deferred while the MPCA considers recategorization to category 4D, as indicated in Table 1-1. Evidence of wild bird and beaver sources of *E. coli* was from MST results (see Section 3.6.2.2.

4.1 Phosphorus

4.1.1 Loading Capacity

4.1.1.1 Lake Response Model

The modeling software BATHTUB (Version 6.1) was selected to link phosphorus loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). It has been used successfully in many lake studies in Minnesota and throughout the United States. BATHTUB is a steady-state annual or seasonal model that predicts a lake's summer (June through September) mean surface water quality. BATHTUB's timescales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. The heart of BATHTUB is a mass-balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and groundwater, and outputs through the lake outlet, water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

System Representation in Model

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

Model Inputs

The input required to run the BATHTUB model includes lake geometry, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data are also entered into the BATHTUB program in order to facilitate model verification and calibration. Lake segment inputs are listed in Table 4-1, and tributary inputs are listed in Table 3-24 and Table 3-25 from Section 3.6.2. Average annual precipitation rates are based on the Minnesota Climatology Working Group Gridded Precipitation Database of annual average precipitation for 2007 through 2016 at the centroid of each impaired lake, and average annual evaporation rates are based on the Minnesota DNR St. Paul Campus Pan Evaporation measurements for 2007 through 2016, multiplied by a pan evaporation coefficient of 0.795. Precipitation and evaporation rates apply only to the lake surface areas. Average phosphorus atmospheric deposition loading rates were estimated to be 0.233 lb/ac/yr for the Red River Basin (Barr 2007), applied over each lake's surface area (Table 3-28 in Section 3.6.2).

Table 4-1. BATHTUB segment input data for impaired lakes

Impaired Lake or Upstream Lake	Average Annual Precipitation (m/yr)	Average Annual Evaporation (m/yr)	Surface area (sq km)	Lake fetch (km)	Mean depth (m)	Total Phosphorus (µg/L)	Total Phosphorus CV (%)
Blackduck	0.654	0.733	10.8673	5.1206	4.23	33.7	11%
Crane	0.637		0.4362	0.9754	3.08	38.1	9%
Strand (North)	0.638		0.2802	0.7620	2.69	35.9	8%
Whitefish (South)	0.623		0.3338	1.2497	2.16	85.5	6%
Bartlett	0.663		1.3444	1.6459	2.22	32.1	6%
Strand (South)*	0.638		0.2802	0.9449	4.66	29.7*	n/a

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

* An uncalibrated BATHTUB model was developed to estimate the in-lake phosphorus concentration of Strand Lake (South Basin), which is upstream of Crane Lake.

Model Equations

BATHTUB allows a choice among several different phosphorus sedimentation models. The Canfield-Bachmann Lake phosphorus sedimentation model (Canfield and Bachmann 1981) best represents the lake water quality response of Minnesota lakes and is the model used by the majority of lake TMDLs in

Minnesota. In order to perform a uniform analysis, Canfield-Bachmann Lakes (model) was selected as the standard equation for the study. However, the Canfield-Bachmann Lakes phosphorus sedimentation model tends to under-predict the amount of internal loading in shallow, frequently mixing lakes. Therefore, an explicit internal load is often added to shallow lake models to improve the lake water quality response of the Canfield-Bachmann Lakes phosphorus sedimentation model.

Model Calibration

The models were calibrated to existing water quality data, found in Table 4-1, and then were used to determine the phosphorus LC (TMDL) of each lake. When the predicted in-lake TP concentration was *lower* than the average observed (monitored) concentration, an explicit additional load was added to calibrate the model. It is widely recognized that Minnesota lakes in agricultural regions have histories of high phosphorus loading and/or very poor water quality. For this reason, it is reasonable that internal loading may be higher than that of the lakes in the data set used to derive the Canfield-Bachmann lakes formulation. When the predicted in-lake TP concentration was *higher* than the average observed (monitored) concentration, the phosphorus sedimentation factor was increased. Increased sedimentation is often found in shallow lakes that have high treatment capacity due to a clear water, aquatic plant-dominated state. Additional information relating to the upstream load from Strand Lake South Basin to Crane Lake is described in Section 3.6.2.1.

Table 4-2. Model calibration summary for the impaired lakes

Impaired Lake or Upstream Lake	Uncalibrated Predicted In-lake P (µg/L)	Calibration Mode	Calibration Value (mg/m²-yr)
Blackduck	20.0	Additional excess/ internal load	0.204
Crane	22.3		0.328
Strand (North)	24.0		0.245
Whitefish (South)	40.8		1.9
Bartlett	23.5		0.09
Strand (South)*	20.9	n/a	0.245*

* An uncalibrated BATHTUB model was developed to estimate the in-lake phosphorus concentration of Strand Lake (South Basin), which is upstream of Crane Lake. Note that the same rate of excess/internal load was added to Strand Lake (South Basin) as the calibrated Strand Lake (North Basin) model to better estimate the in-lake phosphorus concentration of Strand Lake (South Basin).

Determination of Lake Loading Capacity

Using the calibrated existing conditions model as a starting point, the phosphorus concentrations associated with tributaries were reduced until the model indicated that the TP state standard was met, to the nearest tenth of a whole number. First, upstream lake phosphorus concentrations were assumed to meet the lake phosphorus standard of 30 µg/L. Next, the direct drainage flow-weighted mean TP concentration was reduced to no less than 50 parts per billion (µg/L), or until in-lake phosphorus concentration met the lake phosphorus standard. A flow-weighted mean concentration goal of 50 µg/L was chosen to represent reasonable baseline loading conditions from this relatively undisturbed, forested watershed and is equivalent to the river eutrophication standard for the Northern RNR. If further reductions were needed, any added unknown/internal loads were reduced until the in-lake phosphorus concentration met the lake phosphorus standard. In one lake, Whitefish (South Basin), the direct drainage flow-weighted mean TP concentration was lowered below 50 µg/L in order to meet the lake phosphorus standard. Minnesota lake water quality standards assume that once the TP goals are met, the Chl-*a* and Secchi transparency standards will likewise be met (see *Section 0 Applicable Water Quality Standards*). With this process, a series of models were developed that included a level of phosphorus loading consistent with lake water quality state standards or the TMDL goal. Actual load values are calculated within the BATHTUB software, so loads from the TMDL goal models could be compared to the loads from the existing conditions models to determine the amount of load reduction required.

4.1.2 Load Allocation Methodology

The LA includes all sources of phosphorus that do not require NPDES/SDS permit coverage: watershed runoff, internal loading, atmospheric deposition, and any other identified loads described in Section 3.6.2.1. The remainder of the LC (TMDL), after subtraction of the MOS and calculation of the WLA, was used to determine the LA for each impaired lake or stream. The remainder of the LA, after subtraction of atmospheric deposition LA and internal loading LA, was used to determine the watershed runoff LA for each impaired lake or stream on an areal basis. Note that the MOS was distributed proportionately among internal loading and watershed runoff based on the proportion of existing loads relative to the LC. The MOS cannot be accounted for in the atmospheric deposition and upstream impaired lake allocations as no further reductions can be achieved from these sources beyond what is needed to achieve the LC (i.e., atmospheric loads cannot be reduced and upstream impaired lakes are not required to improve in-lake water quality beyond the state eutrophication standards).

4.1.3 Wasteload Allocation Methodology

All NPDES/SDS Permitted stormwater and wastewater were assigned a WLA based on the methods described in the following section.

4.1.3.1 Regulated Construction and Industrial Stormwater

A categorical WLA was assigned to all construction activity in each impaired lake subwatershed. First, the average annual fraction of the impaired subwatershed area, under construction activity over the most recent 10 years, was calculated based on MPCA Construction Stormwater Permit data from January 1, 2009 to December 31, 2018 (Table 4-3) and area-weighted based on the fraction of the subwatershed located in each county. This percentage was multiplied by the watershed runoff load component to determine the construction stormwater WLA. The watershed runoff load component is equal to the total TMDL (LC) minus the sum of the nonwatershed runoff load components (atmospheric load, upstream lake loads, internal loads, and MOS). A categorical WLA was also assigned to all industrial activity in each impaired lake subwatershed. The industrial stormwater WLA was set equal to the construction stormwater WLA because industrial activities make up a very small fraction of the watershed area. Due to the very small WLAs that were calculated, construction and industrial stormwater WLAs were combined into a single WLA.

Table 4-3. Average Annual NPDES/SDS Construction Stormwater Permit Activity by County (1/1/2009-12/31/2018)

County	Total Area (ac)	Average Annual Construction Activity (% County Area)
Beltrami	44.74	0.004%
Koochiching	4.11	0.002%

4.1.3.2 Permitted Feedlots

There are no active NPDES or SDS permitted feedlots located within the impaired lake subwatersheds.

4.1.3.3 Municipal and Industrial Wastewater Treatment Systems

There is one SDS-permitted WWTF (Blackduck WWTF) whose surface discharge stations fall within a phosphorus impaired lake subwatershed (Blackduck Lake). This WWTF is a stabilization pond system that discharges treated water on land through spray irrigation within the Blackduck Lake (04-0069) Subwatershed. No surface discharge is included in the permit for this WWTF, therefore no WLA was assigned.

4.1.4 Margin of Safety

The MOS accounts for uncertainty about pollutant loadings and waterbody response. It reflects the degree of characterization and accuracy of the estimates of the source loads and the level of confidence in the analysis of the relationship between the source loads and the impact upon the receiving water. In concept, it ensures attainment and maintenance of water quality standards for the allocated pollutant. As such, it reduces the remaining pollutant allocation to nonpoint and point sources.

- An explicit MOS equal to 10% of the LC was used for the TMDL based on the following considerations: Two or more years of in-lake water quality data used to calibrate the BATHTUB model;
- BATHTUB model calibration using added internal load with values typical of very shallow, eutrophic lakes (see Section 3.6.2: Internal Loading);
- Generally good agreement between BATHTUB model predicted and observed values indicating that the models reasonably reflect the conditions in the lakes and their subwatersheds;
- Best professional judgement of the overall TMDL development; and
- Reasonable and achievable LAs and WLAs.

In addition to the explicit MOS, an implicit MOS is factored into the TMDL through the use of critical conditions and seasonal variability in the establishment of water quality standards by the State of Minnesota, and the use of conservative assumptions in the determination of critical conditions using the monitoring data, and the use of a watershed pollutant loading model to determine the contribution of phosphorus from point and nonpoint sources.

4.1.5 Seasonal Variation

In-lake water quality varies seasonally. In Minnesota lakes, the majority of the watershed phosphorus load often enters the lake during the spring. During the growing season months (June through September), phosphorus concentrations may not change drastically if major runoff events do not occur. However, Chl-*a* concentration may still increase throughout the growing season due to warmer temperatures fostering higher algal growth rates. In shallow lakes, the phosphorus concentration more frequently increases throughout the growing season due to the additional phosphorus load from internal sources. This can lead to even greater increases in Chl-*a* since not only is there more phosphorus, but temperatures are also higher.

This seasonal variation is taken into account in the TMDL by using the eutrophication standards (which are based on growing season averages) as the TMDL goals. The eutrophication standards were set with seasonal variability in mind. The load reductions are designed so that the lakes and streams will meet the water quality standards over the course of the growing season (June through September). Critical conditions in these lakes occur during the growing season, which is when the lakes are used for aquatic recreation.

4.1.6 TMDL Summary

4.1.6.1 Blackduck Lake (04-0069-00) TP TMDL

Table 4-4. Blackduck Lake TP TMDL and Allocations

Blackduck Lake Load Component		Existing	TMDL		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction/ Industrial stormwater (MNR100001/ MNR500000)	0.058	0.058	0.000166	0.0	0%
	Total WLA	**0.058**	**0.058**	**0.000166**	**0.0**	
Load Allocations*	*Watershed runoff*	*713.6*	*640.8*	*1.755*	*72.8*	*10%*
	Failing septics	*24.2*	*0.0*	*0.000*	*24.2*	*100%*
	Internal/Unknown load	*1,785.1*	*1,079.1*	*2.954*	*706.0*	*40%*
	Total Watershed/In-lake	2,522.9	1,719.9	4.709	803.0	32%
	Atmospheric	625.3	625.3	1.713	0.0	0%
	Total LA	**3,148.2**	**2,345.2**	**6.422**	**803.0**	**26%**
MOS			**260.6**	**0.714**		
TOTAL		**3,148.3**	**2,605.9**	**7.136**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 73 lb/yr from watershed sources.

- 24 lb/yr from converting ~21 failing shoreline septic systems to conforming.
- 706 lb/yr from internal/unknown sources.

Phosphorus Source Summary

- Blackduck Lake is 2,685 acres with a maximum depth of 28 feet and a shallow lake zone (<15 feet) that covers 50% of the lake surface area.
- Water levels have been collected since 1954. The recorded range is 3.95 feet, with a minimum recorded in March 1957 (1343.28 ft) and a maximum recorded in June 2005 (1347.23 ft). Within the last 10 years, water levels have fluctuated between 1344.0 ft and 1346.5 ft compared to the Ordinary High Water (OHW) of 1346 ft (Figure 10-3 in Appendix A.1).
- The lake watershed (including the lake surface area) is 15,598 acres, or 6 times the lake surface area.
- The shoreline is well developed with seasonal conversion of cabins to year-round homes. At the time the TMDL was developed, there were 79 year-round homes and 132 seasonal cabins.
- The watershed is 8% impervious, 12% row crops, and 21% wetlands.
- The majority of unknown/internal load is likely coming from the near shore area (such as shoreline septic and erosion sources) and in-lake sediment phosphorus release.

4.1.6.2 Crane Lake (04-0165-00) TP TMDL

Table 4-5. Crane Lake TP TMDL and Allocations

Crane Lake Load Component		Existing	TMDL		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction/ Industrial stormwater (MNR100001/ MNR500000)	0.0014	0.0014	0.0000036	0.0	0%
	Total WLA	**0.0014**	**0.0014**	**0.0000036**	**0.0**	
Load Allocations*	*Watershed runoff*	*20.1*	*14.3*	*0.040*	*5.8*	*29%*
	Failing septics	*1.2*	*0.0*	*0.000*	*1.2*	*100%*
	Internal/Unknown load	*115.2*	*43.2*	*0.119*	*72.0*	*62%*
	Total Watershed/In-lake	136.5	57.5	0.159	79.0	58%
	Strand Lake South Basin	64.2	64.2	0.176	0.0	0%
	Atmospheric	25.1	25.1	0.068	0.0	0%
	Total LA	**225.8**	**146.8**	**0.403**	**79.0**	**35%**
MOS			**16.3**	**0.044**		
TOTAL		**225.8**	**163.1**	**0.447**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 6 lb/yr from watershed sources.
- 1 lb/yr from converting ~1 failing shoreline septic system to conforming.
- 72 lb/yr from internal/unknown sources.

Phosphorus Source Summary

- Crane Lake is 108 acres with a maximum depth of 30 feet and a shallow lake zone (<15 feet) that covers 76% of the lake surface area.
- Crane Lake receives drainage from upstream Strand Lake and discharges to Julia and Puposky Lakes.
- No water levels have been recorded by DNR.
- No aquatic plant or fish community surveys have been completed by DNR.
- The total watershed (including the lake surface area) is 2,510 acres, or 23 times the lake surface area. The direct drainage area is 248 acres, and the Strand Lake Watershed is 2,154 acres.
- The shoreline is mostly undeveloped.
- The watershed is 3% impervious, 8% row crops, and 22% wetlands.
- The majority of unknown/internal load is likely coming from in-lake sediment phosphorus release or shallow lake biology impacts on water quality.

4.1.6.3 Strand Lake, North Basin (04-0178-00) TP TMDL

Table 4-6. Strand Lake, North Basin TP TMDL and Allocations

Strand Lake (North Basin) Load Component		Existing	TMDL		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction/Industrial stormwater (MNR100001/MNR500000)	0.004	0.004	0.000012	0.0	0%
	Total WLA	**0.004**	**0.004**	**0.000012**	**0.0**	
Load Allocations*	*Watershed runoff*	*62.9*	*56.5*	*0.154*	*6.4*	*10%*
	Failing septics	*1.2*	*0.0*	*0.000*	*1.2*	*100%*
	Internal/Unknown load	*55.3*	*23.7*	*0.064*	*31.6*	*57%*
	Total Watershed/In-lake	119.4	80.2	0.220	39.2	33%
	Atmospheric	16.1	16.1	0.044	0.0	0%
	Total LA	**135.5**	**96.3**	**0.262**	**39.2**	**29%**
MOS			**10.7**	**0.029**		
TOTAL		**135.5**	**107.0**	**0.291**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 6 lb/yr from watershed sources.
- 1 lb/yr from converting ~1 failing shoreline septic systems to conforming.
- 32 lb/yr from internal/unknown sources.

Phosphorus Source Summary

- Strand Lake is comprised of two distinct basins. The north basin is 69 acres with a maximum depth of 18 feet and a shallow lake zone (<15 feet) that covers 91% of the basin surface area. The south basin is 69 acres with a maximum depth of 62 feet and a shallow lake zone (<15 feet) that covers 56% of the basin surface area.
- The north basin of Strand Lake flows into the south basin of Strand Lake and then discharges to Crane Lake.
- No water levels have been recorded by DNR.
- No aquatic plant or fish community surveys have been completed by DNR.
- The lake watershed is 1,711 acres, or 25 times the lake surface area.
- The shoreline is mostly undeveloped.
- The watershed is 3% impervious, 7% row crops, and 22% wetlands.
- The majority of unknown/internal load is likely coming from in-lake sediment phosphorus release or shallow lake biology impacts on water quality.

4.1.6.4 Whitefish Lake, South Basin (04-0309-00) TP TMDL

Table 4-7. Whitefish Lake, South Basin TP TMDL and Allocations

Whitefish Lake (South Basin) Load Component		Existing	TMDL		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction/ Industrial stormwater (MNR100001/ MNR500000)	0.018	0.018	0.000048	0.0	0%
	Total WLA	**0.018**	**0.018**	**0.000048**	**0.0**	
Load Allocations*	*Watershed runoff*	*323.9*	*195.7*	*0.536*	*128.2*	*40%*
	Failing septics	*1.2*	*0.0*	*0.000*	*1.2*	*100%*
	Internal/Unknown load	*510.7*	*0.0*	*0.000*	*510.7*	*100%*
	Total Watershed/In-lake	835.8	195.7	0.536	640.1	77%
	Atmospheric	19.2	19.2	0.053	0.0	0%
	Total LA	**855.0**	**214.9**	**0.589**	**640.1**	**75%**
MOS			**23.9**	**0.066**		
TOTAL		**855.0**	**238.8**	**0.655**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 128 lb/yr from watershed sources.
- 1 lb/yr from converting ~1 failing shoreline septic systems to conforming.
- 511 lb/yr from internal/unknown sources.

Phosphorus Source Summary

- Whitefish Lake is comprised of two distinct basins. The north basin is 41 acres with a maximum depth of 4 feet and a shallow lake zone (<15 feet) that covers 100% of the basin surface area. The south basin is 82 acres with a maximum depth of 14 feet and a shallow lake zone (<15 feet) that covers 100% of the basin surface area.
- No water levels have been recorded by DNR.
- No aquatic plant or fish community surveys have been completed by DNR.
- The lake watershed (including the lake surface area) is 4,985 acres, or 60 times the lake surface area.
- The shoreline is mostly undeveloped.
- The watershed is 5% impervious, 34% row crops, and 18% wetlands.

- The majority of unknown/internal load is likely coming from in-lake sediment phosphorus release.

4.1.6.5 Bartlett Lake (36-0018-00) TP TMDL

Table 4-8. Bartlett Lake TP TMDL and Allocations

Bartlett Lake Load Component		Existing	TMDL		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction/ Industrial stormwater (MNR100001/ MNR500000)	0.004	0.004	0.000012	0.0	0%
	Total WLA	**0.004**	**0.004**	**0.000012**	**0.0**	
Load Allocations*	*Watershed runoff*	*90.9*	*78.4*	*0.214*	*12.5*	*14%*
	Failing septics	*1.0*	*0.0*	*0.000*	*1.0*	*100%*
	Internal/Unknown load	*97.4*	*61.9*	*0.170*	*35.5*	*37%*
	Total Watershed/In-lake	189.3	140.3	0.384	49.0	26%
	Atmospheric	77.4	77.4	0.212	0.0	0%
	Total LA	**266.7**	**217.7**	**0.595**	**49.0**	**18%**
MOS			**24.2**	**0.066**		
TOTAL		**266.7**	**241.9**	**0.661**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 13 lb/yr from watershed sources.
- 1 lb/yr from converting ~1 failing shoreline septic systems to conforming.
- 36 lb/yr from internal/unknown sources.

Phosphorus Source Summary

- Bartlett Lake is 332 acres with a maximum depth of 16 feet and a shallow lake zone (<15 feet) that covers 96% of the lake surface area.
- Water levels were collected between 2002 and 2015. The recorded range was 2.02 feet, with a minimum recorded in May 2015 (1401.71 ft) and a maximum recorded in May 2013 (1403.73 ft). Within the last 10 years, water levels were near 1403.5 ft from 2010 through 2014 and then dropped to the minimum recorded level in May 2015, at which time lake level monitoring stopped (Figure 10-20 in Appendix B.5).
- The lake watershed (including the lake surface area) is 2,033 acres, or 6 times the lake surface area.
- The shoreline is mostly undeveloped.

- The watershed is 7% impervious, <1% row crops, and 36% wetlands.
- The majority of unknown/internal load is likely coming from shallow lake biology impacts on water quality. The EOR 2018 Bartlett Lake In-Lake Management Alternatives report discusses the relationship between shallow lake biology and water quality in Bartlett Lake and discusses management recommendations for improving water quality (attached as Appendix D).

4.1.7 TMDL Baseline

The lake phosphorus TMDLs are based on flow and water quality record results for the period 2007 through 2016. Any activities implemented after the mid-point of the TMDL time period (2012) that lead to a reduction in loads or an improvement in an impaired lake water quality may be considered as progress towards meeting a WLA or LA.

4.2 Bacteria (*E. coli*)

4.2.1 Loading Capacity Methodology

The loading capacities for impaired stream reaches receiving a TMDL, as a part of this study, were determined using LDCs. Flow and LDCs are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. An example flow duration curve is shown in Figure 4-1. LDCs take the flow distribution information constructed for the stream and factor pollutant loading into the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (LC) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

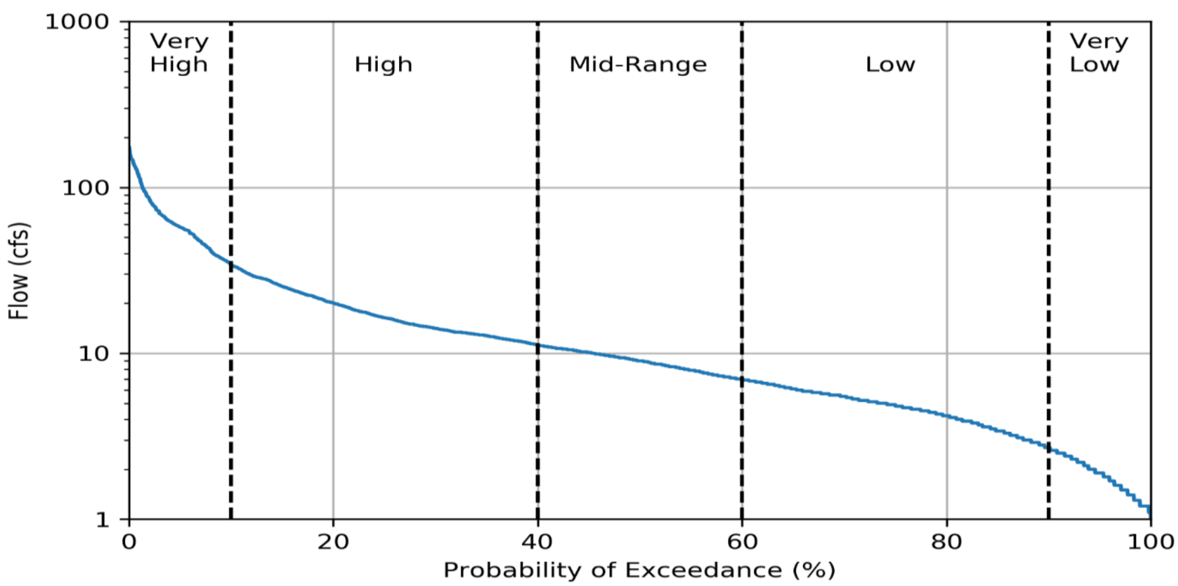


Figure 4-1. Example flow duration curve for Shotley Brook (-502).

For the stream TMDL derivation, HSPF modeled flows for the period 2007 through 2014. The loading capacities were determined by applying the *E. coli* water quality standard (126 org/100 mL) to the flow duration curve to produce a bacteria standard curve. Loading capacities presented in the allocation tables represent the median *E. coli* load (in billion org/day) along the bacteria standard curve within each flow regime. A bacteria LDC and a TMDL allocation table are provided for each stream in Section 4.2.6. Limited observations and estimates of existing bacteria loads are plotted along with the bacteria standard curve for each impaired stream. Existing loads were estimated by pairing observed *E. coli* concentrations with flow records for each impaired reach.

The LDC method is based on an analysis that encompasses the cumulative frequency of historical flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL tables of this report, 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.

4.2.2 Load Allocation Methodology

LAs represent the portion of the LC that is designated for nonregulated sources of *E. coli*, as described in Section 3.6.2.2, that are located downstream of any other impaired waters with TMDLs located in the ULRLW. The remainder of the LC (TMDL) after subtraction of the MOS and calculation of the WLA was used to determine the LA for each impaired stream on an aereal basis.

The TMDLs for the stream reaches located partially within the boundaries of the reservation were calculated to the outlet of each stream reach to Lower Red Lake within the reservation boundaries. LAs for watershed runoff for tribal land are included for these reaches as boundary conditions and no reductions are assigned to the tribal land runoff. The boundary condition load allocated to tribal runoff is based on the amount of tribal government land located in the drainage area of the impaired stream reach and is for tribal guidance only for managing their water resources based on their proposed water quality standards. It is understood that the MPCA has no jurisdiction on tribal lands and that EPA will not approve that part of a TMDL that is located within the boundaries of tribal lands. These TMDLs were developed in cooperation with, and assistance from, the RL DNR.

4.2.3 Wasteload Allocation Methodology

4.2.3.1 Regulated Construction Stormwater

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

4.2.3.2 Regulated Industrial Stormwater

There are no *E. coli* benchmarks associated with the industrial stormwater permit because no industrial sectors regulated under the permit are known to be *E. coli* sources. Therefore, *E. coli* TMDLs will not include an industrial stormwater WLA.

4.2.3.3 Permitted Feedlots

There are no NPDES or SDS permitted feedlot operations (CAFO) within an *E. coli* impaired stream reach drainage area in the ULRLW. See Section 3.6.2 for registered feedlots.

4.2.3.4 Municipal and Industrial Wastewater Treatment Systems

An individual WLA was provided for all NPDES-permitted WWTF that have fecal coliform discharge limits (200 org/100ml, March 1 through October 31) and whose surface discharge stations fall within an impaired stream subwatershed. There are no NPDES-permitted WWTF whose surface discharge stations fall within an *E. coli* impaired stream subwatershed. The City of Blackduck is served by an SDS permitted pond system with treated wastewater land applied using a spray irrigation system. No surface discharge is included in the permit for this facility; therefore, no WLA was assigned.

4.2.4 Margin of Safety

The MOS accounts for uncertainty about pollutant loadings and waterbody response. It reflects the degree of characterization and accuracy of the estimates of the source loads and the level of confidence in the analysis of the relationship between the source loads and the impact upon the receiving water. In concept, it ensures attainment and maintenance of water quality standards for the allocated pollutant. As such, it reduces the remaining pollutant allocation to nonpoint and point sources.

An explicit MOS equal to 10% of the LC was used for the stream TMDL based on the following considerations:

- Sufficient monitoring data available for the impaired reach.
- Adequate calibration and validation of the HSPF model.
- Some uncertainty in extrapolating flows in upstream areas of the watershed based on HSPF model calibration at stream gauges near the outlet of the ULRLW.
- Bacteria re-growth in sediments, die-off, and natural background levels that are not accounted for in the LDC methodology.
- Best professional judgement of the overall TMDL development.
- Reasonable and achievable LAs and WLAs.

In addition to the explicit MOS, an implicit MOS is factored into the TMDL through the use of critical conditions and seasonal variability in the establishment of water quality standards by the State of Minnesota, and the use of conservative assumptions in the determination of critical conditions using the monitoring data, and the use of MST and other statewide databases to determine the contribution of *E. coli* from point and nonpoint sources.

4.2.5 Seasonal Variation

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

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

4.2.6 TMDL Summary

4.2.6.1 Battle River, North Branch (-503) *E. coli* TMDL

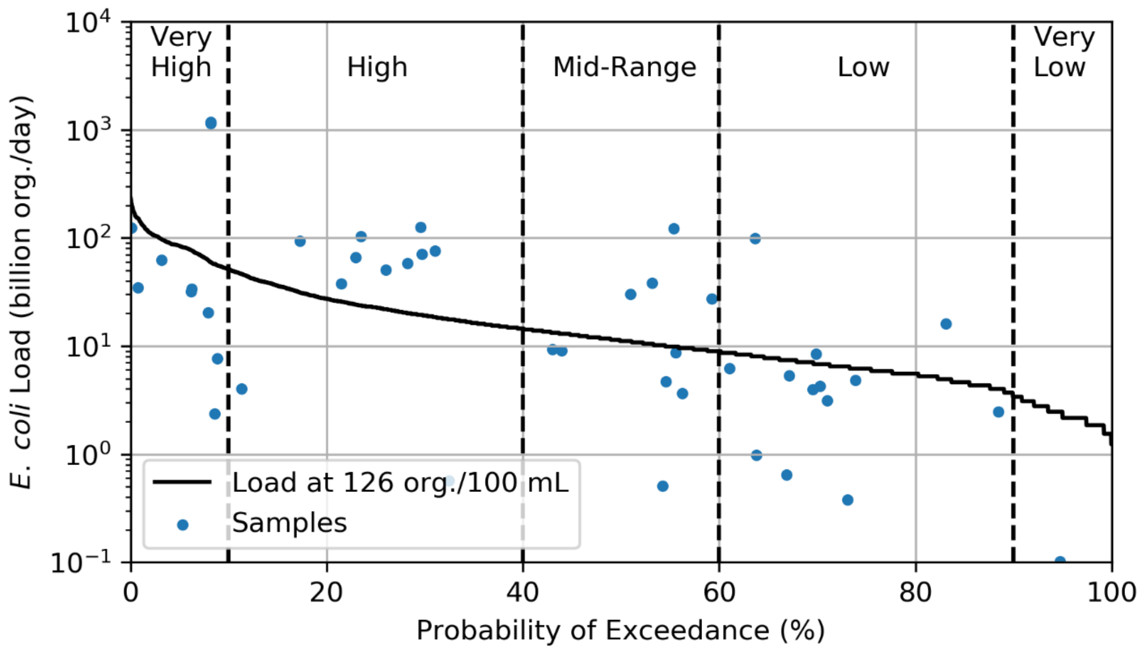


Figure 4-2. Battle River, North Branch (AUID 09020302-503) *E. coli* Load Duration Curve, BATT-NB (S003-962).

Existing *E. coli* loads are based on all samples from AUID 09020302-503 (Table 3-6) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for subbasin 255 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007-2014 HSPF modeled mean daily flows for subbasin 255.

Table 4-9. Battle River, North Branch (AUID 09020302-503) *E. coli* TMDL and allocations

Battle River, North Branch 09020302-503 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		***34.2***	***65.8***	***9.2***	***4.1***	***0.1***
Existing Load excluding the Boundary Condition		**22.8**	**62.7**	**7.7**	**3.3**	**N/A**
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Load Allocations	*Nonregulated sources*	*65.8*	*17.7*	*8.6*	*4.9*	*1.7*
	Total LA	**65.8**	**17.7**	**8.6**	**4.9**	**1.7**
10% MOS		**7.3**	**2.0**	**1.0**	**0.5**	**0.2**
MN Loading Capacity		**73.1**	**19.7**	**9.6**	**5.4**	**1.9**
Estimated Load Reduction		NA	43.0	NA	NA	NA
		NA	69%	NA	NA	NA
Boundary Conditions	*Red Lake Nation Loading Capacity**	**11.4**	**3.1**	**1.5**	**0.8**	**0.3**
Total Loading Capacity		**84.5**	**22.8**	**11.1**	**6.2**	**2.2**

*The Red Lake Nation Loading Capacity is based on the amount of tribal government land located in the impaired stream reach drainage area (13.5%). No reductions are assigned to this allocation.

4.2.6.2 North Cormorant River (-506) *E. coli* TMDL

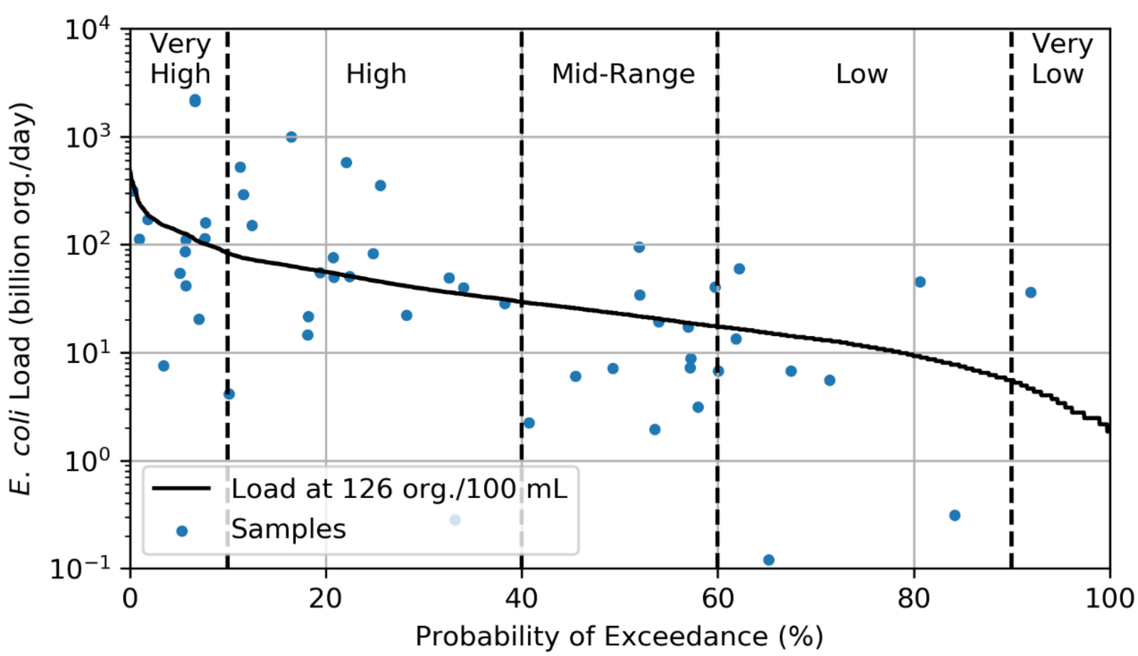


Figure 4-3. North Cormorant River (AUID 09020302-506) *E. coli* Load Duration Curve, (CORM-B (S003-961), CORM 72, CORM 36 (S007-606), CORM 102).

Existing *E. coli* loads are based on all samples from AUID 09020302-506 (Table 3-7) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for sub-basin 277 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007 through 2014 HSPF modeled mean daily flows for sub-basin 277.

Table 4-10. North Cormorant River (AUID 09020302-506) *E. coli* TMDL and allocations

North Cormorant River 09020302-506 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		*113.4*	*50.3*	*8.1*	*6.8*	*36.0*
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Load Allocations	*Watershed Runoff*	*118.2*	*41.6*	*20.5*	*10.3*	*3.1*
	Total LA	**118.2**	**41.6**	**20.5**	**10.3**	**3.1**
10% MOS		**13.1**	**4.6**	**2.3**	**1.1**	**0.3**
Total Loading Capacity		**131.3**	**46.2**	**22.8**	**11.4**	**3.4**
Estimated Load Reduction		*NA*	*4.1*	*NA*	*NA*	*32.6*
		NA	*8%*	*NA*	*NA*	*91%*

4.2.6.3 South Cormorant River (-507) *E. coli* TMDL

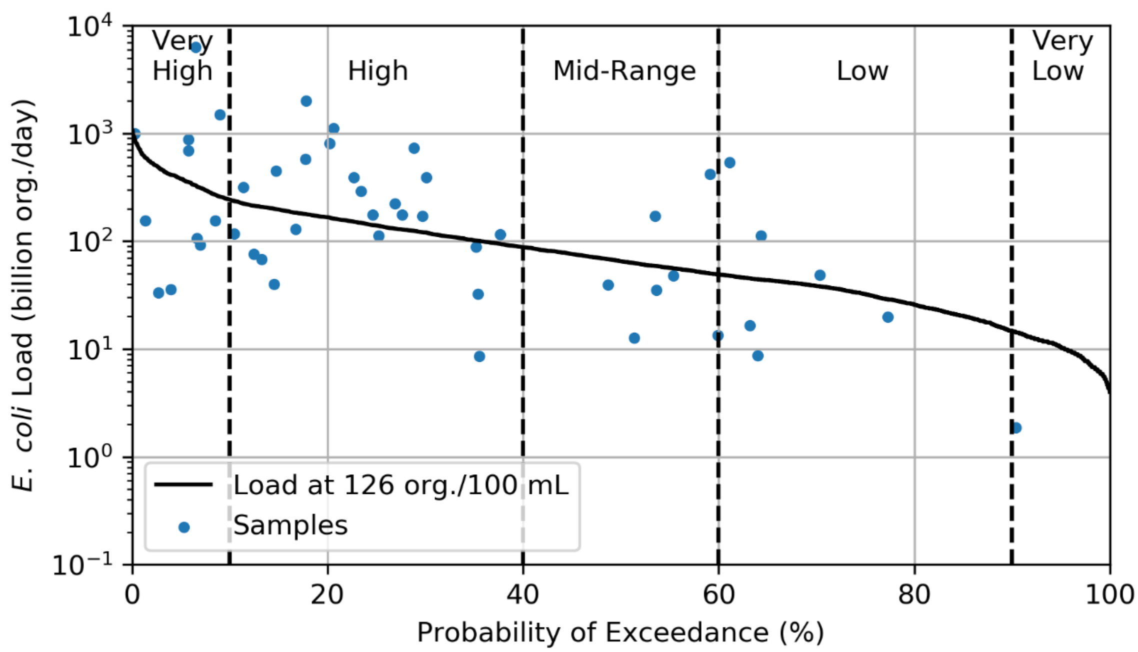


Figure 4-4. South Cormorant River (AUID 09020302-507) *E. coli* Load Duration Curve, S007-883, S004-834.

Existing *E. coli* loads are based on all samples from AUID 09020302-507 (Table 3-8) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for sub-basin 301 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007 through 2014 HSPF modeled mean daily flows for sub-basin 301.

Table 4-11. South Cormorant River (AUID 09020302-507) *E. coli* TMDL and allocations

South Cormorant River 09020302-507 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		*155.5*	*175.5*	*39.6*	*34.3*	*1.9*
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Load Allocations	*Watershed Runoff*	*341.1*	*125.8*	*58.5*	*29.0*	*9.4*
	Total LA	**341.1**	**125.8**	**58.5**	**29.0**	**9.4**
10% MOS		**37.9**	**14.0**	**6.5**	**3.2**	**1.1**
Total Loading Capacity		**379.0**	**139.8**	**65.0**	**32.2**	**10.5**
Estimated Load Reduction		*NA*	*35.7*	*NA*	*2.1*	*NA*
		NA	*20%*	*NA*	*6%*	*NA*

4.2.6.4 Darrigans Creek (-508) *E. coli* TMDL

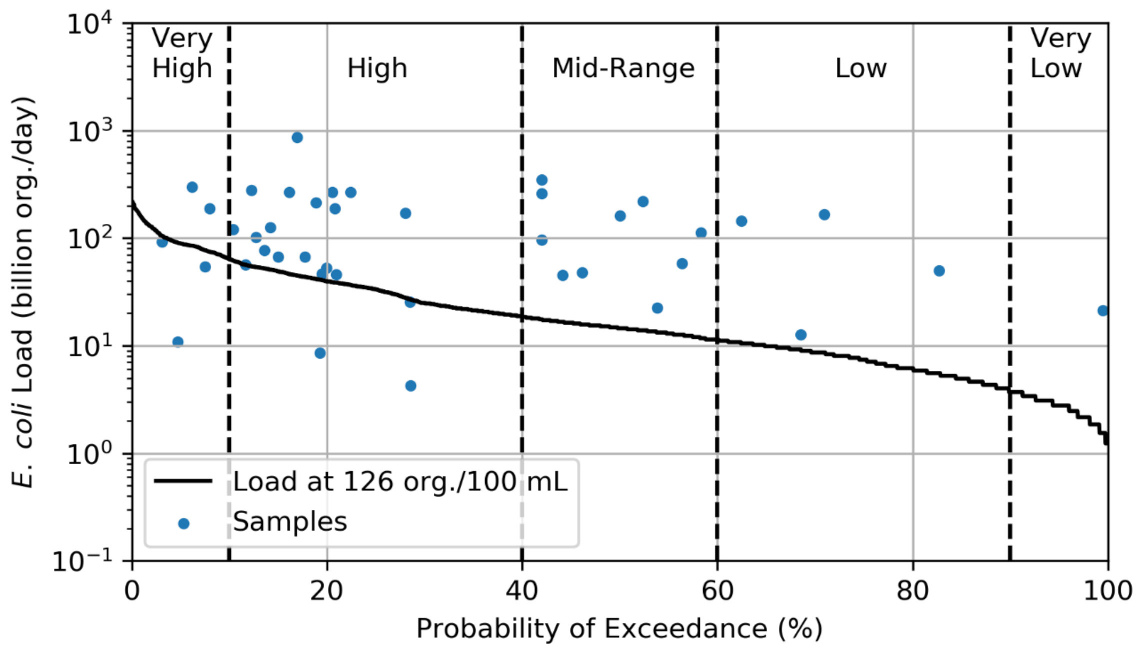


Figure 4-5. Darrigans Creek (AUID 09020302-508) *E. coli* Load Duration Curve, S004-832.

Existing *E. coli* loads are based on all samples from AUID 09020302-508 (Table 3-9) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for sub-basin 314 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007-2014 HSPF modeled mean daily flows for sub-basin 314.

Table 4-12. Darrigans Creek (AUID 09020302-508) *E. coli* TMDL and allocations

Darrigans Creek 09020302-508 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		*92.0*	*102.0*	*103.8*	*97.1*	*21.2*
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	n/a	n/a	n/a	n/a	n/a
Load Allocations	*Watershed Runoff*	*80.2*	*30.0*	*13.1*	*6.7*	*2.5*
	Total LA	80.2	30.0	13.1	6.7	2.5
10% MOS		8.9	3.3	1.4	0.7	0.3
Total Loading Capacity		89.1	33.3	14.5	7.4	2.8
Estimated Load Reduction		*2.9*	*68.7*	*89.3*	*89.7*	*18.4*
		3%	*67%*	*86%*	*92%*	*87%*

4.2.6.5 Blackduck River (-510) *E. coli* TMDL

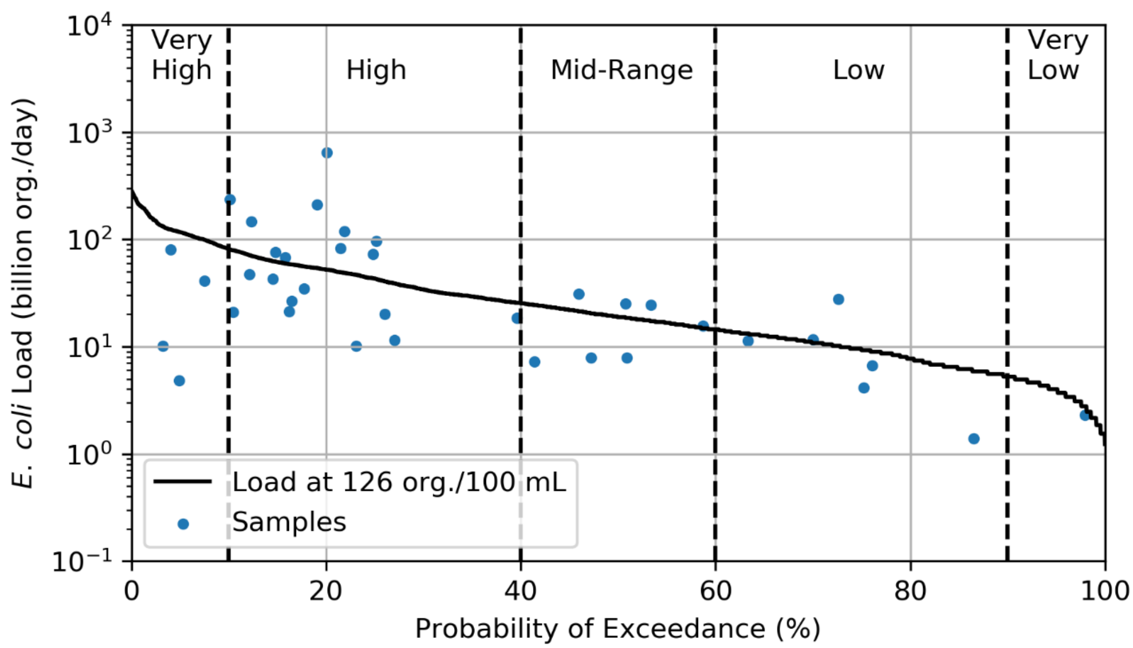


Figure 4-6. Blackduck River (AUID 09020302-510) *E. coli* Load Duration Curve, S004-831.

Existing *E. coli* loads are based on all samples from AUID 09020302-510 (Table 3-10) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for sub-basin 305 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007 through 2014 HSPF modeled mean daily flows for sub-basin 305.

Table 4-13 Blackduck River (AUID 09020302-510) *E. coli* TMDL and allocations

Blackduck River 09020302-510 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		*25.5*	*57.5*	*15.7*	*8.9*	*2.3*
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Load Allocations	*Watershed Runoff*	*105.0*	*38.9*	*16.9*	*8.3*	*3.6*
	Total LA	**105.0**	**38.9**	**16.9**	**8.3**	**3.6**
10% MOS		**11.7**	**4.3**	**1.9**	**0.9**	**0.4**
Total Loading Capacity		**116.7**	**43.2**	**18.8**	**9.2**	**4.0**
Estimated Load Reduction		*NA*	*14.3*	*NA*	*NA*	*NA*
		NA	*25%*	*NA*	*NA*	*NA*

4.2.6.6 Sandy River (-522) *E. coli* TMDL

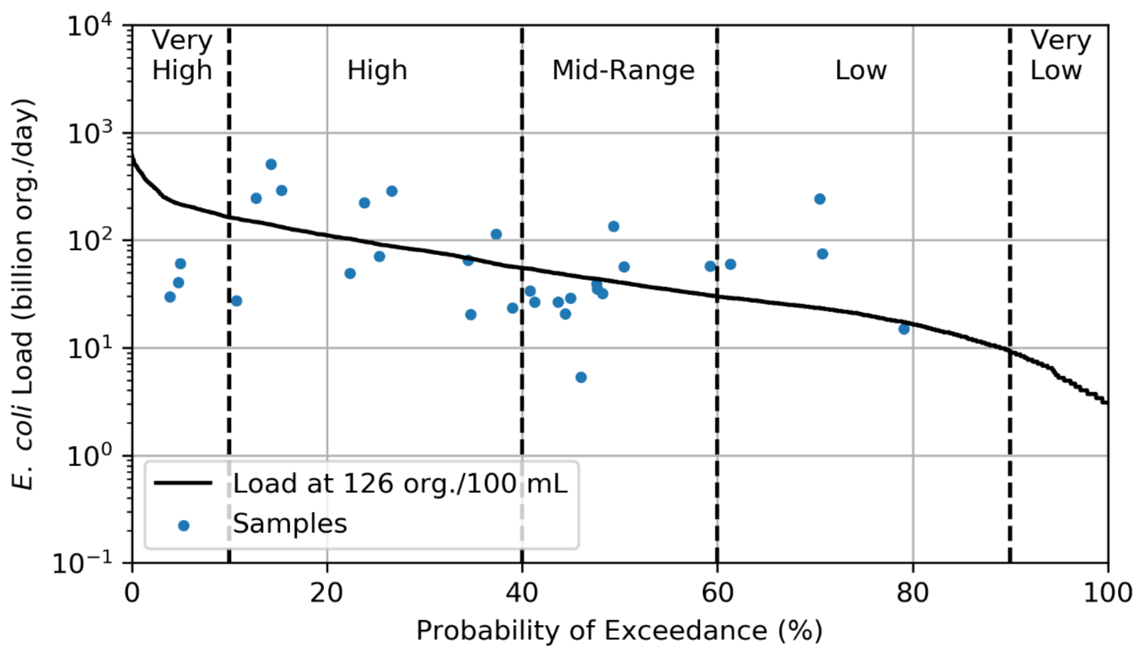


Figure 4-7. Sandy River (AUID 09020302-522) *E. coli* Load Duration Curve (09RD003 (S007-877), SANDY_32, SANR-U).

Existing *E. coli* loads are based on all samples from AUID 09020302-522 (Table 3-13) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for sub-basin 359 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007 through 2014 HSPF modeled mean daily flows for sub-basin 359.

Table 4-14. Sandy River (AUID 09020302-522) *E. coli* TMDL and allocations

Sandy River 09020302-522 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		*40.4*	*92.9*	*32.9*	*67.7*	*NA*
Existing Load excluding the Boundary Condition		**NA**	**65.9**	**21.1**	**61.8**	**NA**
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Load Allocations	*Nonregulated sources*	*136.9*	*58.9*	*25.7*	*12.7*	*3.3*
	Total LA	**136.9**	**58.9**	**25.7**	**12.7**	**3.3**
10% MOS		**15.2**	**6.6**	**2.9**	**1.4**	**0.4**
MN Loading Capacity		**152.1**	**65.5**	**28.6**	**14.1**	**3.7**
Estimated Load Reduction		NA	0.4	NA	47.7	NA
		NA	0.6%	NA	77%	NA
Boundary Conditions	*Red Lake Nation Loading Capacity**	**62.8**	**27.0**	**11.8**	**5.9**	**1.5**
Total Loading Capacity		**214.9**	**92.5**	**40.4**	**20.0**	**5.2**

*The Red Lake Nation Loading Capacity is based on the amount of tribal government land located in the impaired stream reach drainage area (29.2%). No reductions are assigned to this allocation.

4.2.6.7 Mud River (-541) *E. coli* TMDL

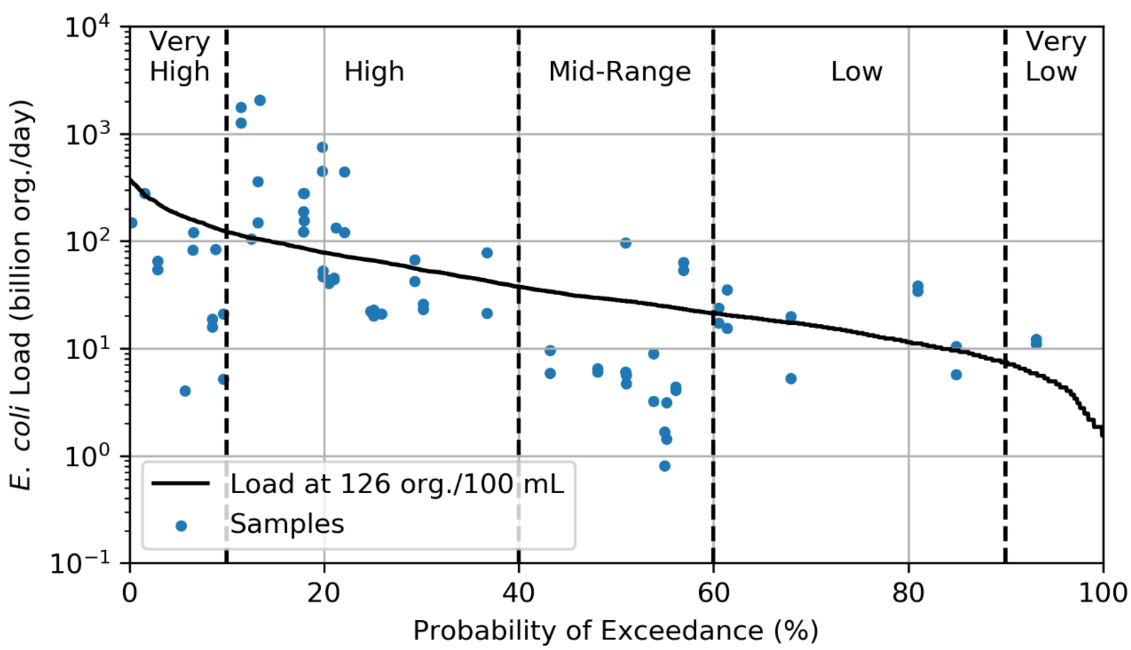


Figure 4-8. Mud River (AUID 09020302-541) *E. coli* Load Duration Curve (MUDR-M (S007-881), MUDR-U, MUDR-I).

Existing *E. coli* loads are based on all samples from AUID 09020302-541 (Table 3-14) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for sub-basin 339 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007 through 2014 HSPF modeled mean daily flows for sub-basin 339.

Table 4-15. Mud River (AUID 09020302-541) *E. coli* TMDL and allocations

Mud River 09020302-541 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		***59.7***	***105.2***	***5.8***	***18.6***	***11.6***
Existing Load excluding the Boundary Condition		**34.6**	**95.9**	**1.8**	**16.6**	**10.9**
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Load Allocations	*Watershed Runoff*	*137.3*	*51.0*	*22.0*	*10.7*	*3.8*
	Total LA	**137.3**	**51.0**	**22.0**	**10.7**	**3.8**
10% MOS		**15.3**	**5.7**	**2.4**	**1.2**	**0.4**
MN Loading Capacity		**152.6**	**56.7**	**24.4**	**11.9**	**4.2**
Estimated Load Reduction		NA	39.2	NA	4.7	6.7
		NA	41%	NA	28%	61%
Boundary Conditions	*Red Lake Nation Loading Capacity**	**25.1**	**9.3**	**4.0**	**2.0**	**0.7**
Total Loading Capacity		**177.7**	**66.0**	**28.4**	**13.9**	**4.9**

*The Red Lake Nation Loading Capacity is based on the amount of tribal government land located in the impaired stream reach drainage area (14.1%). No reductions are assigned to this allocation.

4.2.6.8 O'Brien Creek (-544) *E. coli* TMDL

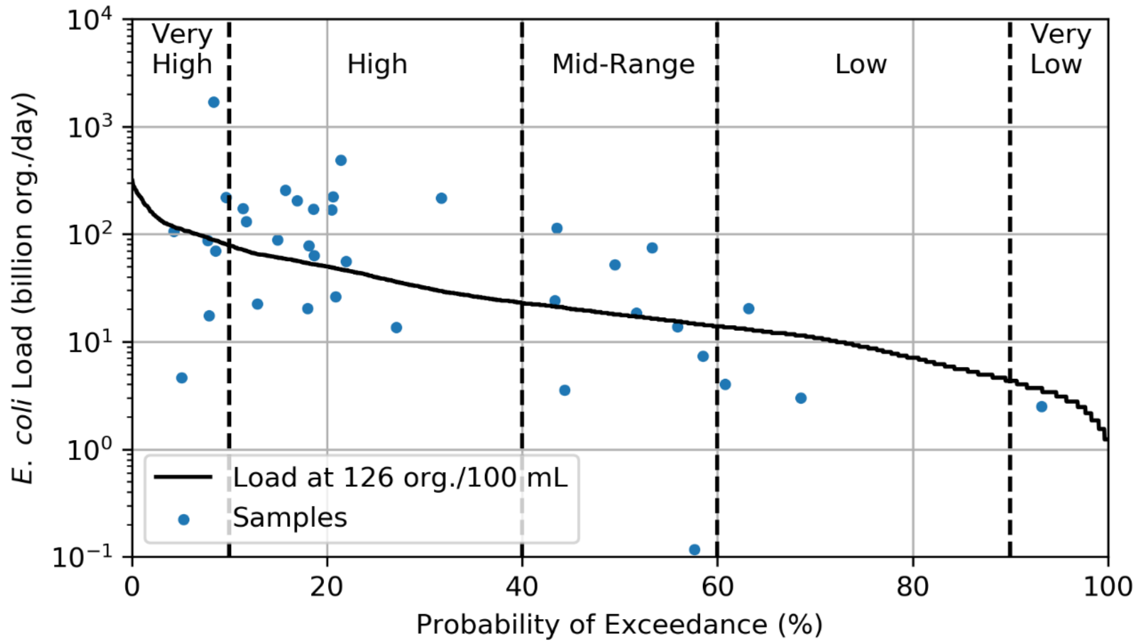


Figure 4-9. O'Brien Creek (AUID 09020302-544) *E. coli* Load Duration Curve, S004-833.

Existing *E. coli* loads are based on all samples from AUID 09020302-544 (Table 3-15) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for sub-basin 311 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007 through 2014 HSPF modeled mean daily flows for sub-basin 311.

Table 4-16. O'Brien Creek (AUID 09020302-544) *E. coli* TMDL and allocations

O'Brien Creek 09020302-544 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		*87.7*	*131.0*	*18.5*	*4.0*	*2.5*
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Load Allocations	*Watershed Runoff*	*100.7*	*35.8*	*16.1*	*8.0*	*2.8*
	Total LA	**100.7**	**35.8**	**16.1**	**8.0**	**2.8**
10% MOS		**11.2**	**4.0**	**1.8**	**0.9**	**0.3**
Total Loading Capacity		**111.9**	**39.8**	**17.9**	**8.9**	**3.1**
Estimated Load Reduction		*NA*	*91.2*	*0.6*	*NA*	*NA*
		NA	*70%*	*3%*	*NA*	*NA*

4.2.6.9 Unnamed creek (-600) *E. coli* TMDL

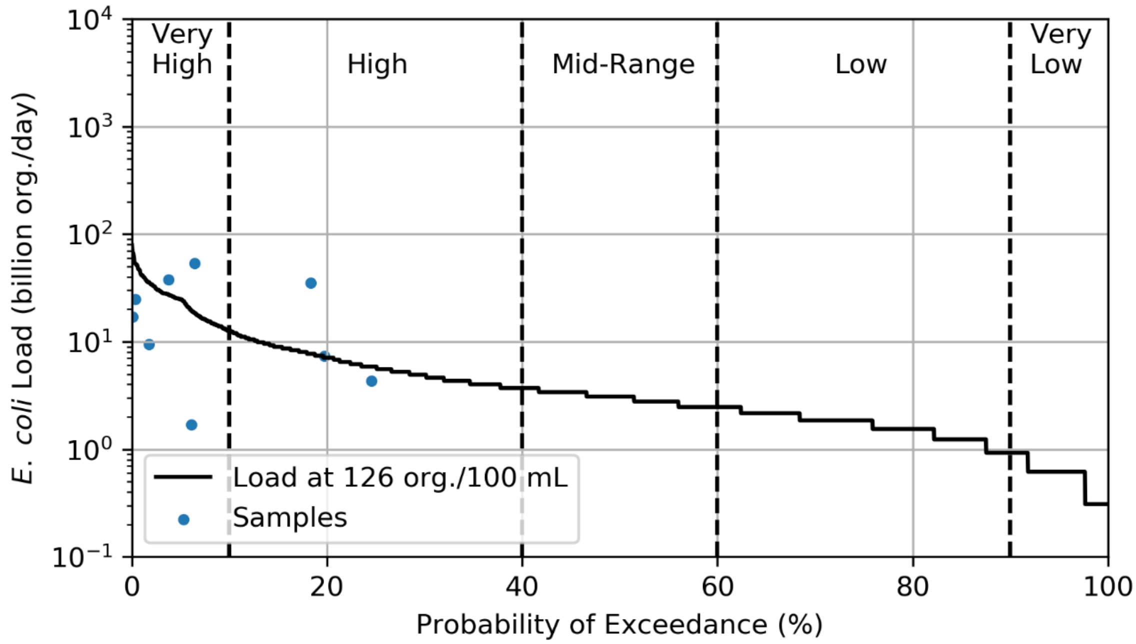


Figure 4-10. Unnamed creek (AUID 09020302-600) *E. coli* Load Duration Curve, S007-888.

Existing *E. coli* loads are based on all samples from AUID 09020302-600 (Table 3-16) during the months of April through October between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for sub-basin 43 on the water quality sample date. The LDC is based on the state water quality standard of 126 org/100 mL multiplied by 2007-2014 HSPF modeled mean daily flows for sub-basin 43.

Table 4-17. Unnamed creek (AUID 09020302-600) *E. coli* TMDL and allocations

Unnamed creek 09020302-600 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		***20.8***	***7.4***	***NA***	***NA***	***NA***
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Load Allocations	*Watershed Runoff*	*22.2*	*5.3*	*2.8*	*1.6*	*0.5*
	Total LA	**22.2**	**5.3**	**2.8**	**1.6**	**0.5**
10% MOS		**2.5**	**0.6**	**0.3**	**0.2**	**0.1**
Total Loading Capacity		**24.7**	**5.9**	**3.1**	**1.8**	**0.6**
Estimated Load Reduction		*NA*	*1.5*	*NA*	*NA*	*NA*
		NA	*25%*	*NA*	*NA*	*NA*

4.2.7 Reductions

Based on the water quality monitoring data plotted with the *E. coli* standard curves in Section 4.2.6, exceedances of the *E. coli* standard occurred most frequently at the high flow regime for the impaired streams. Reductions of 0 to 70% in *E. coli* loads are needed to meet the water quality standard at the high flow regime.

For most streams, paired water quality and flow data were limited to five to six samples collected in 2014. Exceedances of the *E. coli* water quality standard were also observed at several of the impaired streams during 2015; however, paired flow data (modeled flow) were not available for samples collected during 2015 (See Appendix C). Longer *E. coli* data records were available for two impaired reaches: Blackduck River (-501) and O'Brien Creek (-544). These data records also indicate that exceedances are greatest at the high flow regime.

4.2.8 TMDL Baseline

The stream *E. coli* TMDLs are based on flow and water quality record results for the period 2007 through 2014. Any activities implemented after the mid-point of the TMDL time period (2010) that lead to a reduction in loads or an improvement in an impaired stream water quality may be considered as progress towards meeting a WLA or LA.

4.3 TSS

4.3.1 Loading Capacity Methodology

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

For the stream TMDL derivation, HSPF modeled flows for the period 2007 through 2014 were used to develop flow duration curves. The loading capacities were determined by applying the TSS water quality standard (15 mg/L) to the flow duration curve to produce a TSS standard curve. The TSS loading capacities were calculated as the median load (in lb/day) along the TSS standard curve within each flow regime. A TSS LDC with monitored TSS data and a TMDL summary table are provided for each stream in Section 4.3.6.

The LDC method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the

TMDL equation tables of this report, only five points on the entire 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 the EPA.

4.3.2 Load Allocation Methodology

LAs represent the portion of the LC that is designated for nonregulated sources of TSS as described in Section 3.6.2.3, that are located downstream of any other impaired waters with TMDLs located in the watershed. The remainder of the LC (TMDL) after subtraction of the MOS and calculation of the WLA was used to determine the LA for each impaired stream on an areal basis.

The TMDLs for the stream reaches located partially within the boundaries of the Red Lake Reservation were calculated to the outlet of each stream reach to Lower Red Lake within the reservation boundaries. LAs for watershed runoff for tribal land are included for these reaches as boundary conditions and no reductions are assigned to the tribal land runoff. The boundary condition load allocated to tribal runoff is based on the amount of tribal government land located in the drainage area of the impaired stream reach and is for tribal guidance only for managing their water resources based on their proposed water quality standards. It is understood that the MPCA has no jurisdiction on tribal lands, and that EPA will not approve that part of a TMDL that is located within the boundaries of tribal lands. These TMDLs were developed in cooperation with, and assistance from, the RL DNR.

4.3.3 Wasteload Allocation Methodology

4.3.3.1 Regulated Construction Stormwater

A categorical WLA was assigned to all construction activity in each impaired stream subwatershed. First, the average annual fraction of the impaired subwatershed area under construction activity over the most recent 10 years was calculated based on the MPCA Construction Stormwater Permit data from January 1, 2009, to December 31, 2018 (Table 4-18) and was area-weighted based on the fraction of the subwatershed located in each county. This percentage was multiplied by the watershed runoff load component to determine the construction stormwater WLA. The watershed runoff load component is equal to the total TMDL (LC) minus the sum of the nonwatershed runoff load components (upstream loads and MOS).

Table 4-18. Average Annual NPDES/SDS Construction Stormwater Permit Activity by County (1/1/2009-12/31/2018)

County	Total Area (ac)	Average Annual Construction Activity (% Total Area)
Beltrami	80,187	0.004%
Itasca	9,350	0.027%
Koochiching	3,662	0.002%

4.3.3.2 Regulated Industrial Stormwater

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

4.3.3.3 Municipal and Industrial Wastewater Treatment Systems

There are no NPDES permitted municipal or industrial wastewater facilities located within the drainage area of a TSS impaired stream addressed by this TMDL.

4.3.3.4 Permitted Feedlots

There are no permitted feedlots located within the drainage area of a TSS impaired stream addressed by this TMDL.

4.3.4 Margin of Safety

The MOS accounts for uncertainty about pollutant loadings and waterbody response. It reflects the degree of characterization and accuracy of the estimates of the source loads, and the level of confidence in the analysis of the relationship between the source loads and the impact upon the receiving water. In concept, it ensures attainment and maintenance of water quality standards for the allocated pollutant. As such, it reduces the remaining pollutant allocation to nonpoint and point sources.

An explicit MOS equal to 10% of the LC was used for the stream TMDL based on the following considerations:

- Sufficient monitoring data available for the impaired reach.
- Adequate calibration and validation of the HSPF model.
- Some uncertainty in extrapolating flows in upstream areas of the watershed based on HSPF model calibration at stream gauges near the outlet of the ULRLW.
- Best professional judgement of the overall TMDL development.
- Reasonable and achievable LAs and WLAs.

In addition to the explicit MOS, an implicit MOS is factored into the TMDL through the use of critical conditions and seasonal variability in the establishment of water quality standards by the State of Minnesota, and the use of conservative assumptions in the determination of critical conditions using the monitoring data, and the use of a watershed pollutant loading model to determine the contribution of sediment from point and nonpoint sources.

4.3.5 Seasonal Variation

The TSS water quality standard applies for the period April through September, which corresponds to the open water season when aquatic organisms are most active and when high stream TSS concentrations generally occur. TSS loading varies with the flow regime and season. Spring is associated with large flows from snowmelt, the summer is associated with the growing season as well as periodic storm events and receding streamflows, and the fall brings increasing precipitation and rapidly changing agricultural landscapes.

Critical conditions and seasonal variation are addressed in this TMDL through several mechanisms. The TSS standard applies during the open water months, and data was collected throughout this period. The water quality analysis conducted on these data evaluated variability in flow through the use of five flow regimes; from high flows, such as flood events, to low flows, such as baseflow. Through the use of LDCs and monthly summary figures, TSS loading was evaluated at actual flow conditions at the time of sampling (and by month).

4.3.6 TMDL Summary

4.3.6.1 Mud River (09020302-541) Total Suspended Solids TMDL and allocations

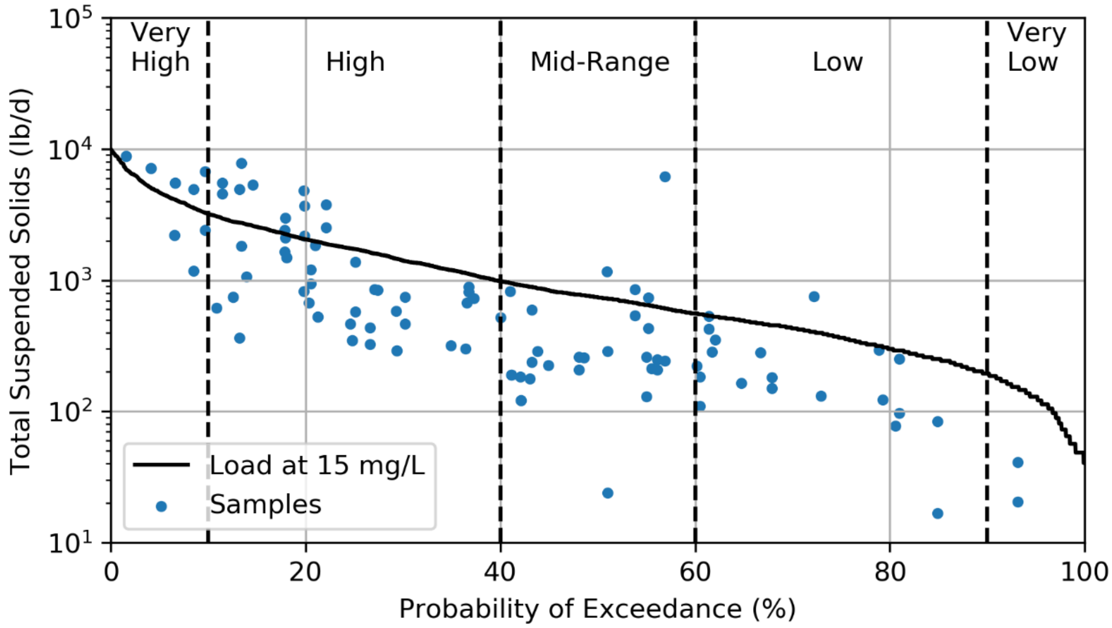


Figure 4-11. Total suspended solids load duration curve for Mud River (09020302-541) (MUDR-M (S007-881), MUDR-I).

Existing TSS loads are based on all samples collected from 09020302-541 (Table 3-19) during the months of April through September between 2007 and 2014, multiplied by the paired 2007 through 2014 HSPF modeled mean daily flow for subbasin 339 on the water quality sample date. The LDC is based on the state water quality standard of 15 mg/L multiplied by 2007 through 2014 HSPF modeled mean daily flows for subbasin 339.

Table 4-19. Mud River (09020302-541) total suspended solids TMDL and allocations

Mud River 09020302-541 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		TSS (lb/day)				
Existing Load*		**8,395.6**	**3,116.3**	**1,339.7**	**655.2**	**233.1**
Existing Load excluding the Boundary Condition		**7,737.0**	**2,871.8**	**1,234.6**	**603.8**	**214.8**
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Construction Stormwater (MNR100001)	*16.8*	*6.2*	*2.7*	*1.3*	*0.5*
	Industrial Stormwater (MNR050000)	*16.8*	*6.2*	*2.7*	*1.3*	*0.5*
	Total WLA	**33.6**	**12.4**	**5.4**	**2.6**	**1.0**
Load Allocations	*Nonregulated sources*	3,571.5	1,325.8	569.9	278.8	99.1
10% MOS		400.6	148.7	63.9	31.3	11.1
MN Loading Capacity		**4,005.7**	**1,486.9**	**639.2**	**312.7**	**111.2**
Estimated Load Reduction		**3,731.3**	**1,384.9**	**595.4**	**291.1**	**103.6**
		48%	48%	48%	48%	48%
Boundary Condition	*Red Lake Nation Loading Capacity***	658.6	244.5	105.1	51.4	18.3
Total Loading Capacity		**4,664.3**	**1,731.4**	**744.3**	**364.1**	**129.5**

*Existing load is based on the 90th percentile TSS concentration from Table 3-19 of all samples collected at MUDR-M (S007-881), and MUDR-I during the months of April-September and the years 2007-2016 multiplied by the median flow for each flow regime predicted by the HSPF model for sub-basin 339.

**The Red Lake Nation Loading Capacity is based on the amount of tribal government land located in the impaired stream reach drainage area (14.1%). No reductions are assigned to this allocation.

4.3.7 Reductions

Paired water quality and flow data for the impaired TSS streams were limited to samples collected during 2014. Additional monitoring is recommended to more accurately estimate existing TSS load and to identify TSS reduction strategies.

4.3.8 TMDL Baseline

TSS TMDLs are based on data from the period 2007 through 2014. Any activities implemented during or after 2014 that lead to a reduction in loads or an improvement in an impaired stream water quality may be considered as progress towards meeting a WLA or LA.

5 Future Growth/Reserve Capacity

According to the 2010 Census (U.S. Census Bureau 2011), approximately 10,800 people reside in the ULRLW. The largest communities include Blackduck, Hines, Nebish, Langor, Funkley, Northome, and Kelliher and the Reservation communities of Little Rock, Red Lake, Ponemah, and Redby. Approximately 81% of the watershed is located in Beltrami County. From 2010 to 2018, the population growth rate for

Beltrami County increased at a rate of 5.4%. Approximately 16% of the watershed is located in Koochiching County. From 2010 to 2018, the population growth rate for Koochiching County decreased at a rate of 6.6%. From 2000 to 2010, the Red Lake Reservation had a population increase of 735 individuals, equivalent to a 15% population gain in these 10 years.

Traditionally, the economy of Northwest Minnesota including the ULRLW has relied upon the availability of natural resources and tourism based on the appeal of its natural environment. The economic impact of travel and tourism to Beltrami County in 2016 was over $96 million, making it the third highest in northern Minnesota. An analysis prepared for Explore Minnesota, found almost three quarters of the travelers visit the northwest region for the opportunity that the regional lakes and rivers provide (Beltrami County, 2017). Land use within the ULRLW is not expected to change much in the future, as it has not changed much in the recent past. Less than 2% of the watershed is considered developed, approximately 6% is pasture/hay, and crop production is estimated under 1%.

How changing sources of pollutants may or may not impact TMDL allocations are discussed below, in the event that population and land use in the ULRLW do change over time.

5.1 New or Expanding Permitted MS4 WLA Transfer Process

Note that there are currently no MS4s located in the ULRLW. 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. One or more nonregulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
2. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES/SDS permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL (see Section 4.1.3). The MPCA will make these allocation shifts. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment.

5.2 New or Expanding Wastewater

There are two municipal wastewater facilities, two industrial facilities, and three permitted feedlots that require NPDES or SDS permitting located in the ULRLW. All existing permitted facilities within the ULRLW are in compliance with permitted effluent limits; no further pollutant reductions are needed from these facilities.

The MPCA, in coordination with the EPA Region 5, has developed a streamlined process for setting or revising WLAs for TSS and *E. coli* for new or expanding wastewater discharges to waterbodies with an EPA approved TMDL (MPCA 2012). 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 TSS and *E. coli* 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.

For more information on the overall process, visit the MPCA's [TMDL Policy and Guidance] webpage.

6 Reasonable Assurance

A TMDL needs to provide reasonable assurance that water quality targets will be achieved through the specified combination of point and nonpoint source reductions reflected in the LAs and WLAs, respectively. According to EPA guidance (EPA 2002):

> "When a TMDL is developed for waters impaired by both point and nonpoint sources, and the WLA is based on an assumption that nonpoint-source load reductions will occur ... the TMDL should provide reasonable assurances that nonpoint source control measures will achieve expected load reductions in order for the TMDL to be approvable. This information is necessary for the EPA to determine that the TMDL, including the LA and WLAs, has been established at a level necessary to implement water quality standards."

In order to address phosphorus, bacteria, and sediment loading in the ULRLW, already required point source controls will be effective in improving water quality if accompanied by considerable reductions in nonpoint source loading. Reasonable assurance for permitted sources, such as construction stormwater, industrial stormwater, and wastewater is provided via compliance with their respective NPDES permit programs, as described in Section 3.6.

The following sections provide reasonable assurance that implementation will occur and result in pollutant load reductions in the ULRLW. These reasonable assurances are outlined in the following areas:

1. Availability of reliable means of addressing pollutant loads (see Sections 6.1 Nonpermitted source reduction programs and 6.3 Example nonpermitted source reduction projects and partners);
2. A means of prioritizing and focusing management (see ULRLW WRAPS Report);
3. Development of a strategy for implementation (see Section 8 Implementation strategy summary);
4. Availability of funding to execute projects (see Section 6.4 Funding availability);
5. A system of tracking progress and monitoring water quality response (see Sections 7 Monitoring plan and 8.7 Adaptive management);
6. Nonpoint source pollution reduction examples at multiple scales (see Section 6.6 Example nonpermitted source reduction projects and partners)
7. None of the impairments within the ULRLW are extreme in nature. Restoration of these water resources is feasible.

6.1 Examples of source reduction programs

There are many opportunities available through local, county, state, and federal programs to address the pollutant loads in the ULRLW. These programs identify BMPs, provide means of focusing BMPs, and support their implementation via state initiatives, ordinances, and/or provide dedicated funding. The following examples describe large-scale programs that have proven to be effective and/or will reduce phosphorus, sediment, and *E. coli* loads going forward.

6.1.1 Nonregulatory

Watershed load reductions will be achieved through management of septic systems, shoreline erosion, implementation of BMPs, preventative education, development of habitat protection strategies and ordinances, and expanding monitoring efforts. The RL DNR Water Resources Program led a watershed-wide study to identify and address threats to water quality not only on the Red Lake Reservation but also throughout the ULRLW. This study was funded by the MPCA and included many partners throughout the watershed such as Beltrami Soil and Water Conservation District (SWCD) and Environmental Services, RLWD, and local governments. The RL DNR Nonpoint Source Program has implemented programs that target the implementation of BMPs and work towards watershed management to improve water quality, conducted environmental education efforts, developed general habitat and environmental protection ordinances, and managed stormwater issues, erosion reduction projects, and education and outreach.

The Red Lake Band NPS Assessment Report, Management Plan, and application for TAS were approved by the EPA on October 8, 2008 (RLBCI 2008). This plan identified agriculture as the number one source of NPS pollution in Reservation waters, especially in the Blackduck River, Pike Creek, and Battle River watersheds (RLBCI 2008). The tribe is actively cooperating with the MPCA, Natural Resources Conservation Service (NRCS), and local SWCDs to abate these problems.

Beltrami SWCD and Environmental Services, Koochiching County SWCD, RLWD, and locally-led groups such as the Upper Red Lake Area Association are playing a similar role in areas outside of the Reservation. Both Beltrami County and Koochiching County have recently developed comprehensive local water management plans (2017 and 2018 respectively) that prioritize implementation efforts during the effective period (10 years) of their respective plans. The City of Northome and RLWD are developing a Lake Management Plan for Bartlett Lake.

6.1.1.1 Woodland Stewardship Areas

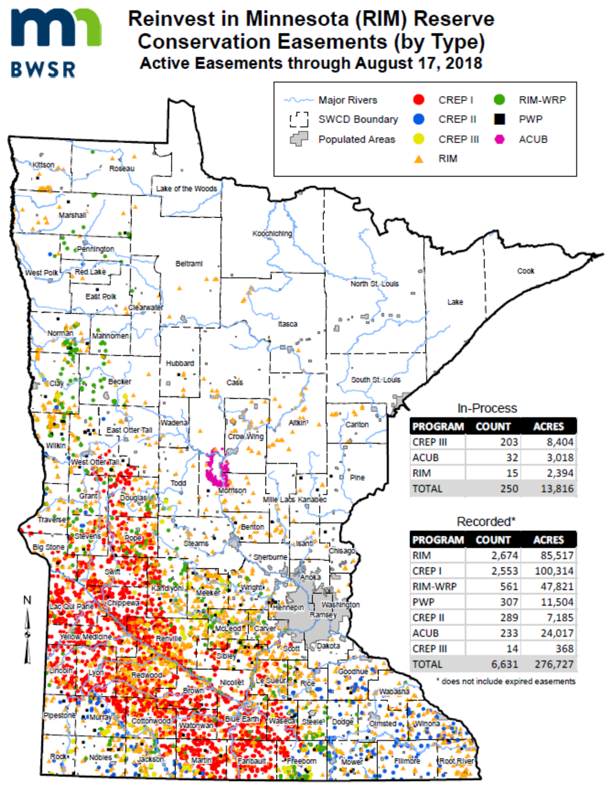
The DNR Forest Stewardship Program helps woodland owners manage forestlands through advice and education, cost-share programs, and the development of Woodland Stewardship Plans. A unique plan is developed for each woodland area based on the landowner's land management goals. Plans are written for woodland owners with 20 to 5,000 acres where at least 10 acres have or will have trees. Plans are updated every 10 years to stay current with needs. Plans are developed and written by foresters trained in woodland stewardship from the DNR, environmental organizations, SWCDs, and consulting foresters.

The development of a Woodland Stewardship Plan registered with the DNR allows landowners to qualify for woodland tax and financial incentive programs. One of these programs is the Sustainable Forest

[Incentive Act (SFIA) program](). The SFIA provides annual incentive payments to encourage private landowners to keep their wooded areas undeveloped.

Private landowners can receive a payment for each acre of qualifying forestland they enroll in SFIA. In return, they agree not to develop the land and to follow a forest management plan for a set period: either 8, 20, or 50 years. The DNR handles forestland management on all SFIA lands. In the ULRLW, there are 17,694 acres of woodlands with existing woodland stewardship plans. Of these 17,694 acres, 16,826 (95%) are enrolled in the SFIA program.

6.1.1.2 Conservation Easements



Conservation easements are a critical component of the state's efforts to improve water quality by reducing soil erosion, phosphorus loading and nitrogen loading, and improving wildlife habitat and flood attenuation on private lands. Easements protect the state's water and soil resources by permanently restoring wetlands, adjacent native grassland wildlife habitat complexes, and permanent riparian buffers. In cooperation with county SWCDs and the United States Department of Agriculture (USDA) NRCS, Board of Water and Soil Resources (BWSR) programs compensate landowners for granting conservation easements and establishing native vegetation habitat on economically marginal, flood-prone, environmentally sensitive or highly erodible lands. These easements vary in length of time from 10 years to permanent/perpetual easements. Types of conservation easements in Minnesota include Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), Reinvest in Minnesota (RIM), and the Wetland Reserve Program (WRP) or Permanent Wetland Preserve (PWP). As of December 2019, there were 64 acres of long term or permanent easements (CREP, RIM, WRP) in the ULRLW. The low enrollment in the ULRLW is reflective of the fact that the majority of the land in the ULRLW is publicly or federally owned.

6.1.1.3 Agricultural Water Quality Certification Program

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

MINNESOTA WATER QUALITY CERTIFIED FARM

Through this program, certified producers receive the following:

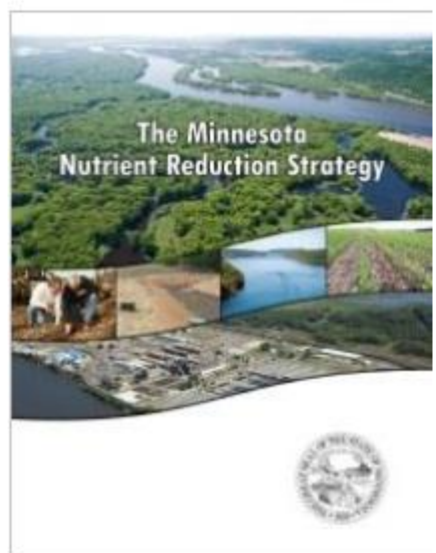
- **Regulatory certainty**: Certified producers are deemed to be in compliance with any new water quality rules or laws during the period of certification.
- **Recognition**: Certified producers may use their status to promote their business as protective of water quality.
- **Priority for assistance**: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

Through this program, the public receives assurance that certified producers are using conservation practices to protect Minnesota's lakes, rivers, and streams. Since the start of the program in 2014, the Ag Water Quality Certification Program has several statewide accomplishments:

- Enrolled over 750,000 acres;
- Included over 1,000 producers;
- Added more than 1,500 new conservation practices;
- Kept over 66 million pounds of sediment out of Minnesota rivers;
- Saved 163 million pounds of soil and 39,766 pounds of phosphorus on farms; and
- Reduced nitrogen losses by up to 49%.

6.1.1.4 Minnesota Nutrient Reduction Strategy

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



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

Included within the strategy discussion are alternatives and tools for consideration by drainage authorities, information on available tools and approaches for identifying areas of phosphorus and nitrogen loading and tracking efforts within a watershed, and additional research priorities. The NRS is focused on incremental progress and provides meaningful and achievable nutrient load reduction milestones that allow for better understanding of incremental and adaptive progress toward final goals. It has set a 10% reduction from 2003 conditions for phosphorus and 13% reduction from 2003 conditions for nitrogen for Lake Winnipeg, downstream of the ULRLW.

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

- IWM;
- Assessment of watershed health;
- Development of TMDL and WRAPS reports; and
- Management of NPDES and other regulatory and assistance programs.

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

6.1.2 Regulatory

6.1.2.1 Regulated Construction Stormwater

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

6.1.2.2 Regulated Industrial Stormwater

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

All local stormwater management requirements must also be met.

6.1.2.3 Wastewater National Pollutant Discharge Elimination System and State Disposal System Permits

The MPCA issues permits for WWTF that discharge into waters of the state. The permits have site specific limits on bacteria that are based on water quality standards. Permits regulate discharges with the following goals: (1) protecting public health and aquatic life, and (2) assuring that every facility treats wastewater. In addition, SDS permits set limits and establish controls for land application of sewage. All existing permitted facilities within the ULRLW are in compliance with permitted effluent limits; no further pollutant reductions are needed from these facilities.

6.1.2.4 Subsurface Sewage Treatment Systems Program

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

These regulations detail:

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

In 2008, the MPCA amended and adopted rules concerning the governing of SSTS. In 2010, the MPCA was mandated to appoint an SSTS Implementation and Enforcement Task Force (SIETF). Members of the SIETF include representatives from the Association of Minnesota Counties, Minnesota Association of Realtors, Minnesota Association of County Planning and Zoning Administrators, and the Minnesota Onsite Wastewater Association. The group was tasked with the following:

- Developing effective and timely implementation and enforcement methods to reduce the number of SSTS that are an IPHT and enforce all violations of the SSTS rules (See report to the legislature; MPCA 2011); and
- Assisting MPCA in providing counties with enforcement protocols and inspection checklists.

All Counties within the ULRLW have ordinances establishing minimum requirements for regulation of SSTS, for the treatment and dispersal of sewage within the applicable jurisdiction of the county, to protect public health and safety, groundwater quality, and prevent or eliminate the development of public nuisances. Ordinances serve the best interests of the county's citizens by protecting its health, safety, general welfare, and natural resources. In addition, each county zoning ordinance prescribes the technical standards that on-site septic systems are required to meet for compliance and outlines the requirements for the upgrade of systems found not to be in compliance.

6.1.2.5 Feedlot Rules

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

There are two primary concerns about feedlots in protecting water:

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

6.1.2.6 Buffer Program

The Buffer Law signed by Governor Dayton in June 2015 was amended on April 25, 2016, and further amended by legislation signed by Governor Dayton on May 30, 2017. The Buffer Law requires the following:

- For all public waters, the more restrictive of:
    - a 50-foot average width, 30-foot minimum width, continuous buffer of perennially rooted vegetation, or
    - the state shoreland standards and criteria.
- For public drainage systems established under Minn. Stat. 103E, a 16.5-foot minimum width continuous buffer.

Alternative practices are allowed in place of a perennial buffer in some cases. The amendments enacted in 2017 clarify the application of the buffer requirement to public waters and provide the following:

- additional statutory authority for alternative practices,
- address concerns over the potential spread of invasive species through buffer establishment,
- establish a riparian protection aid program to fund local government buffer law enforcement and implementation, and
- allowed landowners to be granted a compliance waiver until July 1, 2018, when they filed a compliance plan with the SWCD.

BWSR provides oversight of the buffer program, which is primarily administered at the local level; compliance with the Buffer Law in the state is displayed at the Buffer Program Update webpage. As of January 2020, 94% to 100% of all parcels are in compliance in with the buffer law in both Beltrami and Koochiching County.

6.2 Prioritization and Focusing Management

As part of the complementary ULRL WRAPS Report, EOR worked with staff from the RL DNR and MPCA to prioritize protection and restoration strategies for the watershed. The findings from this TMDL and the restoration and protection strategies from the WRAPS will be incorporated into local county water management plans. The listing of implementation activities within a local water management plan will improve the likelihood of those projects being funded by state grant funds.

6.3 Implementation Strategy

The WRAPS, TMDLs, and all supporting information provide a starting point for progressing the watershed to cleaner water. Future local watershed plans including county water plans and/or BWSR's One Watershed, One Plan (1W1P) will further develop tools and identify ways to improve water quality in the watershed as well as provide a detailed implementation plan. As of March 2021, the ULRLW had not been selected for a BWSR 1W1P. However, as previously mentioned, both Beltrami County and Koochiching County have recently developed comprehensive local water management plans. These plans identify and prioritize implementation activities within the 10-year timeframe of these water plans.

6.4 Funding Availability

At the local level, Beltrami County, Koochiching County, Itasca County, and Clearwater County SWCDs will continue to leverage state grants such as the Natural Resources Block Grant, BWSR grants for SWCD for operations, the Erosion Sediment Control and Water Quality Cost-Share Program, and existing local, state, and federal funding sources. Both Beltrami and Koochiching Counties have identified priority implementation activities that will be completed over the next 10 years with currently approved funding. Additionally, both Counties have identified secondary and partner-led implementation activities that will require additional sources of funding, staff resources, or shared service.

At the state level, there are a variety of funding sources to help cover some of the costs to implement practices that reduce pollutants from entering surface waters and groundwater. There are several programs listed below that contain web links to the programs and contacts for each entity. The contacts for each grant program can assist in the determination of eligibility for each program, as well as funding requirements and amounts available.

- Agriculture BMP Loan Program (MDA)
- Agricultural Water Quality Certification Program (MDA)
- Clean Water Fund Grants (BWSR)
- Clean Water Partnership Loans (MPCA)
- Environment and Natural Resources Trust Fund (Legislative-Citizen Commission on Minnesota Resources)
- Environmental Assistance Grants Program (MPCA)
- Phosphorus Reduction Grant Program (Minnesota Public Facilities Authority)
- Clean Water Act Section 319 Grant Program (MPCA)
- Small Community Wastewater Treatment Construction Loans & Grants (Minnesota Public Facilities Authority)
- Source Water Protection Grant Program (Minnesota Department of Health)
- Surface Water Assessment Grants (MPCA)
- Wastewater and storm water financial assistance (MPCA)
- Conservation Partners Legacy Grant Program (DNR)
- Environmental Quality Incentives Program (Natural Resources Conservation Service)
- Conservation Reserve Program (USDA)
- Clean Water State Revolving Fund (EPA)

Additional funds to improve water quality are available through Minnesota's Legacy Fund. The Legacy Fund is the result of a constitutional amendment passed by Minnesota's voters in 2008 that provides funding to protect drinking water sources, protect, enhance, and restore wetlands, prairies, forests, and fish, game, and wildlife habitat, preserve arts and cultural heritage, support parks and trails, and protect, enhance and restore lakes, rivers, streams, and groundwater. Since 2010, the Clean Water Fund, one of the funds funded through the Clean Water, Land, and Legacy amendment, has received $943.8 million (MPCA et. al 2018).

6.5 Tracking Progress and Monitoring Water Quality Response

The MPCA has set up the IWM program to monitor and assess the water quality of Minnesota. More information about monitoring in the watershed is provided in Section 7.

In addition, the MPCA maintains an online database of BMPs implemented by major watershed since 2004: https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed. A summary of BMPs implemented in the ULRLW since 2004 is shown in Figure 6-1. From 2004 through 2018, 538 BMPs have been installed in the ULRLW. The three most common strategies used were forage and biomass planting (59), converting land to perennials via tree/shrub establishment (42), and development of forestry management plans (33).

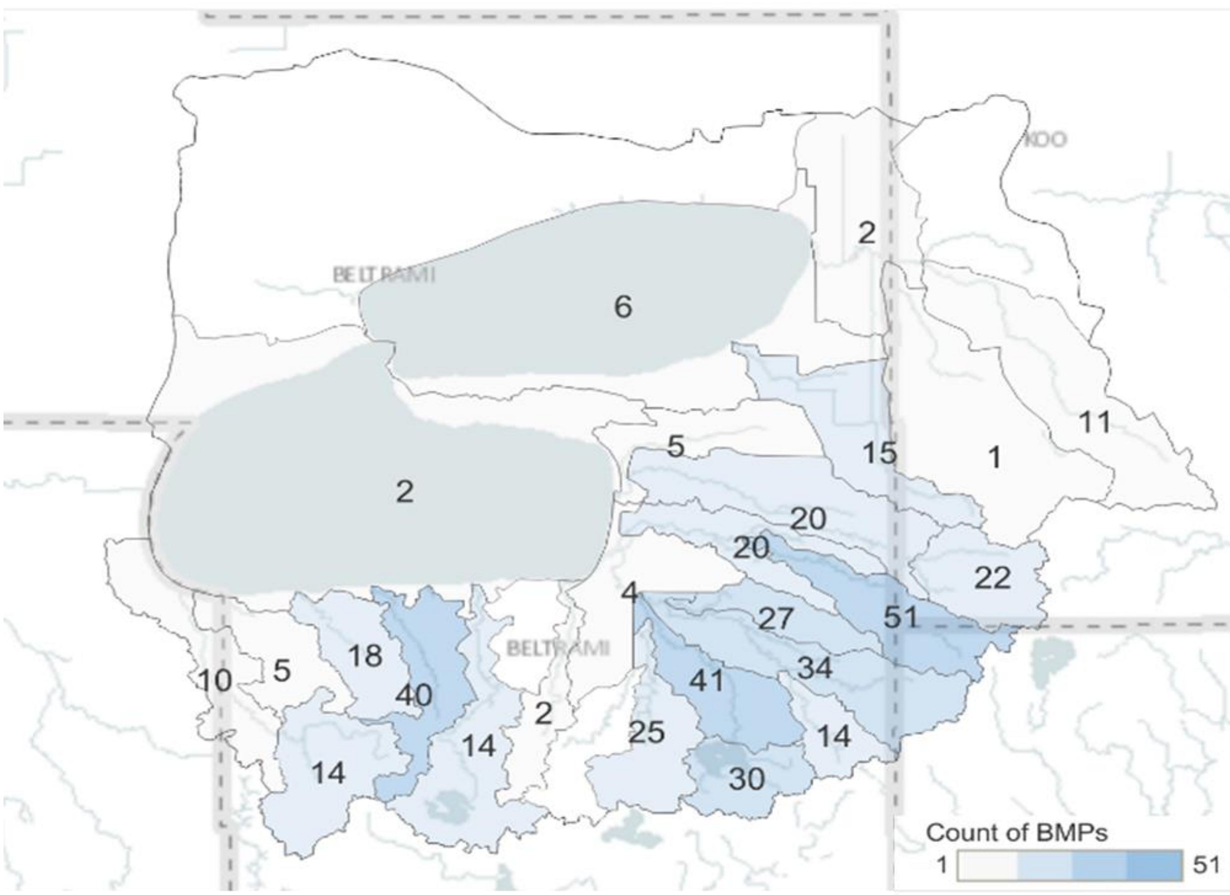


Figure 6-1. BMPs implemented in the ULRLW since 2004

6.6 Nonpoint Source Pollution Reduction

Analysis of water quality data from 80 monitoring locations across Minnesota has shown that five pollutants (TSS, TP, ammonia, BOD, and bacteria) have decreased while nitrate and chloride concentrations have increased over a 30-year period (MPCA 2014d). These trends continue in the Red Lake River downstream of Upper and Lower Red Lake. These trends are a result of the state's efforts to control municipal and industrial discharges, and a continuing effort by state, county and local groups to reduce nonpoint source pollution through nonpoint source projects.

In summary, significant time and resources have been devoted to identifying the best BMPs, providing means of focusing them in the ULRLW TMDL Study Area, and supporting their implementation via state initiatives and dedicated funding. The ULRLW TMDL process engaged partners to arrive at reasonable examples of BMP combinations that attain pollutant reduction goals. Minnesota is a leader in watershed planning as well as monitoring and tracking progress toward water quality goals and pollutant load reductions. Finally, examples cited herein confirm that BMPs and restoration projects have proven to be effective over time and as stated by the State of Minnesota Court of Appeals in A15-1622 MCEA vs MPCA and MCES:

> We conclude that substantial evidence exists to conclude that voluntary reductions from nonpoint sources have occurred in the past and can be reasonably expected to occur in the future. The Nutrient Reduction Strategy (NRS) […] provides substantial evidence of existing state programs designed to achieve reductions in nonpoint source pollution as evidence that reductions in nonpoint pollution have been achieved and can reasonably be expected to continue to occur.

7 Monitoring Plan

7.1 Lake and Stream Monitoring

The RL DNR has been monitoring sites in the ULRLW since the early 1990s. Fourteen stream sites are monitored in the watershed on a regular basis (Table 7-3). Thirteen of the sites flow into Upper and Lower Red Lake, and one monitoring site is at the outlet of Lower Red Lake on the Red Lake River. Sites are monitored for nutrients (TP, ammonia-nitrogen, total Kjeldahl nitrogen [TKN], nitrite-nitrate, and TSS) four times per year, including a storm event. Stream physical parameters are measured twice per month from snowmelt to freeze up and include stage (tape-down or gage readings), DO, temperature (temp.), pH, specific conductivity (sp. cond.), and turbidity.

The Red Lake Watershed District (RLWD) has been collecting water quality samples in the watershed for its long-term monitoring program since 2008. They monitor six stream sites four times each year for stage, DO, temp., sp. cond., pH, turbidity, TP, orthophosphate (ortho-P), TSS, TKN, ammonia-nitrogen, *E. coli*, nitrite-nitrate, and biological oxygen demand at some sites (Table 7-4 and Figure 7-2). In addition, RLWD coordinates monthly monitoring May through September of Long Lake near Pinewood (04-0295-00) and Bartlett Lake for TP, Chl-*a* and Secchi depth.

As part of the MPCA IWM strategy, 35 stream sites were monitored for biology (fish and macroinvertebrates; Table 7-2) and 16 sites for water chemistry (Table 7-1) in 2014-2015. Prior to the next 10-year cycle, sampling sites will be evaluated to determine if some, all of the same, or some new sites will be sampled during the next round of IWM sampling. Details about the MPCA IWM strategy can be found in the ULRLW Monitoring and Assessment Report (MPCA 2017).

The RL DNR maintains a robust lake monitoring program throughout ULRLW with frequency and intensity of the lake monitoring grouped into four lake monitoring categories: Primary Lakes, Red Lakes, Secondary Lakes, and Shallow Lakes (Table 7-5). A description of each lake monitoring category is summarized below:

- Primary Lakes: monitored once monthly June-September for physical parameter profiles (DO, temp., sp. cond., pH), TP, chl-*a*, turbidity, and alkalinity as well as Secchi depth and site conditions (algae presence, etc.). In the winter, these lakes are also monitored once through the ice if conditions permit for physical profiles, TP, turbidity, alkalinity, snow and ice depth, as well as site conditions (presence of algae, etc.).
- Red Lakes: monitored twice monthly May through September at 10 sites for physical parameter profiles, Secchi depth, site conditions, TP, chl-*a*, turbidity and alkalinity. Once a month, surface water samples are also analyzed for TKN, nitrite-nitrate, ammonia-nitrogen, ortho-P, total dissolved solids, TSS, total suspended volatile solids, and bottom water samples are collected and analyzed for TP and ortho-P. In addition, plankton tows are collected at each event May through September and identified by the DNR as part of an invasive species monitoring effort. During the winter, Upper and Lower Red Lake is sampled once through the ice at each of the 10 sites for physical profiles, TP, turbidity, alkalinity, snow, and ice depth.
- Secondary Lakes: monitored every four years, June through September once monthly with one additional sample (for a total of five during those months) for physical parameter profiles, TP, chl-*a*, turbidity, and alkalinity as well as Secchi depth and site conditions (algae presence, etc.). In the winter, these lakes are also monitored once through the ice if conditions permit for physical profiles, TP, turbidity, alkalinity, snow and ice depth, as well as site conditions (presence of algae, etc.).
- Shallow Lakes: initially monitored as part of an intensive study about 10 years ago for 3 years, then revisited for 2 years. RL DNR intends to revisit these lakes at least every 10 years. These lakes are monitored once per month May through September for surface physical conditions (DO, temp., sp. cond., and pH), TP, total dissolved phosphorus, ortho-P, TKN, nitrite-nitrate, ammonia-nitrogen, total nitrogen, chl-*a*, turbidity and alkalinity, and fish and invertebrates.

The RL DNR and RLWD will continue to monitor their long-term sites at the same frequencies. If data collected indicates issues at a particular site, additional monitoring or additional monitoring sites may be added to determine where issues may be arising.

Table 7-1. ULRLW 2014-2015 Intensive Watershed Monitoring Stream Chemistry Stations

EQuIS ID	Biological Station ID	AUID	Waterbody Name	Location
S003-952	14RD129	09020302-539	South Branch Battle River	At CSAH 23, 0.5 mi N of Saum
S003-961	14RD124	09020302-506	North Cormorant River	At CSAH 23, 2.5 mi S of Saum
S003-962	14RD130	09020302-503	North Branch Battle River	At CSAH 23, 2 mi N of Saum
S007-883	14RD115	09020302-507	South Cormorant River	Adjacent to MN 1, 0.8 mi. SW of Quiring
S007-884	14RD136	09020302-502	Shotley Brook	At CR 23, 3.5 mi. NE of Shotley
S007-885	14RD138	09020302-614	Little Tamarack River	At Balsiger Rd, 5 mi SE of Waskish
S007-887	14RD139	09020302-501	Tamarac River	At Steel Bridge Rd, 0.5 mi S of Waskish
S007-886	14RD148	09020302-602	Lost River	At Balsiger Rd, 6 mi E of Waskish
S007-888	14RD149	09020302-600	Tributary to Upper Red Lake	At North Shore Dr, 6.5 mi NW of Waskish
S007-877	14RD100	09020302-522	Sandy River	Indian Service Rd 6, 7 mi SW of Little Rock, MN
S007-878	14RD104	09020302-548	Big Rock Creek	At BIA 8, 5mi. W of Little Rock
S007-881	14RD106	09020302-541	Mud River	On trail W of subdivision road off of BIA 15 in SW Redby
S007-880	14RD109	09020302-518	Hay Creek	At BIA 18, 5 mi E of Redby
S007-882	14RD122	09020302-513	Blackduck River	Along BIA 18, 3 mi NW of Quiring
S007-879	14RD126	09020302-521	Pike Creek	0.5 mi W of unnamed road that meets end of BIA 12, 1 mi S of Red Lake
S003-955	--	09020302-557	Manomin Creek	0.25 mi upstream of Upper Red Lake, 18 mi N of Red Lake

Table 7-2. ULRLW 2014-2015 Intensive Watershed Monitoring Stream Biological Stations

AUID	Biological Station ID	Waterbody Name	Biological Station Location
09020302-501	14RD139	Tamarac River	Upstream of Steel Bridge Rd, 0.5 mi. S of Waskish
09020302-501	14RD143	Tamarac River	NW of Balsiger Rd, 6 m.i E of Waskish
09020302-614	14RD138	Little Tamarac River	Upstream of Balsiger Rd, 5 mi. SE of Waskish
09020302-602	14RD148	Lost River	Downstream of Balsiger Rd, 6 mi. E of Waskish
09020302-603	14RD142	Lost River	Upstream of Lost River Rd, 8 mi. N of Forest Grove
09020302-502	14RD136	Shotley Brook	Downstream of CSAH 23, 3.5 mi. NE of Shotley
09020302-547	14RD137	Hoover Creek	Upstream of CR 105, 2.5 mi. N of Kelliher
09020302-503	14RD130	Battle River, North Branch	Downstream of CSAH 23, 2 mi. N of Saum

AUID	Biological Station ID	Waterbody Name	Biological Station Location
09020302-523	14RD134	Trib. to Battle River, South Branch	Upstream of CSAH 38, 7 mi. SW of Saum
09020302-538	09RD064	Battle River, South Branch	Upstream of CR 103, 2.7 mi. SW of Kelliher
09020302-539	14RD129	Battle River, South Branch	Downstream of CSAH 23, 0.5 mi. N of Saum
09020302-574	14RD132	Armstrong Creek	Across private property at end of CR 63, 5 mi. NW of Northome
09020302-508	14RD112	Darrigans Creek	Upstream of Everts Rd (CSAH 23), 5.5 mi. S of Quiring
09020302-510	14RD114	Blackduck River	Uprstream of Deertrail Rd, 3 mi. NW of Langor
09020302-511	14RD158	Blackduck River	0.3 mi. E of CSAH 23, 1.25 mi. SW of Quiring
09020302-512	05RD088	Blackduck River	Upstream of CR 23, 13 mi. SW of Kelliher
09020302-513	14RD122	Blackduck River	Upstream of BIA 18, 3 mi. NW of Quiring
09020302-514	14RD110	O'Brien Creek	West of Darrigans Creek Rd NE, 2 mi. S of Quiring
09020302-506	14RD124	North Cormorant River	Downstream of CSAH 23, 2.5 mi. S of Saum
09020302-506	14RD127	North Cormorant River	Downstream of Hwy 72, 0.5 mi. N of Shooks
09020302-506	14RD128	North Cormorant River	Downstream of CSAH 36, 5.5 mi SW of Kelliher
09020302-542	14RD141	Meadow Creek	Upstream of Fireweed Ln NE, 5.5 mi. SE of Saum
09020302-507	14RD115	South Cormorant River	Adjacent to Hwy 1, 0.8 mi. SW of Quiring
09020302-507	14RD117	South Cormorant River	Upstream of fire road crossing S of Buckeye rd, 3 mi. W of Inez
09020302-507	14RD119	South Cormorant River	Downstream of CSAH 41, 3.5 mi. NW of Funkley
09020302-552	14RD121	Spring Creek	East end of CR 306 and Hwy 72 intersection, 4 mi. N of Blackduck
09020302-605	14RD116	Perry Creek	At end of unnamed rd S of Hwy 1, 2.5 mi. SW of Quiring
09020302-518	14RD109	Hay Creek	Upstream of BIA 18, 5 mi. E of Redby
09020302-521	14RD126	Pike Creek	On unnamed trail, 0.5 mi. S of Red Lake
09020302-521	14RD153	Pike Creek	Downstream of BIA 1, 3 mi. NE of Island Lake
09020302-540	14RD107	Mud River	Downstream of Farmer Dr, 2 mi. NW of Nebish
09020302-541	14RD106	Mud River	At end of unnamed trail in Redby (streets near trail unnamed)
09020302-613	14RD157	Mud River	Upstream of CSAH 13, 5 mi. NW of Puposky
09020302-522	14RD100	Sandy River	Upstream of BIA 5, 7 mi. SW of Little Rock
09020302-522	14RD102	Sandy River	Upstream of CSAH 32 (Lumberjack Rd), 2 mi. NW of Debs
09020302-604	14RD103	North Fork River	Downstream of CR 32, 3 mi. NE of Debs

AUID	Biological Station ID	Waterbody Name	Biological Station Location
09020302-501	14RD139	Tamarac River	Upstream of Steel Bridge Rd, 0.5 mi. S of Waskish

Table 7-3. RL DNR Stream Monitoring Sites

AUID	Site ID	Waterbody Name	Monitoring Location
09020302-505	BATT-I	Battle River	at BIA-18
09020302-503	BATT-NB	North Branch Battle River	at CSAH 23
09020302-539	BATT-SB	South Branch Battle River	at CSAH 23
09020302-512	BLAC-H	Blackduck River	at MN HWY 1
09020302-513	BLAC-I	Blackduck River	at BIA-18
09020302-506	CORM-B	North Cormorant River	at CSAH 23
09020302-541	MUDR-I	Mud River	0.1 mi Upstream from Lower Red Lake
09020302-541	MUDR-M	Mud River	On trail E of subdivision road off BIA 60 in Redby
09020302-521	PIKE-B	Pike Creek	at South Boundary Rd
09020302-521	PIKE-I	Pike Creek	at MN HWY 1
09020302-521	PIKE-OR	Pike Creek	at CSAH 32
09020303-560	REDL-O	Red Lake River	at Outlet of Lower Red Lake
09020302-522	SANR-U	Sandy River	0.75 mi Upstream from Lower Red Lake
09020302-501	TAMA-B	Tamarac River	at Steel Bridge Rd

Table 7-4. RLWD Long-term Stream Monitoring Sites

AUID	Site ID	Waterbody Name	Monitoring Location
09020302-508	S004-832	Darrigans Creek	CSAH 23
09020302-544	S004-833	O'Brien Creek	Harvest Rd NE
09020302-510	S004-831	Blackduck River	Deer Trail Rd
09020302-507	S004-834	South Cormorant River	CSAH 37
09020302-515	S000-388	Coburn Creek	N Blackduck Lk Rd
09020302-506	S007-606	North Cormorant River	CSAH 36

Table 7-5. RL DNR Lake Monitoring Locations and Monitoring Category

Lake Site ID	Lake Name	Monitoring Category
ALAS	Alaska Lake	Shallow Lakes
ANKE	Ankeewinsee Lake	Secondary Lakes
ARTI	Artist Lake	Shallow Lakes
BAIL	Bailey Lake	Shallow Lakes

Lake Site ID	Lake Name	Monitoring Category
BALI	Balif Lake	Secondary Lakes
BASS-NW	Bass Lake - Northwest Basin	Primary Lakes
BASS-SE	Bass Lake - Southeast Basin	Primary Lakes
BEAS	Beasty Lake	Secondary Lakes
BEND	Bender Lake	Shallow Lakes
BIGT	Big Thunder Lake	Primary Lakes
BITN	Bitney Lake	Secondary Lakes
BIZH	Bizhiki Lake	Shallow Lakes
BLAK	Blake Lake	Secondary Lakes
BORD	Border Lake	Secondary Lakes
BURN	Burns Lake	Shallow Lakes
BURT	Burt Lake	Secondary Lakes
CAHI	Cahill Lake	Shallow Lakes
CANV	Canvasback Lake	Shallow Lakes
CHAI-M	Chain: Middle Lake	Primary Lakes
CHAI-S	Chain: South Lake	Primary Lakes
COLL	Collier Lake	Shallow Lakes
COLO	Colombo Lake	Secondary Lakes
CROO	Crooked Lake	Secondary Lakes
CURT	Curtis Lake	Shallow Lakes
DICK	Dickens Lake	Primary Lakes
DUNB	Dunbar Lake	Secondary Lakes
DUNE	Dune Lake	Secondary Lakes
EAST	East of Bender Lake	Shallow Lakes
ELEP	Elephant Ear Lake	Secondary Lakes
EMER	Emerald Lake	Primary Lakes
GIBI	Gibibwisher Lake	Secondary Lakes
FAIR	Fairbanks Lake	Secondary Lakes
FOUR	Fourth Lake	Secondary Lakes
FOX	Fox Lake	Secondary Lakes
FRAN	Francis Lake	Secondary Lakes
FRIS	Frisby Lake	Secondary Lakes
FULL-E	Fullers Lake - East Basin	Primary Lakes
FULL-W	Fullers Lake - West Basin	Primary Lakes
GIMI	Gimiwan Lake	Shallow Lakes

Lake Site ID	Lake Name	Monitoring Category
GOUR	Gourd Lake	Secondary Lakes
GRAN	Graning Lake	Secondary Lakes
GRAS	Grass Island Lake	Secondary Lakes
GREE-REDBY	Green Lake - Redby	Primary Lakes
GREE-REDLAKE	Green Lake - Red Lake	Primary Lakes
GROU	Grouse Lake	Shallow Lakes
GWIN	Gwin Lake	Secondary Lakes
HEAR	Heart Lake	Primary Lakes
HERI	Heritage Lake	Shallow Lakes
ISLA	Island Lake	Primary Lakes
JOHN	Johnson Lake	Primary Lakes
JOUR	Jourdain lake	Secondary Lakes
KESA	Kesagiagan Lake	Secondary Lakes
KINN	Kinney Lake	Primary Lakes
LAXO	Laxon Lake	Secondary Lakes
LESL	Leslin Lake	Secondary Lakes
LITT	Little Thunder Lake	Primary Lakes
LONG	Long Lake (Burt)	Primary Lakes
LUSS	Lussier Lake	Secondary Lakes
MASQ	Masquot Lake	Shallow Lakes
MCCA	McCall Lake	Secondary Lakes
METH	Methane Lake	Shallow Lakes
MISK	Miskogineau Lake	Shallow Lakes
MIST	Mistic Lake	Shallow Lakes
MORR	Morrison Lake	Primary Lakes
MUER	Muerlin Lake	Secondary Lakes
NONA	No-Name Lake	Primary Lakes
REDH	Redhead Lake	Shallow Lakes
RICH	Richards Lake	Shallow Lakes
ROOS	Roosevelt Lake	Shallow Lakes
ROUN	Round Lake	Primary Lakes
RUSH	Rush Lake	Secondary Lakes
SAND	Sandy Lake	Primary Lakes
SHAC	Shackle Lake	Secondary Lakes
SHEL	Shell Lake	Primary Lakes

Lake Site ID	Lake Name	Monitoring Category
SHEM	Shemahgun Lake	Primary Lakes
SQUA	Squaw Smith Lake	Primary Lakes
STON	Stone Lake	Secondary Lakes
TEAL	Teal Lake	Shallow Lakes
TOWN	Townline Lake	Secondary Lakes
TUCK	Tuck Lake	Shallow Lakes
WEND	Wending Lake	Shallow Lakes
WILL	Williams Lake	Secondary Lakes
LRW	Lower Red West	Red Lakes
LRW-C	Lower Red West-Central	Red Lakes
LRC	Lower Red Central	Red Lakes
LRE-C	Lower Red East-Central	Red Lakes
LRE	Lower Red East	Red Lakes
URW	Upper Red West	Red Lakes
URW-C	Upper Red West-Central	Red Lakes
URC	Upper Red Central	Red Lakes
URE-C	Upper Red East-Central	Red Lakes
URE	Upper Red East	Red Lakes

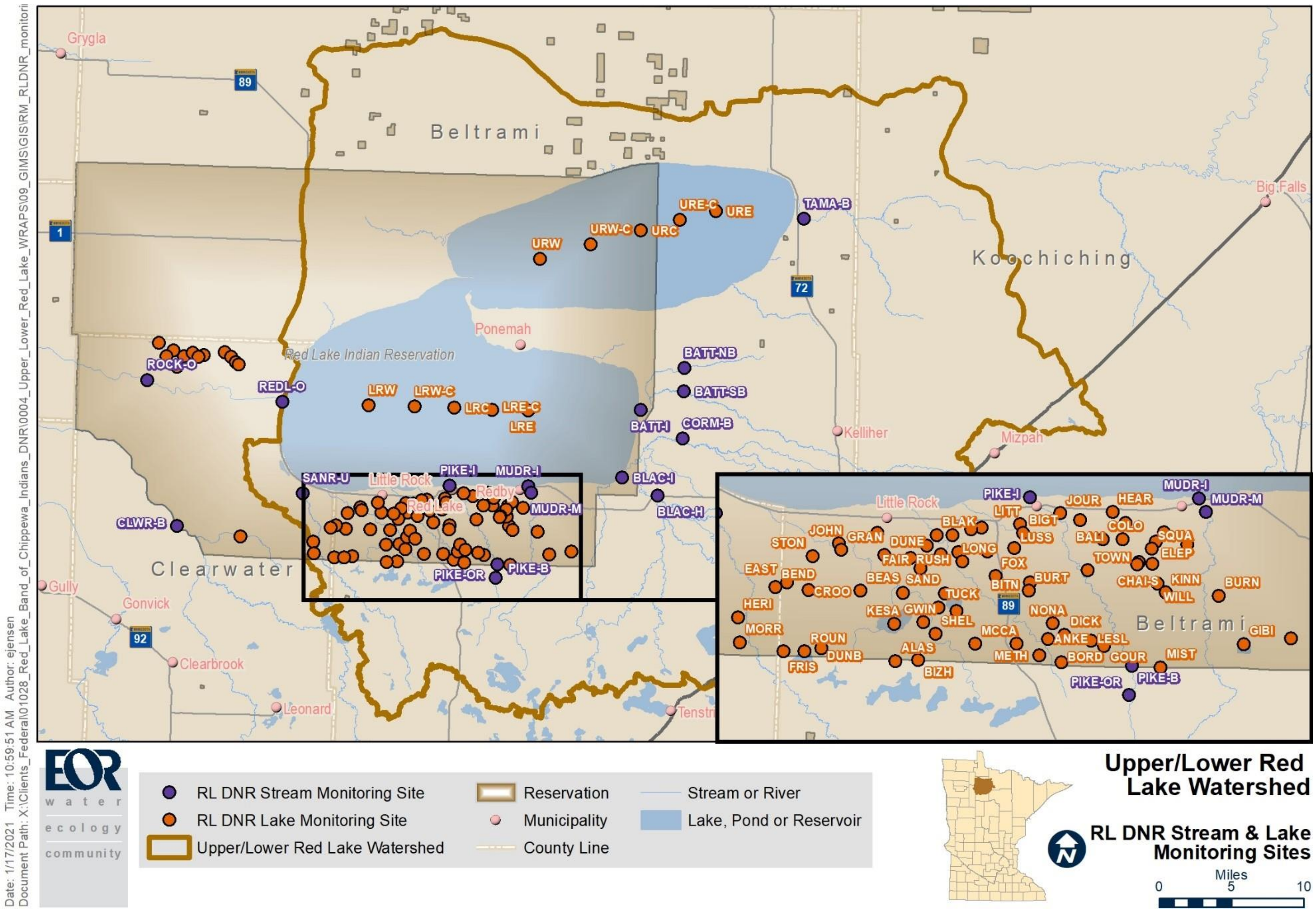


Figure 7-1. RL DNR Stream and Lake Monitoring Sites

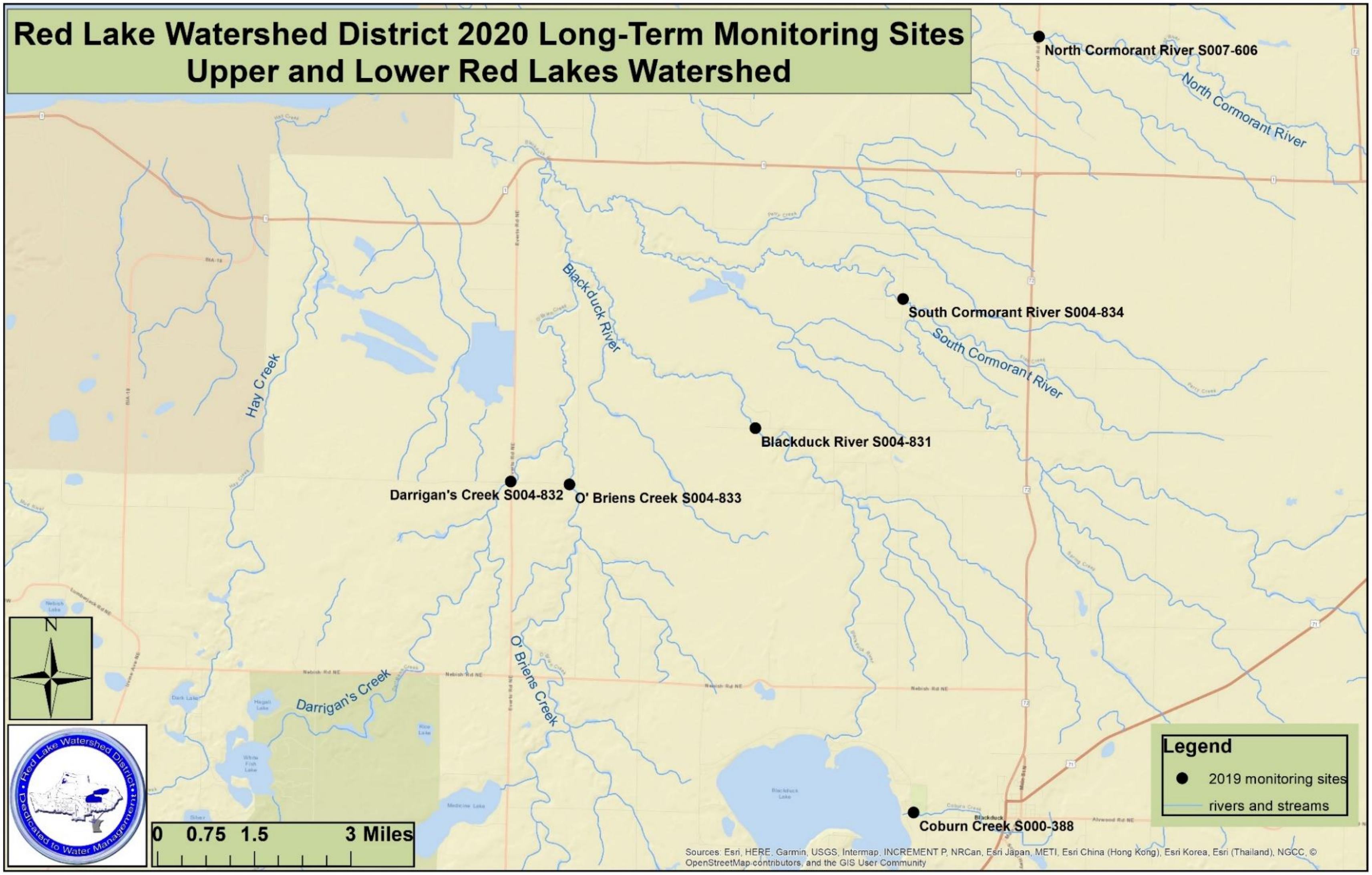


Figure 7-2. RLWD Long-Term Monitoring Stream Sites

7.2 BMP Monitoring

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

8 Implementation Strategy Summary

The TMDL study's results aided in the selection of implementation strategies during the ULRL WRAPS process. The purpose of the WRAPS process is to support local working groups in developing scientifically-supported restoration and protection strategies for subsequent implementation planning. Following completion of the WRAPS process, the Upper/Lower Red Lake WRAPS Report will be publically available on the MPCA ULRLW website: https://www.pca.state.mn.us/water/watersheds/upperlower-red-lake

8.1 Permitted Sources

Pollutant reductions needed in the watershed are primarily from nonpoint sources. Permitted sources of pollutants will be addressed through the State's NPDES/SDS programs (see Section 6.1.2).

8.2 NonPermitted Sources

8.2.1 Pollutant Sources

A variety of BMPs to restore and protect the lakes and streams within the ULRLW are outlined and prioritized in the WRAPS report. Listed below are specific strategies aimed at reducing TP, TSS, and *E. coli* sources identified in Section 3.6.2 of this report. Detailed information on each strategy is provided in Section 3.3 of the ULRL WRAPS Report and is not replicated in this report. Specific strategies and actions proposed for the impairments addressed by this TMDL are included in Table 8-1 below.

Table 8-1. Strategies and actions to reduce pollutant loads to impaired lakes and stressed addressed by this TMDL (from Section 3.3 of the ULRL WRAPS)

Impaired lake or stream	Pollutant	Strategy Category	Strategy Description
Battle River, North Branch (-503)	*E. coli*	Livestock/Pasture Management	Cattle exclusion and prescribed grazing BMPs.
		Wildlife Management	Education and outreach about natural background sources of bacteria from wildlife.
North Cormorant River (-506)	TSS, *E. coli*	Shoreland Protection	Opportunities for enhanced field buffers in North Cormorant drainage.
		Livestock/Pasture Management	Cattle exclusion and prescribed grazing BMPs.
		Rice Paddy Discharge Management	Installation of main line tile drainage in rice paddies.
		Forest Protection Programs	Target private lands for forest protection programs.
South Cormorant River (-507)	*E. coli*	Wildlife Management	Education and outreach about natural background sources of bacteria from wildlife.
		Livestock/Pasture Management	Cattle exclusion and prescribed grazing BMPs.
Darrigans Creek (-508)	*E. coli*	Livestock/Pasture Management	Cattle exclusion and prescribed grazing BMPs.
Blackduck River (-510)	*E. coli*	Livestock/Pasture Management	Cattle exclusion and prescribed grazing BMPs.
Sandy River (-522)	*E. coli*	Livestock/Pasture Management	Cattle exclusion and prescribed grazing BMPs.
Mud River (-541)	TSS, *E. coli*	In-stream Management	Replace undersized road culverts.
		Livestock/Pasture Management	Cattle exclusion, prescribed grazing, and manure management BMPs.
		Forest Protection Programs	Target private lands for forest protection programs.
O'Brien Creek (-544)	*E. coli*	Livestock/Pasture Management	Cattle exclusion and prescribed grazing BMPs.
Unnamed Creek (-600)	*E. coli*	Livestock/Pasture Management	Cattle exclusion and prescribed grazing BMPs.
Blackduck Lake (04-0069-00)	TP	Monitoring	Continue lake monitoring to assess effectiveness of alum treatment.
		Stormwater Management	Continue nutrient load monitoring on Coburn Creek – RLWD and RL DNR has some data as part of a SWAG.

Impaired lake or stream	Pollutant	Strategy Category	Strategy Description
			Implement buffers on City-owned golf course. Use the golf course to demonstrate desirable examples of what golf courses can look like. Explore partnership and education opportunities with the City.
			Stormwater retrofit assessment for City and golf course to identify phosphorus reduction practices.
		Forest Protection Programs	Target private lands for forest protection programs.
Crane Lake (04-0165-00)	TP	In-Lake Management	Complete aquatic plant and fish community surveys. Collect bottom water phosphorus concentrations over 1-2 seasons. Complete in-lake management plan. Potential future alum treatment.
Strand Lake (04-0178-00)	TP	In-Lake Management	Complete aquatic plant and fish community surveys. Collect bottom water phosphorus concentrations over 1-2 seasons. Complete in-lake management plan. Potential future alum treatment.
Whitefish Lake (04-0309-00)	TP	In-Lake Management	Review historic aerials to identify potential livestock legacy loads near lake. Alum treatment.
Bartlett Lake (36-0018-00)	TP	In-lake Management	Lake Management Plan in development by RLWD and the City of Northome.

8.2.2 Nonpollutant Stressors

The following implementation activities were identified during the SID study to address nonpollutant based stressors that are impairing aquatic life:

- Prevent or mitigate activities that will further alter the hydrology of the watershed.
- Consider opportunities and options to reduce peak flows and increase base flows throughout the watershed.
- Incorporate the principles of natural channel design into stream restoration and ditch maintenance activities.
- Increase the quantity and quality of instream habitat throughout the watershed.
- Establish and/or protect riparian corridors along all waterways, including ditches, using native vegetation whenever possible.
- Remove or retrofit physical connectivity barriers to enable fish passage at a greater range of flow conditions.
- Conduct an inventory of culverts in the watershed that are limiting fish passage.

8.3 Strategies from Local Water Management Plans

Local water management plans include objectives, goals, and strategies for addressing water quality issues in the ULRLW. Existing local plans include the following:

1. RLWD 10-Year Plan
2. Red Lake Band NPS Assessment Report, Management Plan
3. Beltrami County Local Water Management Plan
4. Koochiching County Local Water Management Plan
5. Itasca County Water Plan

8.4 Public Information and Outreach

A crucial part in the success of the TMDL pollutant reductions and the WRAPS designed to clean up the impaired streams and protect the nonimpaired water bodies will be participation from local citizens. In order to gain support from these citizens, public participation opportunities will be necessary. A variety of communication avenues can and will be used throughout the ULRLW. These include (but are not limited to):

- Events, meetings, workshops, focus groups, trainings
    - Northwest Minnesota Water Festivals (Warren, Minnesota; Fertile, Minnesota)
    - Monthly watershed district meetings
    - Public meetings for TMDL, WRAPS, and 1W1P or County Water Plan Reports

- Publications
  - Monthly water quality reports
  - Annual reports
  - County newsletters
- Websites
  - RL DNR website: https://www.redlakednr.org/
  - RLWD website: www.redlakewatershed.org
  - RLWD Subwatersheds website (includes a webpage on the ULRLW): www.rlwdwatersheds.org
  - RLWD Facebook page: https://www.facebook.com/Red-Lake-Watershed-District-266521753412008/
  - Red Lake DNR Facebook page: https://www.facebook.com/Red-Lake-DNR-207861292563239
  - Beltrami SWCD website: https://www.co.beltrami.mn.us/Departments/SWCD/SWCD%20home.html
  - Koochiching SWCD website: https://koochichingswcd.org/

Local staff (conservation district, watershed, county, etc.) and board members work to educate the residents of the watersheds about ways to clean up their streams on a regular basis. Public information and participation will continue throughout the ULRLW.

8.5 Technical Assistance

The RL DNR, SWCDs, RLWD, NRCS, and county staff within the watershed provide assistance to landowners for a variety of projects that benefit water quality. Assistance provided to landowners includes agricultural and rural BMPs. This technical assistance includes education and one-on-one training. Many opportunities for technical assistance are as a result of workshops or trainings. It is important that these outreach opportunities for watershed residents continue.

8.6 Partnerships

This TMDL was completed through a partnership between MPCA and the RL DNR. While the MPCA does not have jurisdiction on the Red Lake Nation lands, the Red Lake Nation and the MPCA cooperated on this watershed-wide project due to the benefits that would be realized by both the tribe and the State of Minnesota as a result of this project. The RL DNR accompanied the MPCA staff during biological sampling in tribal waters, assisted with water quality sampling, participated in assessment activities, conducted public participation events within the Reservation and in other areas of the watershed outside their jurisdiction, provided a wealth of local knowledge of the watershed, and wrote significant sections of this TMDL report.

Partnerships with counties, cities, townships, citizens, businesses, and watersheds, are one mechanism through which the RLWD, RL DNR, and local SWCDs will protect and improve water quality. Strong partnerships with state and local government and the RL DNR to protect and improve water resources, and to bring waters within the ULRLW into compliance with state and tribal standards, will continue. A partnership with local government units (LGUs) and regulatory agencies such as cities, townships and counties may be formed to develop and update ordinances to protect the watershed's water resources. It is understood that oversight of implementation efforts for restoration and protection for the bacteria and TSS TMDLs will be by the MPCA for portions of the subwatersheds within the State of Minnesota only. The boundary condition LAs within the boundary of the Red Lake Nation are for RL DNR water quality management only. No reductions are required on tribal lands.

8.7 Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation of the cost to implement a TMDL [Minn. Stat. 2007, §114D.25].

8.7.1 Impaired (Excess Phosphorus) Lakes

Table 8-2. Impaired (Excess Phosphorus) Lake TMDL Implementation Costs

Lake Name	Activity	Cost	Assumptions/ Notes
Blackduck Lake (-04-0069-00)	**Septic System Upgrades**	1) $6,500/system upgraded 2) 21 systems upgraded 3) Total Cost = $136,500	Cost-share dollars through county programs may provide financial assistance for septic system upgrades
	Aquatic Plant Survey	1) $4,500 / Lake wide point-intercept survey. 2) $2,500 for focused meander survey	2011 plant survey conducted by Minnesota Biological Survey found no invasive plant species. Focused-meander surveys are used to delineate treatment polygons if invasive species (e.g., Starry stonewort, Eurasian watermilfoil, Curly-leaf Pondweed) are identified and treatment is deemed necessary.
	Bi-Annual Walleye Stocking (Based on results of fish survey)	Cost per pound for 5-6" Walleye $2.35 Cost per pound for 6-9" Walleye $2.85	Walleye fry have been stocked in Blackduck Lake by DNR in 70% of years from 2009-2018. Gamefish populations have historically provided top-down control over rough fish populations (freshwater drum, brown bullhead) in Blackduck Lake.
	Alum Dosing & Treatment	1) $1,500 ($1,200-1,800) per acre treated 2) 50% of surface area is > 15 feet deep = 1342.5 acres 3) 1,342 x $1,500 = $2,013,750	Alum treatment costs are subject to change based on the fluctuating cost of alum, mobilization costs, and the portion of the lake targeted for treatment. Alum treatments should target the portions of the lake that contain sediment with high releasable phosphorus content.
	Land Acquisition/ Conservation Easements	1) $615/lb of TP removed via conversion of row crops to perennial vegetation. 2) TP load reduction required – 33 kg (73 lbs) 3) 73 x $615 = $44,900	Land acquisition costs are highly dependent on the capacity of the land to produce crops. According to Acrevalue.com, average farmland cost in Beltrami County is $3,593/acre. The average Crop Productivity Index (CPI) for Beltrami County is 38. This indicates most areas in Beltrami County are not well suited for agriculture and that securing conservation easements with landowners to set aside marginal farmland represents a feasible financial option.
Crane Lake (04-0165-00)	**Septic System Upgrades**	1) $6,500/system upgraded 2) 1 system upgraded 3) Total Cost - $6,500	Cost-share dollars through county programs may provide financial assistance for septic system upgrades
	Aquatic Plant Survey	1) $2,500 / Lake wide point-intercept survey. 2) $1,500 for focused meander survey	No prior plant survey conducted, extent of invasive species presence/absence is unknown. Focused-meander surveys are used to delineate treatment polygons if invasive species (e.g., Starry stonewort, Eurasian watermilfoil, Curly-leaf

Lake Name	Activity	Cost	Assumptions/ Notes
			Pondweed) are identified and treatment is deemed necessary.
	Fishery Survey	$3,000-$4,000/ Survey	No prior fishery survey conducted. The health of the gamefish community and need for supplemental stocking is unknown.
	Alum Dosing & Treatment	1) $1,500 ($1,200-1,800) per acre treated 2) 24% of surface area is > 15 feet deep = 26 acres 3) 26 x $1,500 = $39,000	Alum treatment costs are subject to change based on the fluctuating cost of alum, mobilization costs, and the portion of the lake targeted for treatment. Alum treatments should target the portions of the lake that contain sediment with high releasable phosphorus content.
	Land Acquisition/ Conservation Easements	1) $615/lb of TP removed via conversion of row crops to perennial vegetation. 2) TP load reduction required – 3 kg (7 lbs) 3) 7 x $615 = $4,300	Land acquisition costs are highly dependent on the capacity of the land to produce crops. According to Acrevalue.com, average farmland cost in Beltrami County is $3,593/acre. The average Crop Productivity Index (CPI) for Beltrami County is 38. This indicates most areas in Beltrami County are not well suited for agriculture and that securing conservation easements with landowners to set aside marginal farmland represents a feasible financial option.
Strand Lake (04-0178-00)	**Septic System Upgrades**	1) $6,500/system upgraded 2) 1 system upgraded 3) Total Cost = $6,500	Cost-share dollars through county programs may provide financial assistance for septic system upgrades
	Aquatic Plant Survey	1) $2,500 / Lake wide point-intercept survey. 2) $1,500 for focused meander survey	No prior plant survey conducted, extent of invasive species presence/absence is unknown. Focused-meander surveys are used to delineate treatment polygons if invasive species (e.g., Starry stonewort, Eurasian watermilfoil, Curly-leaf Pondweed) are identified and treatment is deemed necessary.
	Fishery Survey	$3,000-$4,000/ Survey	No prior fishery survey conducted. The health of the gamefish community and need for supplemental stocking is unknown.
	Land Acquisition/ Conservation Easements	1) $615/lb of TP removed via conversion of row crops to perennial vegetation. 2) TP load reduction required – 3 kg (7 lbs) 3) 7 x $615 = $4,300	Land acquisition costs are highly dependent on the capacity of the land to produce crops. According to Acrevalue.com, average farmland cost in Beltrami County is $3,593/acre. The average Crop Productivity Index (CPI) for Beltrami County is 38. This indicates most areas in Beltrami County are not well suited for agriculture and that securing conservation easements with landowners to set aside marginal farmland represents a feasible financial option.
Whitefish Lake (04-0309-00)	**Septic System Upgrades**	1) $6,500/system upgraded 2) 1 system upgraded 3) Total Cost = $6,500	Cost-share dollars through county programs may provide financial assistance for septic system upgrades
	Aquatic Plant Survey	1) $2,500 / Lake wide point-intercept survey. 2) $1,500 for focused meander survey	No prior plant survey conducted, extent of invasive species presence/absence is unknown. Focused-meander surveys are used to delineate treatment polygons if invasive species (e.g., Starry stonewort, Eurasian watermilfoil, Curly-leaf Pondweed) are identified and treatment is deemed necessary.
	Fishery Survey	$3,000-$4,000/ Survey	No prior fishery survey conducted. The health of the gamefish community and need for supplemental stocking is unknown.

Lake Name	Activity	Cost	Assumptions/ Notes
	Land Acquisition/ Conservation Easements	1) $615/lb of TP removed via conversion of row crops to perennial vegetation. 2) TP load reduction required – 58 kg (128 lbs) 3) 128 x $615 = $78,720	Land acquisition costs are highly dependent on the capacity of the land to produce crops. According to Acrevalue.com, average farmland prices in Beltrami County are $3,593/acre. The average Crop Productivity Index (CPI) for Beltrami County is 38. This indicates most areas in Beltrami County are not well suited for agriculture and that securing conservation easements with landowners to set aside marginal farmland represents a feasible financial option.
Bartlett Lake (36-0018-00)	**In-lake Management**	See Bartlett Lake In-Lake Management Strategies (Appendix D)	See Bartlett Lake In-Lake Management Strategies (Appendix D)
	Land Acquisition/ Conservation Easements	1) $615/lb of TP removed via conversion of row crops to perennial vegetation. 2) TP load reduction required – 6 kg (14lbs) 3) 14 x $615 = $8,600	Land acquisition costs are highly dependent on the capacity of the land to produce crops. According to Acrevalue.com, average farmland prices in Beltrami County are $3,593/acre. The average Crop Productivity Index (CPI) for Beltrami County is 38. This indicates most areas in Beltrami County are not well suited for agriculture and that securing conservation easements with landowners to set aside marginal farmland represents a feasible financial option.

8.7.2 *Impaired Streams: E. coli*

Table 8-3. Impaired (*E. coli*) Stream TMDL Implementation Costs

Stream Name	Activity	Cost	Assumptions/ Notes
Battle River, North Branch (-503)	**Septic System Upgrades**	1) $6,500/system upgraded 2) 14 systems upgraded Total Cost - $91,000	Cost-share dollars through county programs may provide financial assistance for septic system upgrades
Battle River, North Branch (-503) **North Cormorant River (-506)**	**Limit livestock from accessing streams/waterbodies by fencing or providing alternative water source**	$0.70-1.50/ linear feet of fencing 3) $3-6/ cu yard to construct a pond as an alternative water source	Total length of fencing required is not currently known. Roughly 400 cattle throughout drainage area.
	Septic System Upgrades	1) $6,500/system upgraded 2) 2 systems upgraded Total Cost - $13,000	Cost-share dollars through county programs may provide financial assistance for septic system upgrades
North Cormorant River (-506) **South Cormorant River (-507)**	**Limit livestock from accessing streams/waterbodies by fencing or providing alternative water source**	$0.70-1.50/ linear feet of fencing 3) $3-6/ cu yard to construct a pond as an alternative water source	Total length of fencing required is not currently known. n. Roughly 700 cattle throughout drainage area.
	Septic System Upgrades	1) $6,500/system upgraded 2) 1 system upgraded Total Cost - $6,500	Cost-share dollars through county programs may provide financial assistance for septic system upgrades
South Cormorant River (-507) **Darrigans Creek (-508)**	**Limit livestock from accessing streams/waterbodies by fencing or providing alternative water source**	$0.70-1.50/ linear feet of fencing 3) $3-6/ cu yard to construct a pond as an alternative water source	Total length of fencing required is not currently known. Roughly 1,150 cattle in headwaters area, 55 cattle near S004-834.
	Septic System Upgrades	1) $6,500/system upgraded 2) 1 system upgraded Total Cost - $6,500	Cost-share dollars through county programs may provide financial assistance for septic system upgrades MST biomarker indicated human waste.
Darrigans Creek (-508)	**Limit livestock from accessing streams/waterbodies by fencing or providing alternative water source**	$0.70-1.50/ linear feet of fencing 3) $3-6/ cu yard to construct a pond as an alternative water source	Total length of fencing required is not currently known. 300 cattle near S004-832, roughly 500 cattle elsewhere in drainage area.

Stream Name	Activity	Cost	Assumptions/ Notes
Blackduck River (-510)	**Limit livestock from accessing streams/waterbodies by fencing or providing alternative water source**	$0.70-1.50/ linear feet of fencing $3-6/ cu yard to construct a pond as an alternative water source	Total length of fencing required is not currently known. Roughly 400 cattle throughout drainage area.
Sandy River (-522)	**Septic System Upgrades**	1) $6,500/system upgraded 2) 2 system upgraded Total Cost - $13,000	Cost-share dollars through county programs may provide financial assistance for septic system upgrades MST biomarker indicated human waste.
Sandy River (-522) **Mud River (-541)**	**Limit livestock from accessing streams/waterbodies by fencing or providing alternative water source**	$0.70-1.50/ linear feet of fencing $3-6/ cu yard to construct a pond as an alternative water source	Total length of fencing is not currently known. Roughly 160 cattle throughout drainage area.
Sandy River (-522)	**Install filter strips/buffers near waterbodies to deter waterfowl from congregating and conduct public outreach on wildlife feeding**	$600- $1,000/acre of buffer	MST biomarker identified birds and beavers as a source of bacteria.
Sandy River (-522) **Mud River (-541)** **Mud River (-541)** **O'Brien Creek (-544)**	**Install filter strips/buffers near waterbodies to deter waterfowl from congregating and conduct public outreach on wildlife feeding**	3) $600- $1,000/acre of buffer	MST biomarker identified birds and beavers as a source of bacteria.
	Limit livestock from accessing streams/waterbodies by fencing or providing alternative water source	$0.70-1.50/ linear feet of fencing $3-6/ cu yard to construct a pond as an alternative water source	Total length of fencing required is not currently known. Roughly 225 cattle throughout drainage area.
	Install filter strips/buffers near waterbodies to deter waterfowl from congregating and conduct public outreach on wildlife feeding	$600- $1,000/acre of buffer	MST biomarker identified birds and beavers as a source of bacteria.
O'Brien Creek (-544) **Unnamed Creek (-600)**	**Limit livestock from accessing streams/waterbodies by fencing or providing alternative water source**	$0.70-1.50/ linear feet of fencing $3-6/ cu yard to construct a pond as an alternative water source	Total length of fencing required is not currently known. 90 cattle pastured by Medicine Lake
	Install filter strips/buffers near waterbodies to deter waterfowl from congregating and conduct public outreach on wildlife feeding	$600- $1,000/acre of buffer	MST biomarker identified birds and beavers as a source of bacteria.

8.7.3 *Impaired Streams: Total Suspended Solids (TSS)*

Table 8-4. Impaired (TSS) Stream TMDL Implementation Costs

Stream Name	Activity	Cost	Assumptions/ Notes
1) North Cormorant River (-506) **2) Mud River (-541)**	**Paired water quality and flow data for the impaired TSS streams were limited to samples collected during 2014**	1) $5,000/stream/year 2) 3 TSS Stream Impairments 3) Total Cost = $15,000/year	Additional monitoring is recommended to more accurately estimate existing TSS Load and to identify TSS reduction strategies.

8.8 Adaptive Management

This list of implementation elements and the more detailed WRAPS report that was prepared in conjunction with this TMDL assessment focus on adaptive management (Figure 8-1). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water bodies.

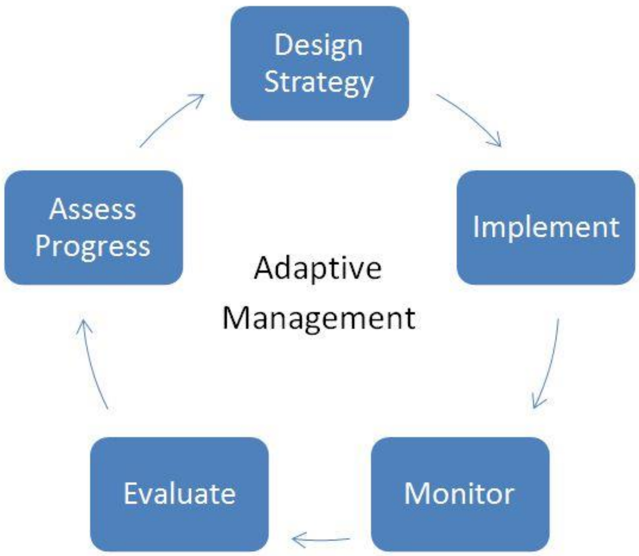


Figure 8-1. Adaptive Management

9 Public Participation

9.1 Technical Committee Meetings

The ULRLW Technical Advisory Committee (TAC) is comprised of numerous local partners who have been involved at various levels throughout the project. The TAC is comprised of members representing the RLWD, RL DNR Water Resources Program, MPCA, DNR, BWSR, Counties, NRCS, and SWCDs within the watershed. The TMDL report was completed with input from the TAC through remote correspondence and communication, with one in-person workshop held on September 30, 2019 to prioritize subwatersheds and develop restoration and protection strategies.

9.2 Public Involvement

The MPCA along with the local partners and agencies in the ULRLW recognize the importance of public involvement in the watershed process. Table 9-1 outlines the opportunities used to engage the public and targeted stakeholders in the watershed.

Table 9-1. ULRLW TMDL Civic Engagement Meetings

ULRLW TMDL Civic Engagement Meetings		
Date	**Location**	**Meeting Focus**
October 11, 2016	Kelliher, MN	Public meeting with Landowners
October 12, 2016	Ponemah, MN	Public meeting with Landowners
October 13, 2016	Red Lake, MN	Public meeting with Landowners
April 24, 2018	Kelliher, MN	Public meeting with Landowners
September 30, 2019	Bemidji, MN	1) Overview of WRAPS, watershed, and completed work 2) Prioritizing resources and subwatersheds. 3) Brainstorming key implementation strategies
December 12, 2019	Kelliher, MN	1) Lake Impairments, TMDL, and Implementation Strategies. 2) WRAPS 3) Stream TSS Impairments

Many LGUs also provide opportunities for participation as well as resources for implementing BMPs. Additional information for these LGUs can be found on their websites:

- RL DNR: http://www.redlakednr.org
- RLWD: http://www.redlakewatershed.org/
- Beltrami County SWCD and ESD: http://www.co.beltrami.mn.us/Departments/ESD/Environmental%20Services.html
- Koochiching County SWCD: https://koochichingswcd.org/
- Koochiching County Environmental Services: https://www.co.koochiching.mn.us/168/Environmental-Services
- Itasca County SWCD: https://www.itascaswcd.org/
- Itasca County Environmental Services: https://www.co.itasca.mn.us/558/Environmental-Services

The Upper/Lower Red Lake WRAPS Report will be publicly available on the MPCA ULRLW website: https://www.pca.state.mn.us/water/watersheds/upperlower-red-lake.

9.3 Public Notice

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from March 22, 2021 through April 21, 2021. There was one comment letter received and responded to as a result of the public comment period.

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Canfield, D. and R. Bachmann, 1981. Prediction of Total Phosphorus Concentrations, Chlorophyll- *a*, and Secchi Depths in Natural and Artificial Lakes. *Canadian Journal of Fisheries and Aquatic Science* 38:414-423.

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Appendix A. LAKE SUMMARIES

A.1 Blackduck Lake

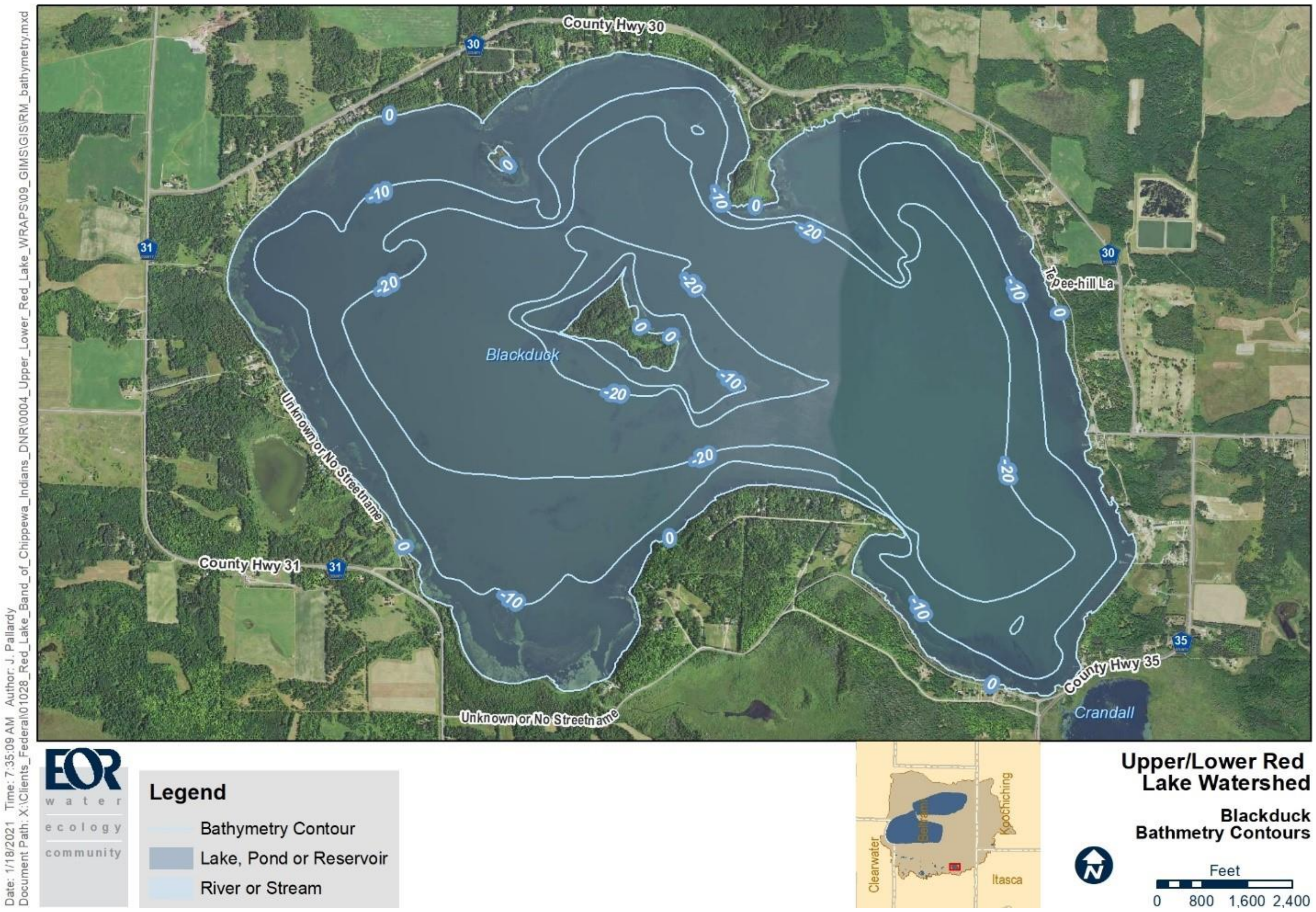

Figure 10-1. Blackduck Lake Bathymetric Map (DNR 1991)

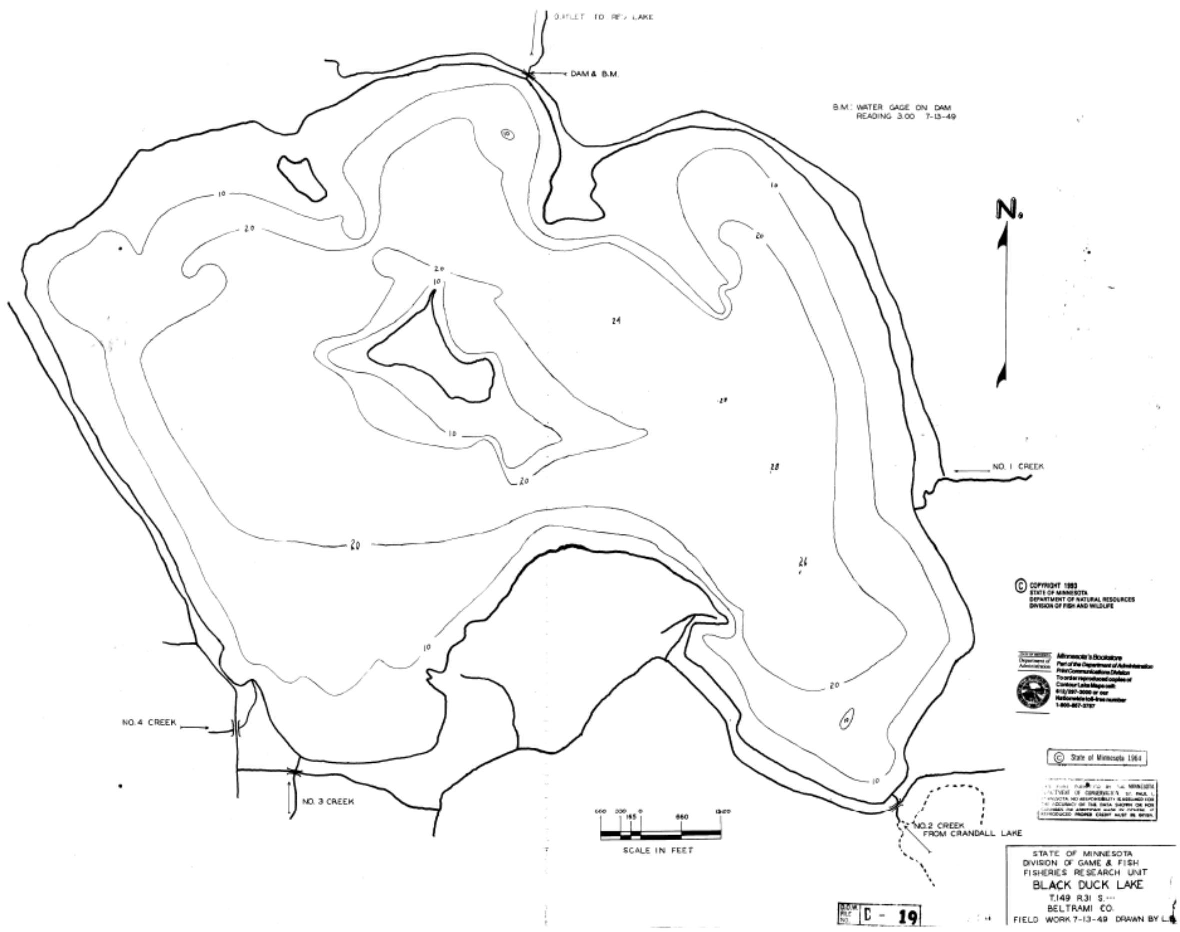

Figure 10-2. Blackduck Lake Historic Bathymetric Map (DNR, July 1949)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of the east shore of Blackduck Lake on August 10, 2011. At the time of the survey, the aquatic plant community was comprised of submersed, floating, emergent and shoreline species. No invasive species were observed.

The most recent DNR fish survey was completed on July 10, 2012. This survey noted:

- Blackduck Lake is a 2,596-acre lake with a maximum depth of 28 feet.
- The lake is located one mile west of the city of Blackduck in Beltrami County.
- There is a DNR public water access located on the eastern shore of the lake off of County Road 30.
- Several resorts and a modest number of lake homes dot the shoreline.
- A special regulation consisting of a five-fish bag limit for sunfish was implemented in 2006. Statewide regulations apply to all other species.
- The walleye population of Blackduck Lake is maintained by fry stocking, which has been a successful management tool in producing consistent walleye fishing.

- Blackduck Lake also provides good fishing opportunities for sunfish (bluegill and pumpkinseed), northern pike, and yellow perch. However, in the 2012 assessment, bluegill were captured in very low numbers, there was a decline in both perch numbers and size since the 2006 assessment, and black crappie abundance was relatively low.

Recorded Water Levels

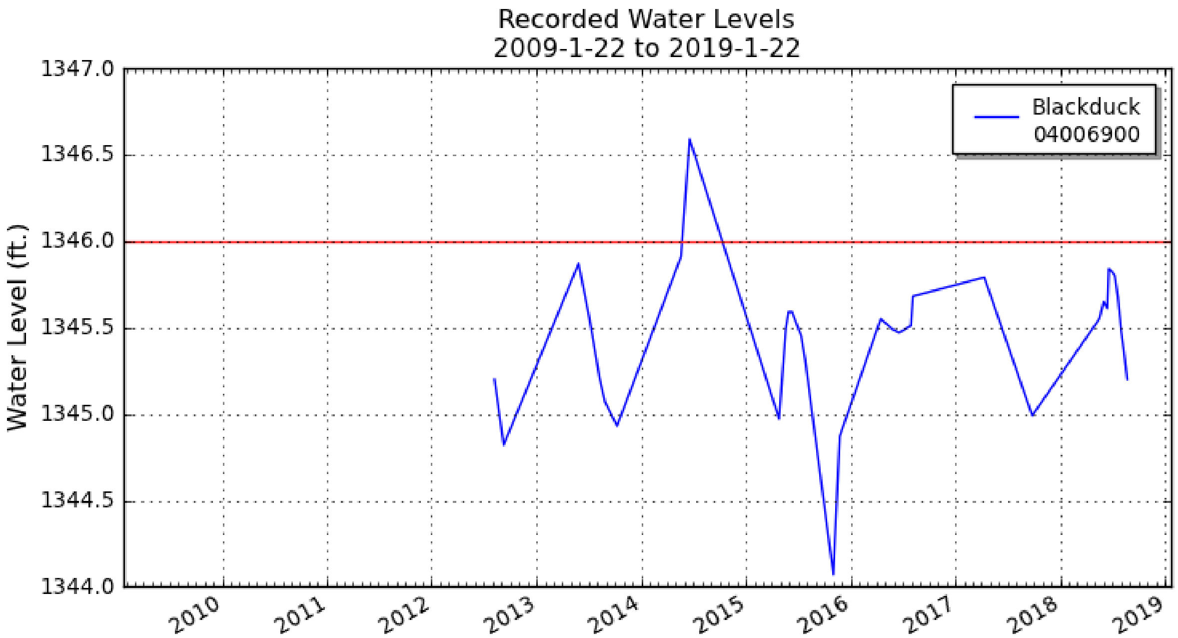

Figure 10-3. Blackduck Lake DNR Recorded Water Levels (2009-1-22 to 2019-1-22)

Growing Season Annual Average Water Quality Figures

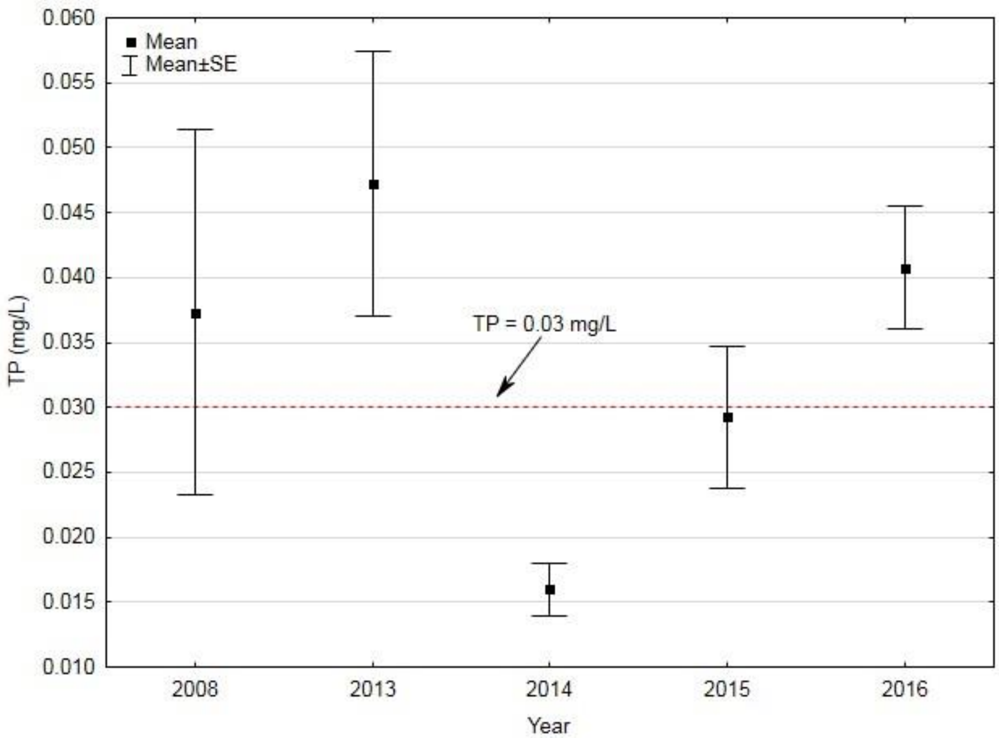

Figure 10-4. Growing Season Means ± SE of Total Phosphorus for Blackduck Lake by Year

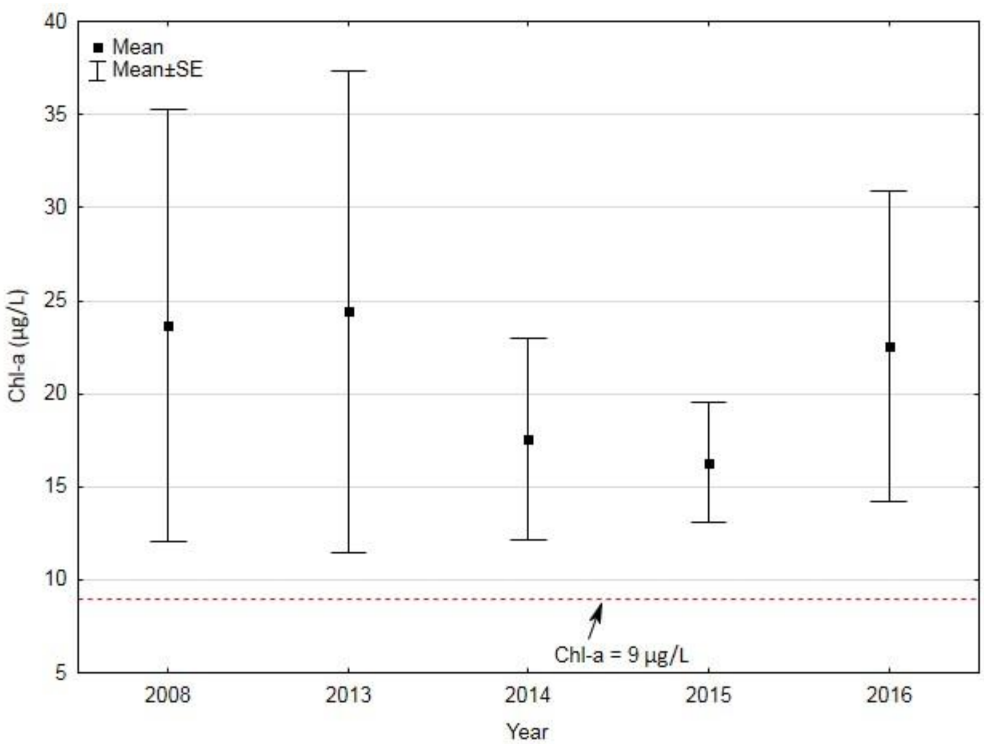

Figure 10-5. Growing Season Means ± SE of Chlorophyll-*a* for Blackduck Lake by Year

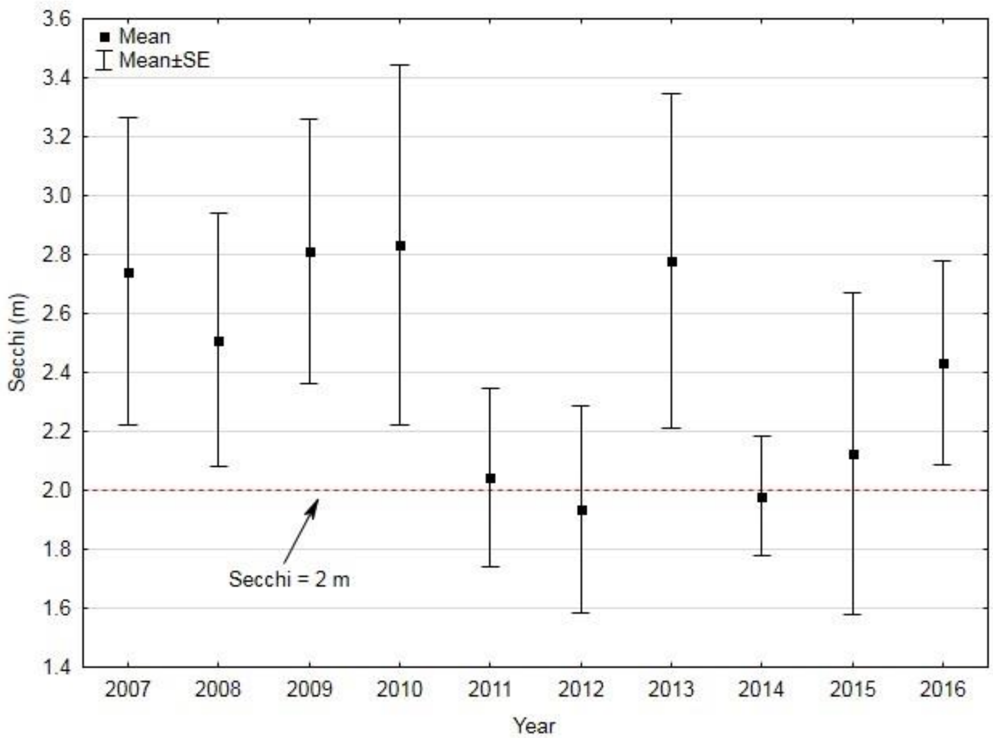

Figure 10-6. Growing Season Means ± SE of Secchi transparency for Blackduck Lake by Year

A.2 Crane Lake

Figure 10-7. Crane Lake Bathymetric Map (EOR, December 2018)

Aquatic Plant and Fish Community

No DNR aquatic plant nor fish community surveys have been completed on Crane Lake.

Recorded Water Levels

Water levels are not being recorded on Crane Lake.

Growing Season Annual Average Water Quality Figures

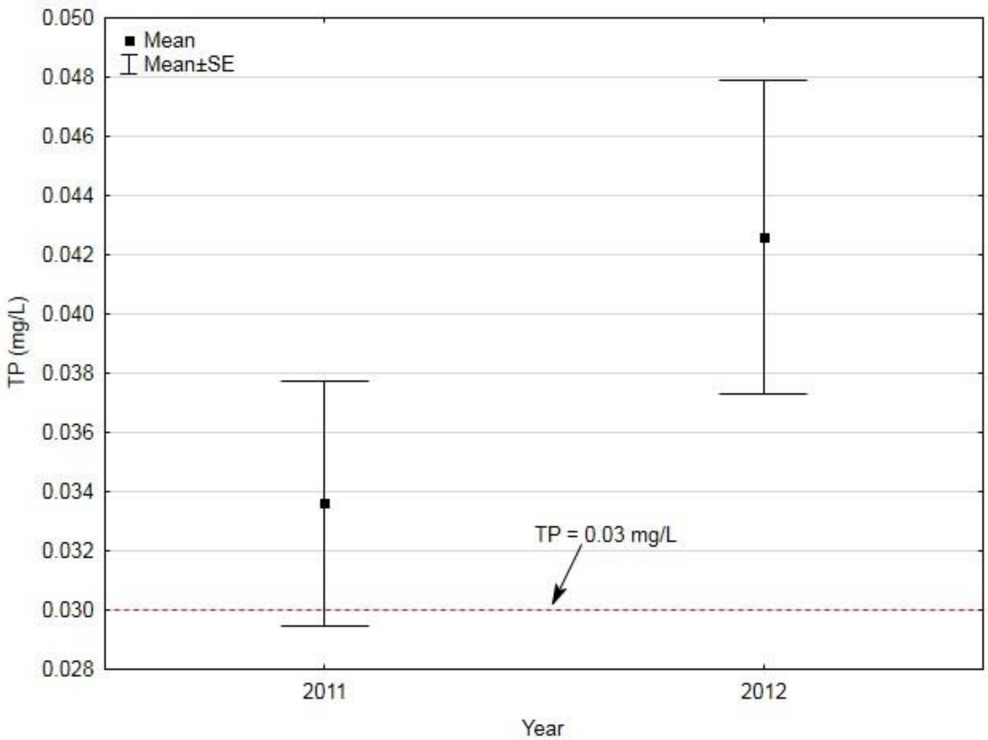

Figure 10-8. Growing Season Means ± SE of Total Phosphorus for Crane Lake by Year

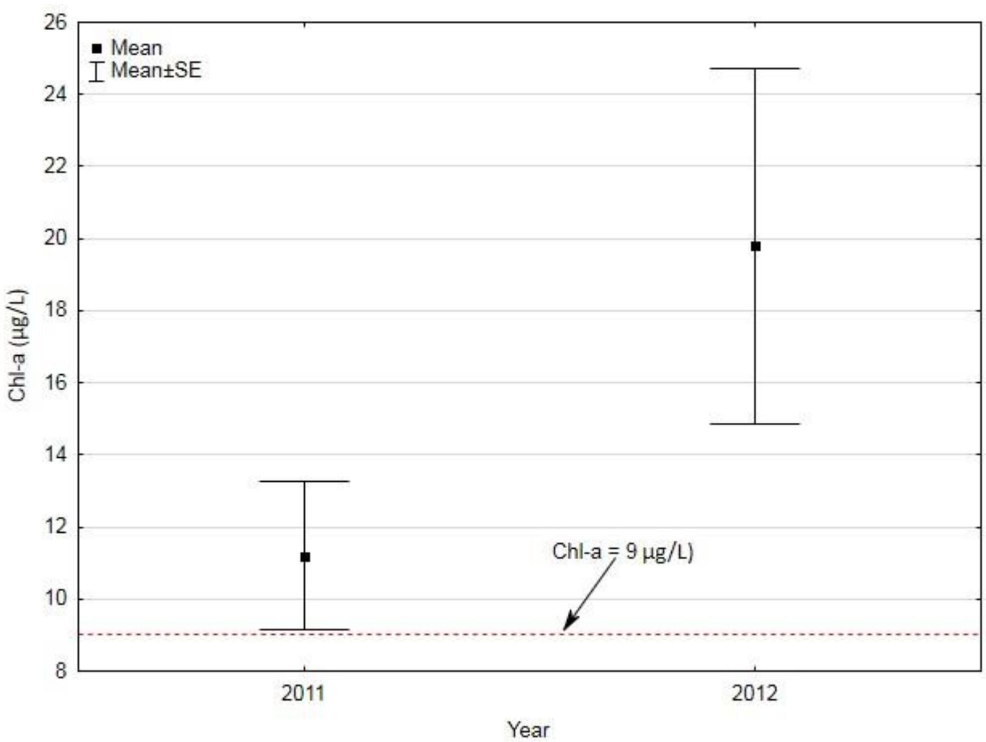

Figure 10-9. Growing Season Means ± SE of Chlorophyll-*a* for Crane Lake by Year

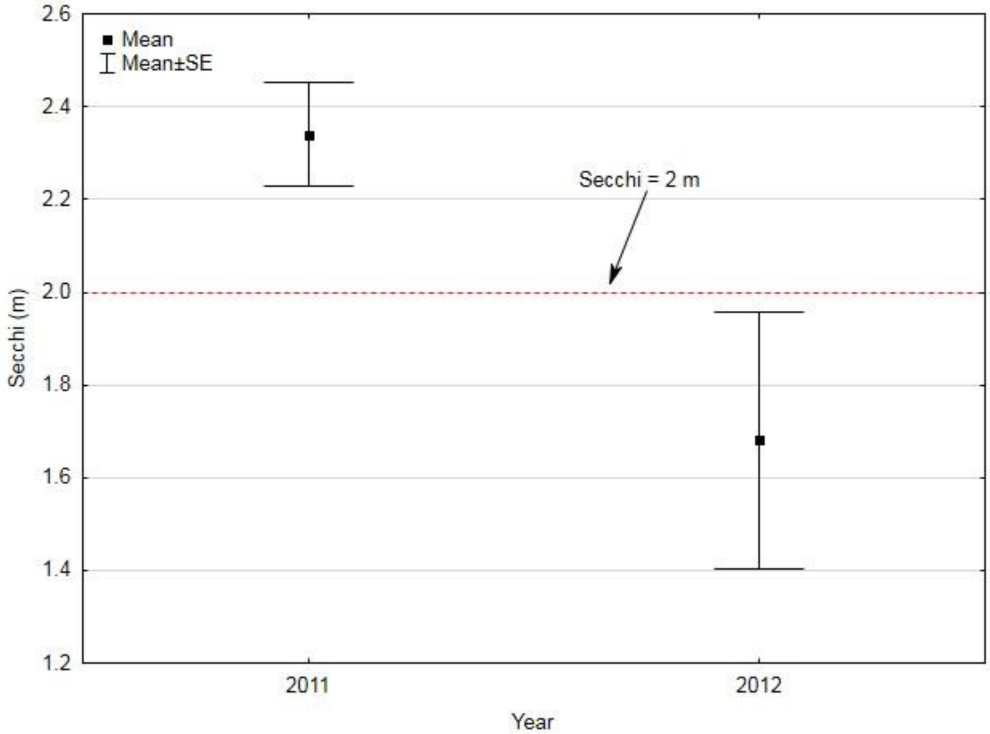

Figure 10-10. Growing Season Means ± SE of Secchi transparency for Crane Lake by Year

A.3 Strand Lake

Figure 10-11. Strand Lake Bathymetric Map (EOR, December 2018)

Aquatic Plant and Fish Community

No DNR aquatic plant nor fish community surveys have been completed on Strand Lake.

Recorded Water Levels

Water levels are not being recorded on Strand Lake.

Growing Season Annual Average Water Quality Figures

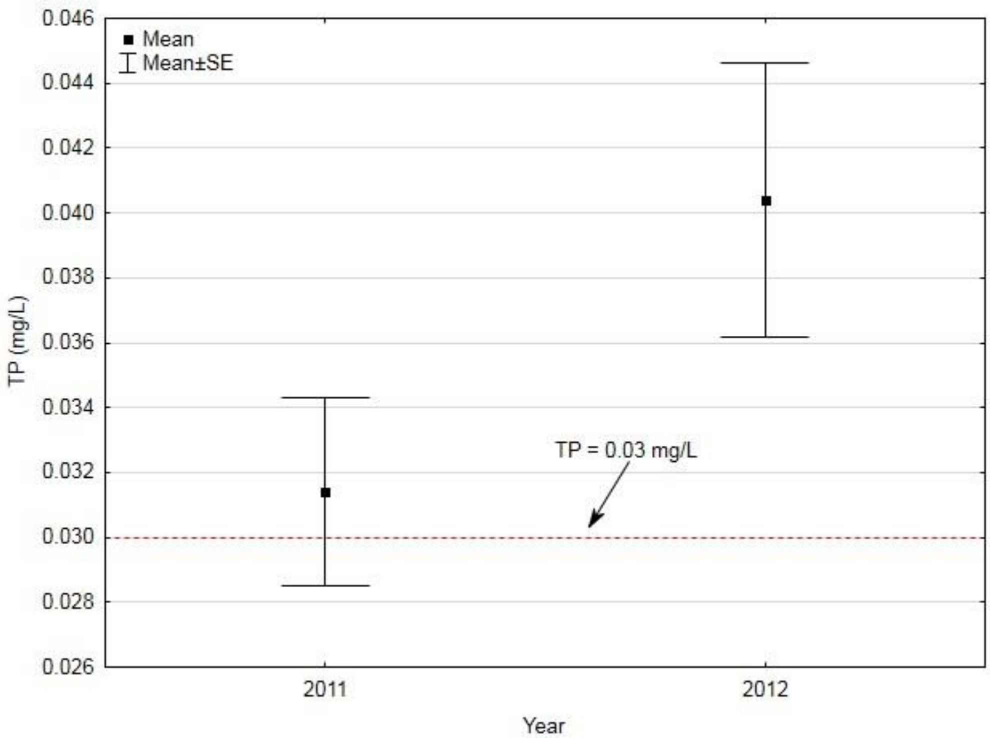

Figure 10-12. Growing Season Means ± SE of Total Phosphorus for Strand Lake by Year

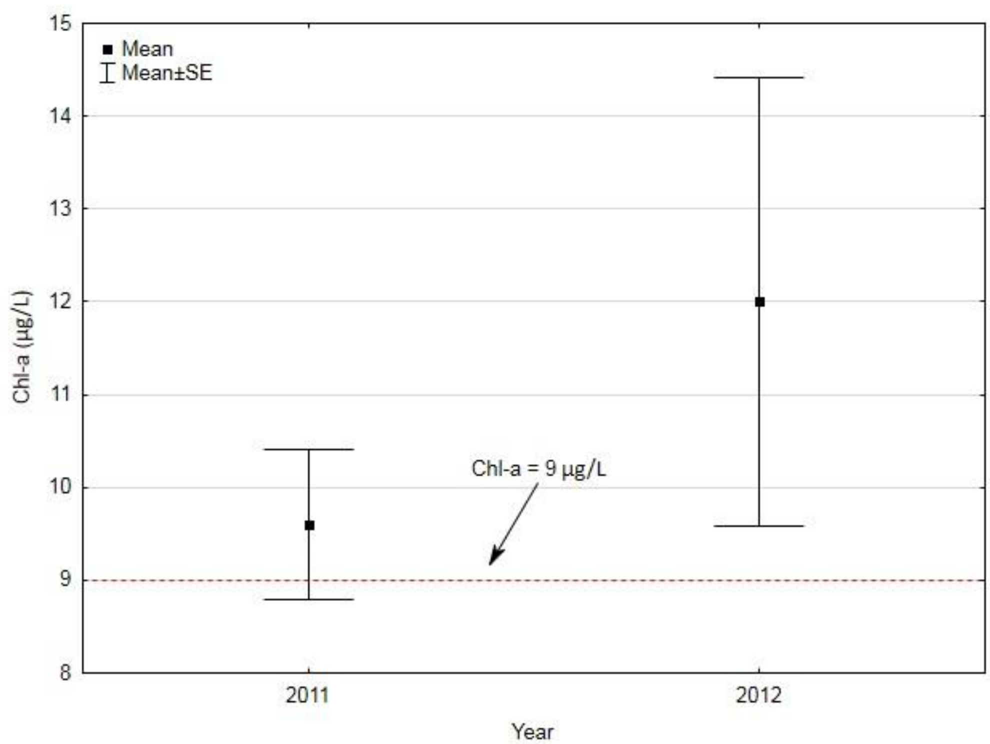

Figure 10-13. Growing Season Means ± SE of Chlorophyll-*a* for Strand Lake by Year

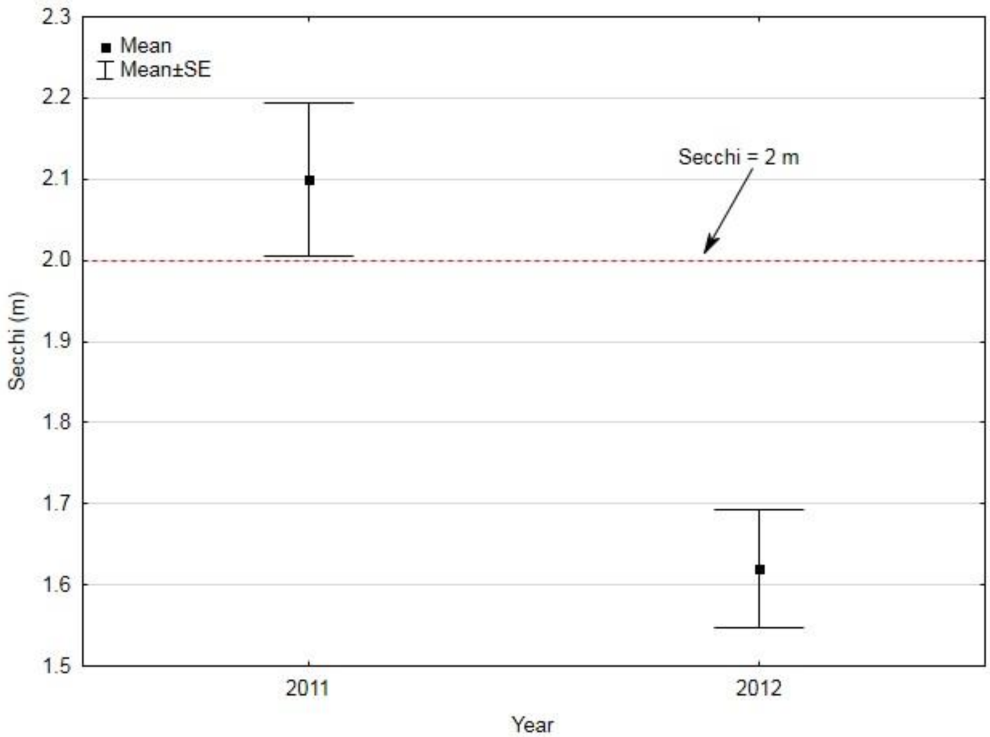

Figure 10-14. Growing Season Means ± SE of Secchi transparency for Strand Lake by Year

A.4 Whitefish Lake

Figure 10-15. Whitefish Lake Bathymetric Map (EOR, December 2018)

Aquatic Plant and Fish Community

No DNR aquatic plant nor fish community surveys have been completed on Whitefish Lake.

Recorded Water Levels

Water levels are not being recorded on Whitefish Lake.

Growing Season Annual Average Water Quality Figures

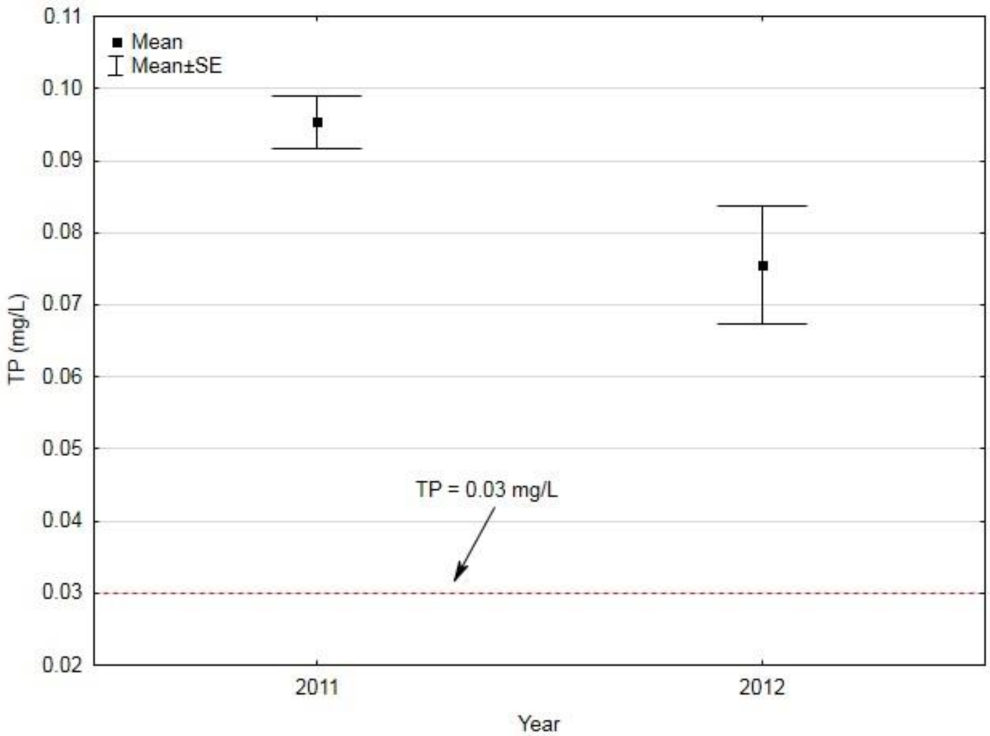

Figure 10-16. Growing Season Means ± SE of Total Phosphorus for Whitefish Lake by Year

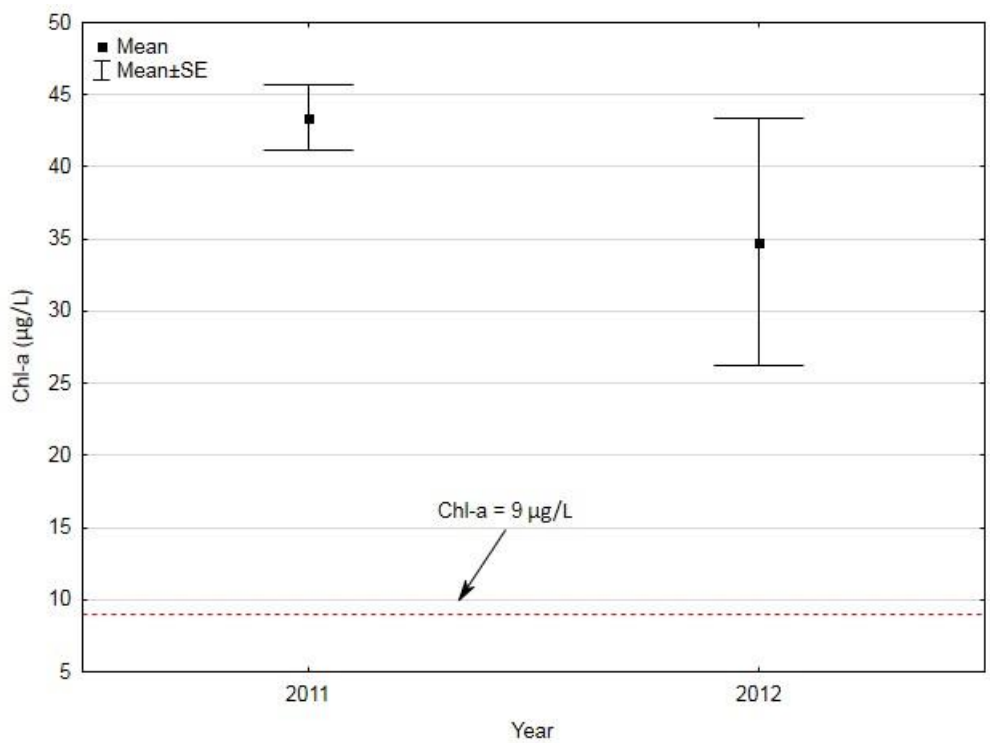

Figure 10-17. Growing Season Means ± SE of Chlorophyll-*a* for Whitefish Lake by Year

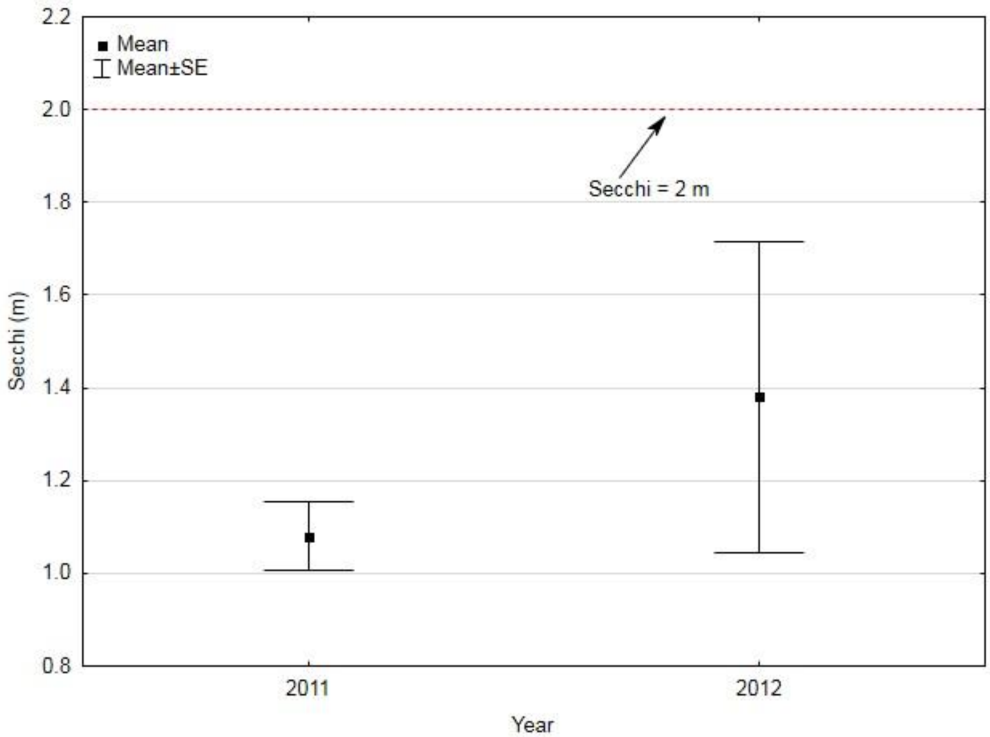

Figure 10-18. Growing Season Means ± SE of Secchi transparency for Whitefish Lake by Year

A.5 Bartlett Lake

Figure 10-19. Bartlett Lake Bathymetric Map (EOR, December 2018)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of the south shore of Bartlett Lake on August 21, 2014. At the time of the survey, the aquatic plant community was comprised of submersed, floating, emergent and shoreline species. No invasive species were observed.

The most recent DNR fish survey was completed on July 11, 2016. This survey noted:

- Bartlett Lake is a 304 acre lake located on the northeastern edge of the town of Northome, Minnesota.
- Bartlett is a highly productive lake that has a history of frequent winterkill events. Between winterkill events, Bartlett is capable of quickly rebounding to provide fish that are of interest to anglers. A winterkill event occurred in 2014, and in response to that event adult Black Crappie and Northern Pike have been stocked in the lake.
- Bartlett should provide a quality fishery for Black Crappie and Northern Pike if another winterkill doesn't occur.

Recorded Water Levels

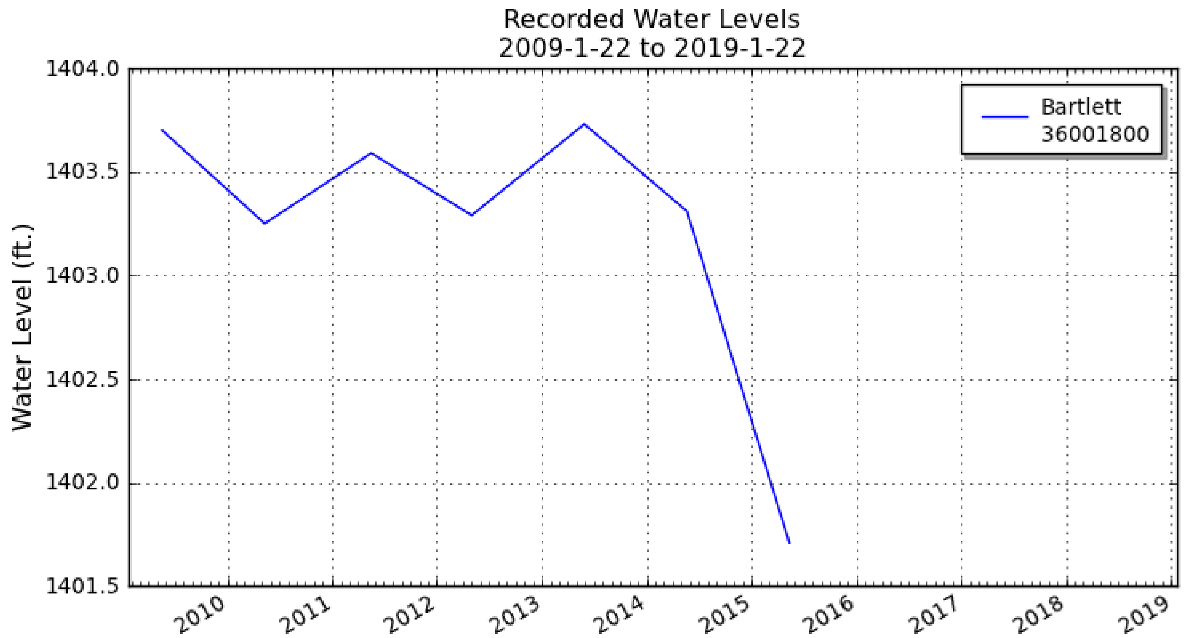

Figure 10-20. Bartlett Lake DNR Recorded Water Levels (2009-1-22 to 2019-1-22)

Growing Season Annual Average Water Quality Figures

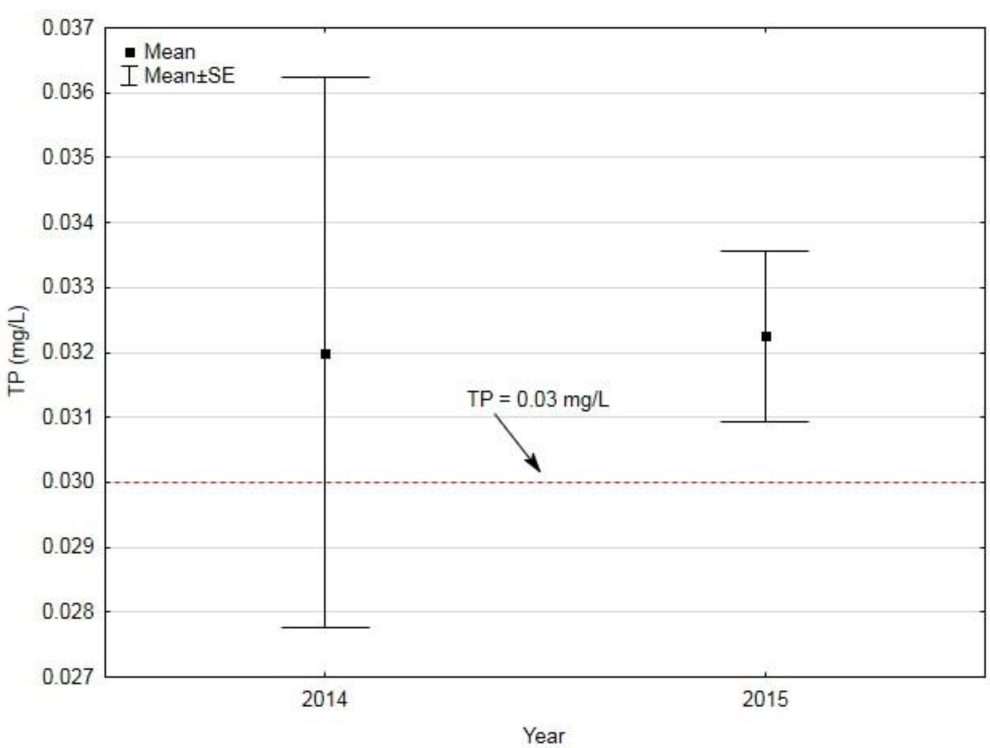

Figure 10-21. Growing Season Means ± SE of Total Phosphorus for Bartlett Lake by Year

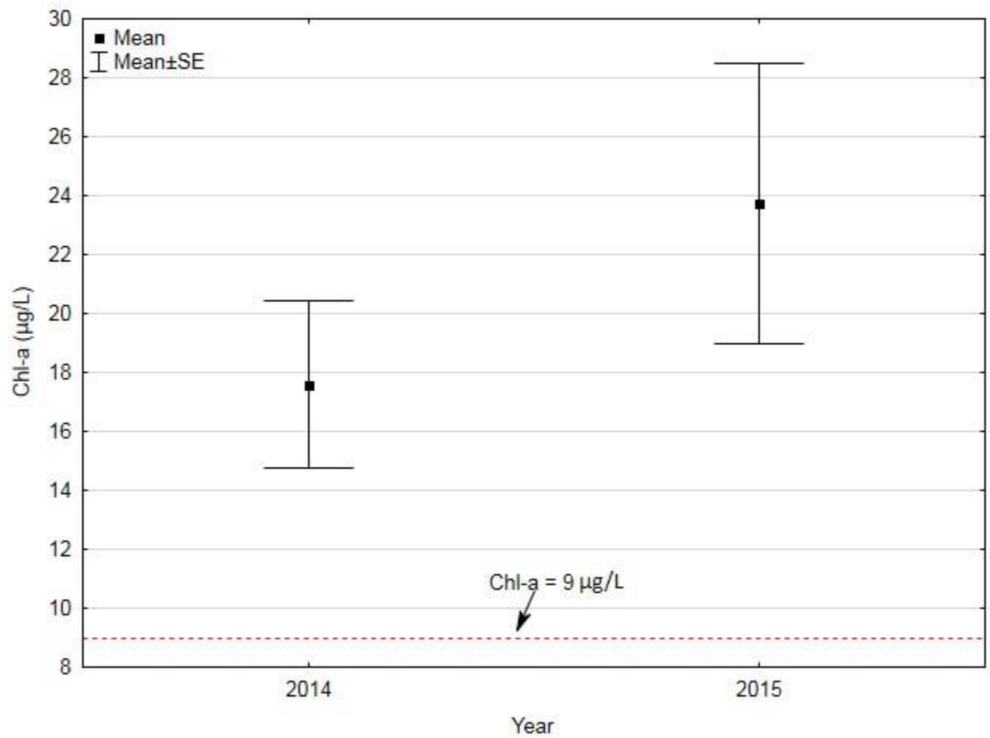

Figure 10-22. Growing Season Means ± SE of Chlorophyll-*a* for Bartlett Lake by Year

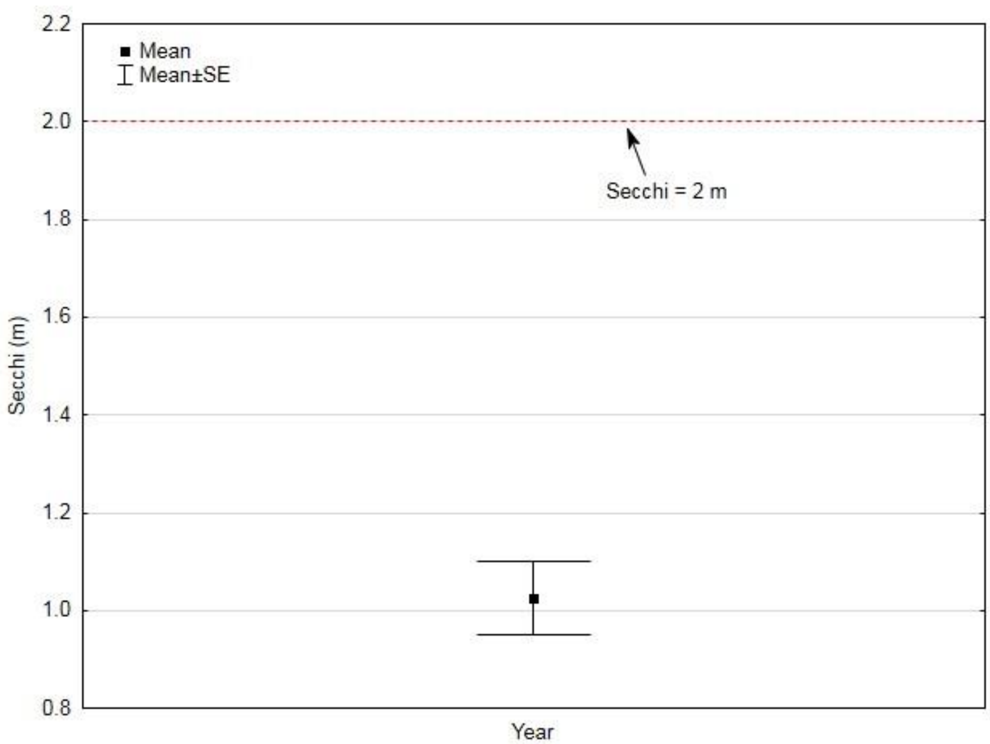

Figure 10-23. Growing Season Means ± SE of Secchi transparency for Bartlett Lake by Year

Appendix B. BATHTUB SUPPORTING INFORMATION

B.1 Blackduck Lake

Table 10-1. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Blackduck				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	33.7	0.37	34.8%	33.7	0.11	34.8%

Table 10-2. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct drai	52.3	7.3	5.33E-01	0.10	0.14
PRECIPITATION				10.9	7.1	5.05E-01	0.10	0.65
TRIBUTARY INFLOW				52.3	7.3	5.33E-01	0.10	0.14
***TOTAL INFLOW				63.1	14.4	1.04E+00	0.07	0.23
ADVECTIVE OUTFLOW				63.1	6.4	3.58E+00	0.29	0.10
***TOTAL OUTFLOW				63.1	6.4	3.58E+00	0.29	0.10
***EVAPORATION					8.0	2.54E+00	0.20	

Overall Mass Balance Based Upon				Predicted	Outflow & Reservoir Concentrations					
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct drai	334.7	23.4%	2.24E+03	73.6%	0.14	45.8	6.4
PRECIPITATION				283.6	19.9%	8.04E+02	26.4%	0.10	39.9	26.1
INTERNAL LOAD				809.7	56.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				334.7	23.4%	2.24E+03	73.6%	0.14	45.8	6.4
***TOTAL INFLOW				1428.1	100.0%	3.05E+03	100.0%	0.04	99.1	22.6
ADVECTIVE OUTFLOW				217.2	15.2%	9.63E+03		0.45	33.7	3.4
***TOTAL OUTFLOW				217.2	15.2%	9.63E+03		0.45	33.7	3.4
***RETENTION				1210.9	84.8%	1.07E+04		0.09		

Overflow Rate (m/yr)	0.6	Nutrient Resid. Time (yrs)	1.0849
Hydraulic Resid. Time (yrs)	7.1345	Turnover Ratio	0.9
Reservoir Conc (mg/m3)	34	Retention Coef.	0.848

Table 10-3. TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Blackduck				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	30.0	0.37	30.2%	33.7	0.11	34.8%

Table 10-4. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct drai	52.3	7.3	5.33E-01	0.10	0.14
PRECIPITATION				10.9	7.1	5.05E-01	0.10	0.65
TRIBUTARY INFLOW				52.3	7.3	5.33E-01	0.10	0.14
***TOTAL INFLOW				63.1	14.4	1.04E+00	0.07	0.23
ADVECTIVE OUTFLOW				63.1	6.4	3.58E+00	0.29	0.10
***TOTAL OUTFLOW				63.1	6.4	3.58E+00	0.29	0.10
***EVAPORATION					8.0	2.54E+00	0.20	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct drai	334.7	28.3%	2.24E+03	73.6%	0.14	45.8	6.4
PRECIPITATION				283.6	24.0%	8.04E+02	26.4%	0.10	39.9	26.1
INTERNAL LOAD				563.6	47.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				334.7	28.3%	2.24E+03	73.6%	0.14	45.8	6.4
***TOTAL INFLOW				1182.0	100.0%	3.05E+03	100.0%	0.05	82.0	18.7
ADVECTIVE OUTFLOW				193.3	16.4%	7.46E+03		0.45	30.0	3.1
***TOTAL OUTFLOW				193.3	16.4%	7.46E+03		0.45	30.0	3.1
***RETENTION				988.6	83.6%	8.67E+03		0.09		

Overflow Rate (m/yr)	0.6	Nutrient Resid. Time (yrs)	1.1670
Hydraulic Resid. Time (yrs)	7.1345	Turnover Ratio	0.9
Reservoir Conc (mg/m3)	30	Retention Coef.	0.836

B.2 Crane Lake

Table 10-5. Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Crane**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	38.1	0.26	40.0%	38.1	0.09	40.0%

Table 10-6. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	**Type**	**Seg**	**Name**	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	1.0	0.2	2.76E-02	1.00	0.17
2	1	1	Strand Sou	8.7	1.0	9.61E-03	0.10	0.11
PRECIPITATION				0.4	0.3	7.72E-04	0.10	0.64
TRIBUTARY INFLOW				9.7	1.1	3.72E-02	0.17	0.12
***TOTAL INFLOW				10.2	1.4	3.79E-02	0.14	0.14
ADVECTIVE OUTFLOW				10.2	1.1	4.20E-02	0.19	0.11
***TOTAL OUTFLOW				10.2	1.1	4.20E-02	0.19	0.11
***EVAPORATION					0.3	4.09E-03	0.20	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	**Type**	**Seg**	**Name**	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	9.6	9.4%	9.39E+01	83.7%	1.00	58.1	9.6
2	1	1	Strand Sou	29.1	28.4%	1.70E+01	15.1%	0.14	29.7	3.3
PRECIPITATION				11.4	11.1%	1.30E+00	1.2%	0.10	41.0	26.1
INTERNAL LOAD				52.3	51.0%	0.00E+00		0.00		
TRIBUTARY INFLOW				38.8	37.9%	1.11E+02	98.8%	0.27	33.8	4.0
***TOTAL INFLOW				102.4	100.0%	1.12E+02	100.0%	0.10	71.9	10.1
ADVECTIVE OUTFLOW				42.1	41.1%	1.77E+02		0.32	38.1	4.1
***TOTAL OUTFLOW				42.1	41.1%	1.77E+02		0.32	38.1	4.1
***RETENTION				60.3	58.9%	1.37E+02		0.19		

Overflow Rate (m/yr)	2.5	Nutrient Resid. Time (yrs)	0.4997
Hydraulic Resid. Time (yrs)	1.2164	Turnover Ratio	2.0
Reservoir Conc (mg/m3)	38	Retention Coef.	0.589

Table 10-7. TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Crane

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	30.0	0.25	30.1%	38.1	0.09	40.0%

Table 10-8. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Dra	1.0	0.2	2.76E-02	1.00	0.17
2	1	1	Strand Sou	8.7	1.0	9.61E-03	0.10	0.11
PRECIPITATION				0.4	0.3	7.72E-04	0.10	0.64
TRIBUTARY INFLOW				9.7	1.1	3.72E-02	0.17	0.12
***TOTAL INFLOW				10.2	1.4	3.79E-02	0.14	0.14
ADVECTIVE OUTFLOW				10.2	1.1	4.20E-02	0.19	0.11
***TOTAL OUTFLOW				10.2	1.1	4.20E-02	0.19	0.11
***EVAPORATION					0.3	4.09E-03	0.20	

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

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Dra	8.3	11.2%	6.96E+01	79.2%	1.00	50.0	8.3
2	1	1	Strand Sou	29.1	39.4%	1.70E+01	19.3%	0.14	29.7	3.3
PRECIPITATION				11.4	15.4%	1.30E+00	1.5%	0.10	41.0	26.1
INTERNAL LOAD				25.2	34.0%	0.00E+00		0.00		
TRIBUTARY INFLOW				37.4	50.6%	8.65E+01	98.5%	0.25	32.6	3.8
***TOTAL INFLOW				74.0	100.0%	8.78E+01	100.0%	0.13	51.9	7.3
ADVECTIVE OUTFLOW				33.1	44.7%	1.05E+02		0.31	30.0	3.3
***TOTAL OUTFLOW				33.1	44.7%	1.05E+02		0.31	30.0	3.3
***RETENTION				40.9	55.3%	7.93E+01		0.22		

Overflow Rate (m/yr)	2.5	Nutrient Resid. Time (yrs)	0.5441
Hydraulic Resid. Time (yrs)	1.2164	Turnover Ratio	1.8
Reservoir Conc (mg/m3)	30	Retention Coef.	0.553

B.3 Strand Lake North Basin

Table 10-9. Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Strand North				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	35.9	0.24	37.4%	35.9	0.08	37.4%

Table 10-10. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	6.6	0.8	6.74E-03	0.10	0.12
PRECIPITATION				0.3	0.2	3.20E-04	0.10	0.64
TRIBUTARY INFLOW				6.6	0.8	6.74E-03	0.10	0.12
***TOTAL INFLOW				6.9	1.0	7.06E-03	0.08	0.14
ADVECTIVE OUTFLOW				6.9	0.8	8.75E-03	0.12	0.11
***TOTAL OUTFLOW				6.9	0.8	8.75E-03	0.12	0.11
***EVAPORATION					0.2	1.69E-03	0.20	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	29.0	47.3%	1.69E+01	96.9%	0.14	35.4	4.4
PRECIPITATION				7.3	11.9%	5.35E-01	3.1%	0.10	40.9	26.1
INTERNAL LOAD				25.1	40.8%	0.00E+00		0.00		
TRIBUTARY INFLOW				29.0	47.3%	1.69E+01	96.9%	0.14	35.4	4.4
***TOTAL INFLOW				61.4	100.0%	1.74E+01	100.0%	0.07	61.4	8.9
ADVECTIVE OUTFLOW				28.5	46.4%	5.44E+01		0.26	35.9	4.1
***TOTAL OUTFLOW				28.5	46.4%	5.44E+01		0.26	35.9	4.1
***RETENTION				32.9	53.6%	5.04E+01		0.22		

Overflow Rate (m/yr)	2.8	Nutrient Resid. Time (yrs)	0.4406
Hydraulic Resid. Time (yrs)	0.9488	Turnover Ratio	2.3
Reservoir Conc (mg/m3)	36	Retention Coef.	0.536

Table 10-11. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Strand North				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	30.0	0.23	30.2%	35.9	0.08	37.4%

Table 10-12. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Direct Dra	6.6	0.8	6.74E-03	0.10	0.12
PRECIPITATION				0.3	0.2	3.20E-04	0.10	0.64
TRIBUTARY INFLOW				6.6	0.8	6.74E-03	0.10	0.12
***TOTAL INFLOW				6.9	1.0	7.06E-03	0.08	0.14
ADVECTIVE OUTFLOW				6.9	0.8	8.75E-03	0.12	0.11
***TOTAL OUTFLOW				6.9	0.8	8.75E-03	0.12	0.11
***EVAPORATION					0.2	1.69E-03	0.20	

Overall Mass Balance Based Upon				Predicted	Outflow & Reservoir Concentrations					
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Direct Dra	29.0	59.8%	1.69E+01	96.9%	0.14	35.4	4.4
PRECIPITATION				7.3	15.1%	5.35E-01	3.1%	0.10	40.9	26.1
INTERNAL LOAD				12.2	25.1%	0.00E+00		0.00		
TRIBUTARY INFLOW				29.0	59.8%	1.69E+01	96.9%	0.14	35.4	4.4
***TOTAL INFLOW				48.5	100.0%	1.74E+01	100.0%	0.09	48.5	7.0
ADVECTIVE OUTFLOW				23.8	49.1%	3.62E+01		0.25	30.0	3.4
***TOTAL OUTFLOW				23.8	49.1%	3.62E+01		0.25	30.0	3.4
***RETENTION				24.7	50.9%	3.32E+01		0.23		

Overflow Rate (m/yr)	2.8	Nutrient Resid. Time (yrs)	0.4662
Hydraulic Resid. Time (yrs)	0.9488	Turnover Ratio	2.1
Reservoir Conc (mg/m3)	30	Retention Coef.	0.509

B.4 Whitefish Lake

Table 10-13. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Whitefish

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	85.5	0.21	74.0%	85.5	0.06	74.0%

Table 10-14. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Dra	19.8	2.5	6.20E-02	0.10	0.13
PRECIPITATION				0.3	0.2	4.32E-04	0.10	0.62
TRIBUTARY INFLOW				19.8	2.5	6.20E-02	0.10	0.13
***TOTAL INFLOW				20.2	2.7	6.25E-02	0.09	0.13
ADVECTIVE OUTFLOW				20.2	2.5	6.49E-02	0.10	0.12
***TOTAL OUTFLOW				20.2	2.5	6.49E-02	0.10	0.12
***EVAPORATION					0.2	2.39E-03	0.20	

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

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Dra	147.5	38.0%	4.35E+02	99.8%	0.14	59.2	7.4
PRECIPITATION				8.7	2.2%	7.59E-01	0.2%	0.10	41.9	26.1
INTERNAL LOAD				231.6	59.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				147.5	38.0%	4.35E+02	99.8%	0.14	59.2	7.4
***TOTAL INFLOW				387.8	100.0%	4.36E+02	100.0%	0.05	143.7	19.2
ADVECTIVE OUTFLOW				209.9	54.1%	2.13E+03		0.22	85.5	10.4
***TOTAL OUTFLOW				209.9	54.1%	2.13E+03		0.22	85.5	10.4
***RETENTION				177.9	45.9%	1.90E+03		0.25		

Overflow Rate (m/yr)	7.4	Nutrient Resid. Time (yrs)	0.1590
Hydraulic Resid. Time (yrs)	0.2938	Turnover Ratio	6.3
Reservoir Conc (mg/m3)	86	Retention Coef.	0.459

Table 10-15. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Whitefish				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	30.0	0.16	30.1%	85.5	0.06	74.0%

Table 10-16. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	19.8	2.5	6.20E-02	0.10	0.13
PRECIPITATION				0.3	0.2	4.32E-04	0.10	0.62
TRIBUTARY INFLOW				19.8	2.5	6.20E-02	0.10	0.13
***TOTAL INFLOW				20.2	2.7	6.25E-02	0.09	0.13
ADVECTIVE OUTFLOW				20.2	2.5	6.49E-02	0.10	0.12
***TOTAL OUTFLOW				20.2	2.5	6.49E-02	0.10	0.12
***EVAPORATION					0.2	2.39E-03	0.20	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	99.6	92.0%	1.99E+02	99.6%	0.14	40.0	5.0
PRECIPITATION				8.7	8.0%	7.59E-01	0.4%	0.10	41.9	26.1
TRIBUTARY INFLOW				99.6	92.0%	1.99E+02	99.6%	0.14	40.0	5.0
***TOTAL INFLOW				108.3	100.0%	1.99E+02	100.0%	0.13	40.1	5.4
ADVECTIVE OUTFLOW				73.6	67.9%	2.11E+02		0.20	30.0	3.6
***TOTAL OUTFLOW				73.6	67.9%	2.11E+02		0.20	30.0	3.6
***RETENTION				34.8	32.1%	1.32E+02		0.33		

Overflow Rate (m/yr)	7.4	Nutrient Resid. Time (yrs)	0.1995
Hydraulic Resid. Time (yrs)	0.2938	Turnover Ratio	5.0
Reservoir Conc (mg/m3)	30	Retention Coef.	0.321

B.5 Bartlett Lake

Table 10-17. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Bartlett				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	32.1	0.32	32.8%	32.1	0.06	32.8%

Table 10-18. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	6.9	1.2	1.50E-02	0.10	0.18
PRECIPITATION				1.3	0.9	7.94E-03	0.10	0.66
TRIBUTARY INFLOW				6.9	1.2	1.50E-02	0.10	0.18
***TOTAL INFLOW				8.2	2.1	2.30E-02	0.07	0.26
ADVECTIVE OUTFLOW				8.2	1.1	6.18E-02	0.22	0.14
***TOTAL OUTFLOW				8.2	1.1	6.18E-02	0.22	0.14
***EVAPORATION					1.0	3.88E-02	0.20	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	41.7	34.5%	3.47E+01	73.8%	0.14	34.0	6.1
PRECIPITATION				35.1	29.0%	1.23E+01	26.2%	0.10	39.4	26.1
INTERNAL LOAD				44.2	36.5%	0.00E+00		0.00		
TRIBUTARY INFLOW				41.7	34.5%	3.47E+01	73.8%	0.14	34.0	6.1
***TOTAL INFLOW				121.0	100.0%	4.70E+01	100.0%	0.06	57.1	14.7
ADVECTIVE OUTFLOW				36.3	30.0%	1.64E+02		0.35	32.1	4.4
***TOTAL OUTFLOW				36.3	30.0%	1.64E+02		0.35	32.1	4.4
***RETENTION				84.6	70.0%	1.69E+02		0.15		

Overflow Rate (m/yr)	0.8	Nutrient Resid. Time (yrs)	0.7925
Hydraulic Resid. Time (yrs)	2.6384	Turnover Ratio	1.3
Reservoir Conc (mg/m3)	32	Retention Coef.	0.700

Table 10-19. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Bartlett**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	30.0	0.31	30.2%	32.1	0.06	32.8%

Table 10-20. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Direct Dra	6.9	1.2	1.50E-02	0.10	0.18
PRECIPITATION				1.3	0.9	7.94E-03	0.10	0.66
TRIBUTARY INFLOW				6.9	1.2	1.50E-02	0.10	0.18
***TOTAL INFLOW				8.2	2.1	2.30E-02	0.07	0.26
ADVECTIVE OUTFLOW				8.2	1.1	6.18E-02	0.22	0.14
***TOTAL OUTFLOW				8.2	1.1	6.18E-02	0.22	0.14
***EVAPORATION					1.0	3.88E-02	0.20	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Direct Dra	41.7	38.0%	3.47E+01	73.8%	0.14	34.0	6.1
PRECIPITATION				35.1	32.0%	1.23E+01	26.2%	0.10	39.4	26.1
INTERNAL LOAD				32.9	30.0%	0.00E+00		0.00		
TRIBUTARY INFLOW				41.7	38.0%	3.47E+01	73.8%	0.14	34.0	6.1
***TOTAL INFLOW				109.7	100.0%	4.70E+01	100.0%	0.06	51.8	13.3
ADVECTIVE OUTFLOW				34.0	31.0%	1.40E+02		0.35	30.0	4.1
***TOTAL OUTFLOW				34.0	31.0%	1.40E+02		0.35	30.0	4.1
***RETENTION				75.7	69.0%	1.46E+02		0.16		

Overflow Rate (m/yr)	0.8	Nutrient Resid. Time (yrs)	0.8176
Hydraulic Resid. Time (yrs)	2.6384	Turnover Ratio	1.2
Reservoir Conc (mg/m3)	30	Retention Coef.	0.690

B.6 Strand Lake South Basin

Table 10-21. Uncalibrated Model Predicted Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Strand South				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	29.7	0.25	29.8%			

Table 10-22. Uncalibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	1.5	0.2	4.52E-04	0.10	0.14
2	1	1	Strand No	6.9	0.8	6.31E-03	0.10	0.11
PRECIPITATION				0.3	0.2	3.20E-04	0.10	0.64
TRIBUTARY INFLOW				8.4	1.0	6.76E-03	0.08	0.12
***TOTAL INFLOW				8.7	1.2	7.08E-03	0.07	0.14
ADVECTIVE OUTFLOW				8.7	1.0	8.77E-03	0.10	0.11
***TOTAL OUTFLOW				8.7	1.0	8.77E-03	0.10	0.11
***EVAPORATION					0.2	1.69E-03	0.20	

Overall Mass Balance Based Upon				Predicted	Outflow & Reservoir Concentrations					
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	6.4	9.6%	8.30E-01	4.7%	0.14	30.3	4.3
2	1	1	Strand No	28.5	42.3%	1.63E+01	92.3%	0.14	35.9	4.1
PRECIPITATION				7.3	10.9%	5.35E-01	3.0%	0.10	40.9	26.1
INTERNAL LOAD				25.1	37.2%	0.00E+00		0.00		
TRIBUTARY INFLOW				35.0	51.9%	1.71E+01	97.0%	0.12	34.7	4.1
***TOTAL INFLOW				67.4	100.0%	1.76E+01	100.0%	0.06	56.8	7.7
ADVECTIVE OUTFLOW				29.1	43.2%	6.04E+01		0.27	29.7	3.3
***TOTAL OUTFLOW				29.1	43.2%	6.04E+01		0.27	29.7	3.3
***RETENTION				38.2	56.8%	5.86E+01		0.20		

Overflow Rate (m/yr)	3.5	Nutrient Resid. Time (yrs)	0.5758
Hydraulic Resid. Time (yrs)	1.3319	Turnover Ratio	1.7
Reservoir Conc (mg/m3)	30	Retention Coef.	0.568

Appendix C. SUPPLEMENTAL *E. COLI* DATA

Table 10-23. Summary of *E. coli* water quality for which no flow data were available. Observances which exceed the water quality standard are shown in bold.

Shotley Brook (-502) at S007-884		Battle River, North Branch (-503) at BATT-NB (S003-962)		North Cormorant River (-506) at CORM-B (S003-961)		South Cormorant River (-507) at S007-883	
Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)
6/4/2015	24.6	6/4/2015	99	6/4/2015	64.4	6/4/2015	44.3
6/23/2015	10.9	6/23/2015	**179.3**	6/23/2015	365.4	6/23/2015	60.9
7/13/2015	52.9	7/13/2015	**360.9**	7/13/2015	57.3	7/13/2015	66.3
7/30/2015	42.6	7/30/2015	34.5	7/30/2015	129.1	7/30/2015	68.3
8/10/2015	52	8/10/2015	193.5	8/10/2015	20	8/11/2015	54.6
8/24/2015	**150**	8/24/2015	**613.1**	8/24/2015	77.1	8/26/2015	30.5

Darrigans Creek (-508) at S004-832		Blackduck River (-510) at S004-831		Blackduck River (-512) at S004-882		Hay Creek (-518) at 10RD011 (S007-880)	
Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)
6/11/2015	10.8	5/6/2015	19.9	6/11/2015	10.8	6/2/2015	42.8
6/25/2015	9.7	6/8/2015	727	6/25/2015	9.7	6/22/2015	95.9
7/13/2015	36.4	8/6/2015	56.3	7/13/2015	36.4	7/13/2015	69.7
7/22/2015	11	8/6/2015	86.2	7/22/2015	11	7/30/2015	108.6
8/4/2015	33.6	10/7/2015	48	8/4/2015	33.6	8/11/2015	101.7
						8/26/2015	111.9

Sandy River (-522) at 09RD003 (S007-877)		Mud River (-541) at MUDR-M (S007-881)		O'Brien Creek (-544) at S004-833		Unnamed Creek (-600) At S007-888	
Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)	Date	Observed *E. coli* (MPN/mL)
6/2/2015	50.4	6/2/2015	55.7	5/6/2015	83.6	6/4/2015	5.2
6/22/2015	290.9	6/22/2015	191.8	6/8/2015	110	6/23/2015	10.9
7/7/2015	166.4	7/7/2015	193.5	6/8/2015	93.3	7/13/2015	23.1
7/20/2015	78	7/20/2015	90.9	8/6/2015	325.5	7/30/2015	69.7
8/3/2015	146.7	8/3/2015	40.4	10/7/2015	83.6	8/10/2015	133.4
						8/24/2015	148.3

Appendix D. BARTLETT LAKE IN-LAKE MANAGEMENT STRATEGIES

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For:

Minnesota Pollution Control Agency

Bartlett Lake In-Lake Management Strategies

05.31.2018

EOR water ecology community

Cover Image

Bartlett Lake from the August 21, 2014 Minnesota Biological Survey List of Plant Species Observed at Bartlett Lake by the Minnesota Department of Natural Resources.

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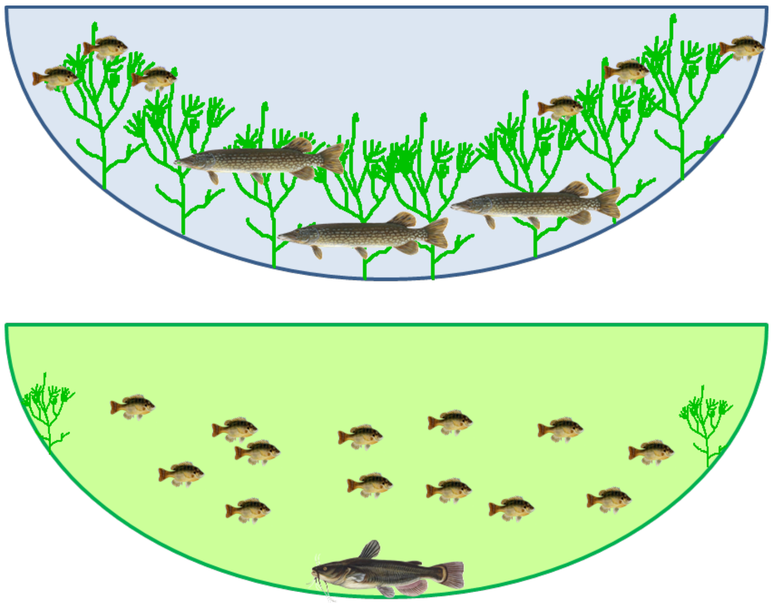
1. SHALLOW LAKE BIOLOGY AND WATER QUALITY

Lakes are considered shallow when most (>80%) of the lake area is less than 15 feet deep. Depths less than 15 feet are important biologically sunlight can penetrate to the lake bottom and support aquatic plant growth. In addition, all the living organisms in shallow lakes are concentrated in a smaller volume than in deeper lakes. Consequently, the relationship between phosphorus concentration and the amount of algae growth (measured by chlorophyll-*a* pigments and water transparency) is often different in shallow lakes as compared to deeper lakes. In deeper lakes, algae abundance is often controlled by physical and chemical factors such as light availability, temperature, and nutrient concentrations. The biological components of the lake (such as microbes, algae, aquatic plants, zooplankton and other invertebrates, and fish) are distributed throughout the lake, along the shoreline, and on the bottom sediments. In shallow lakes, the biological components are more concentrated into less volume and exert a stronger influence on the ecological interactions within the lake. There is a denser biological community at the bottom of shallow lakes than in deeper lakes because oxygen is replenished in the bottom waters and light can often penetrate to the bottom. These biological components can control the relationship between phosphorus and the response factors.

The result of this impact of biological components on the ecological interactions is that **shallow lakes normally exhibit one of two ecologically alternative stable states (Figure 1): the turbid water, algae-dominated state, and the clear water, aquatic plant-dominated state.** The clear state is the most preferred, since algae communities are held in check by diverse and healthy zooplankton and fish communities. In addition, rooted plants stabilize the sediments, lessening the amount of sediment stirred up by the wind.

As shown in Figure 2, the transition in water quality of shallow lakes from clear to turbid is often abrupt. When shallow lakes have historically been in the clear water state and dominated by submerged aquatic vegetation, they are capable of assimilating large amounts of phosphorus loading without becoming dominated by algae. That is to say, they are stable in a clear-water state. They may experience some periods of turbid water conditions, but tend to revert to clear water conditions. However, as phosphorus loading increases, the stability of the clear-water state declines until the lake is stable in a turbid-water state. Consequently, drastic reductions in nutrients or changes in the biological community of a shallow lake are needed to promote a clear-water state (Figure 3).

It is important to note that Bartlett Lake has undergone extensive changes from human disturbances over a long period of time. Therefore, management of this lake should also be expected to be extensive and long-term. That is to say, continual management of shallow lakes is needed to maintain clear water. And it should be noted that a recent study comparing the characteristics of managed shallow lakes to those of other regional shallow lakes manifesting clear- or turbid- state conditions concluded that not all shallow lake rehabilitation efforts succeed and that when improvements occur, management may need to be repeated to maintain clear water in highly modified landscapes (Hanson et al. 2017).



CLEAR

Large fish (or the absence of all fish) and abundant rooted plants keep water clear.

TURBID

Too many panfish or too few rooted plants keep water turbid.

Figure 1. Alternative stable states in shallow lakes

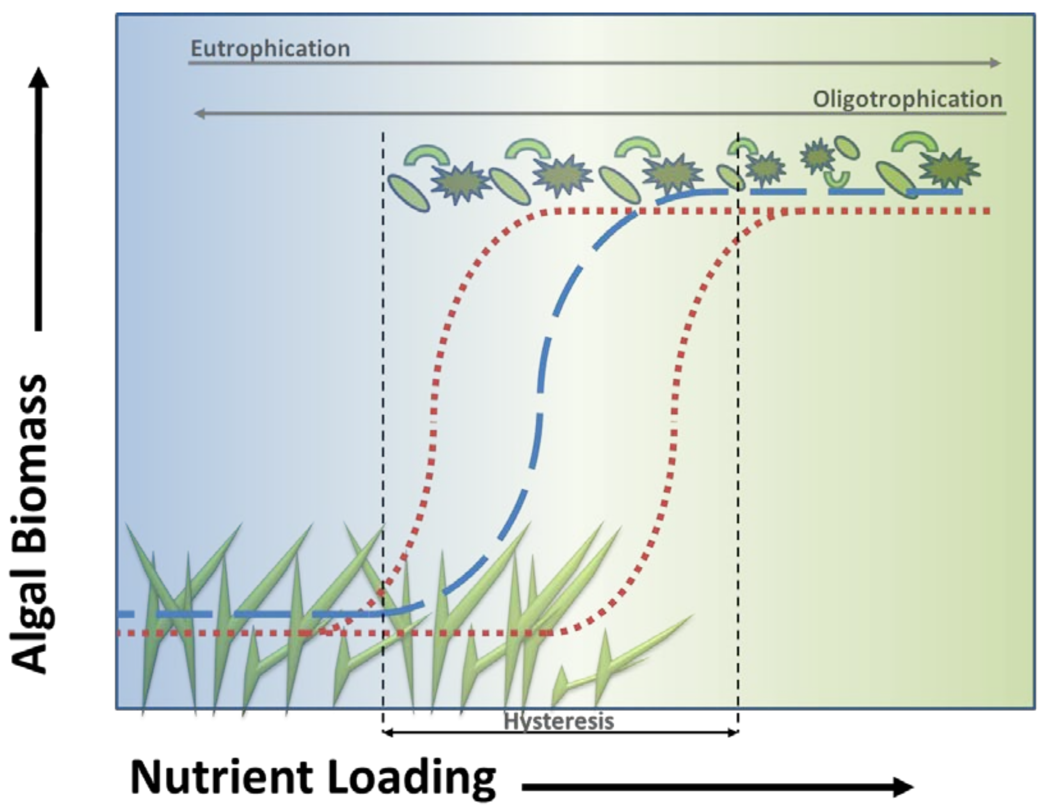


Figure 2. Trophic state shifts in shallow lakes in response to changes in nutrient loading

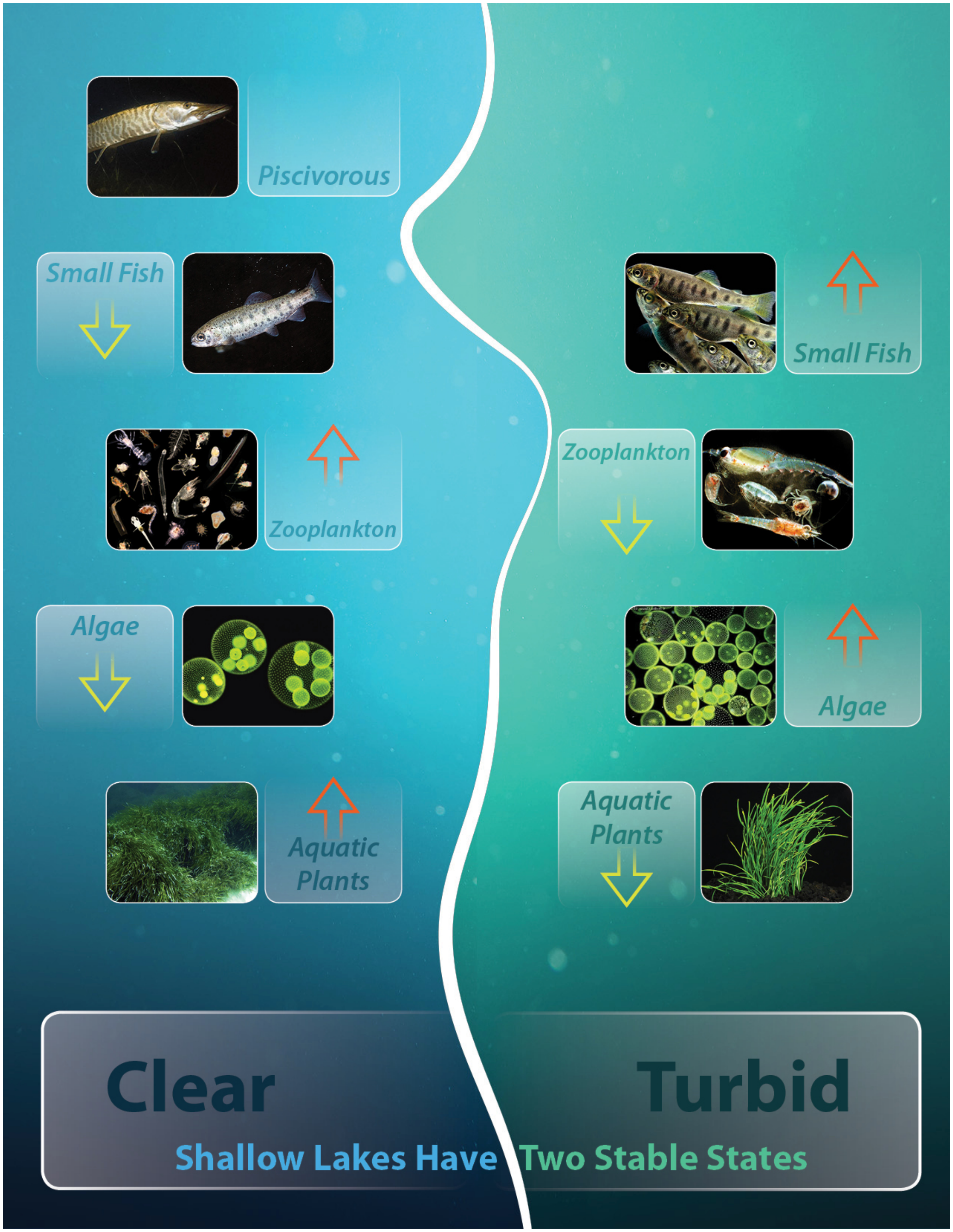


Figure 3. Cascading biological communities in shallow lakes under clear and turbid water states.

1.1. Aquatic Plants

In general, when aquatic plants are present in shallow lakes, the water is clear (Figure 3). Numerous studies have shown that native aquatic plants can sustain good light penetration and water quality, but the challenge is to establish aquatic plants if they are not present. The key to maintaining a clear water, aquatic plant dominated state is to control nutrients and other factors, especially fish disruptions as well as the introduction of invasive species that could limit plant establishment and growth.

While aquatic plants are vital to maintaining the ecologically-preferred clear water state, aquatic plants can prevent or restrict landowners from enjoying certain recreational activities such as boating and swimming.

Aquatic plants can contribute to the internal phosphorus load of lakes in two ways. First, the physical breakdown of plant biomass can potentially result in a large release of phosphorus into the water. Second, the decay of plant materials can also strip oxygen from the water column and cause a release of phosphorus from the sediments. As plant decay rates rise with an increase in the eutrophic nature (or fertility) of a lake, the bacteria involved in the decay of plant matter can also consume oxygen in the lake. Plant decay under ice cover is one of the mechanisms by which oxygen can become depleted in the winter and cause a fish kill (Figure 4).

1.2. Dissolved Oxygen Levels

Dissolved oxygen is the amount of oxygen dissolved in lake water. Individual fish species have different dissolved oxygen level requirements in water. Certain gamefish species, such as northern pike and yellow perch, are better suited for periodic low levels of dissolved oxygen than other gamefish species, such as walleye, bass, and bluegills. The major sources of dissolved oxygen in shallow lakes includes diffusion from the atmosphere, wind mixing (wave action), and photosynthesis from aquatic plants. The major uses of dissolved oxygen include respiration and decomposition. Respiration is essentially the act of breathing; when aquatic organisms breathe, they consume oxygen and release carbon dioxide. Decomposition is the breakdown of organic matter by invertebrates, bacteria, and fungi, which consumes oxygen. During the winter, shallow lakes can become anoxic (without oxygen) as oxygen consuming activities (respiration and decomposition) continue under the ice without any new sources of oxygen from the air or plant photosynthesis.

Installation of aeration equipment can create small plumes of oxygen for fish during periods of low oxygen. However, some shallow lakes are better managed as boom or bust fisheries in which gamefish are stocked following winterkills. These gamefish tend to grow fast due to the lack of competition with other fish for food following a winterkill. A boom or bust fishery maintains clear water by allowing zooplankton to forage on algae in the presence of no small fish immediately following a winterkill, or few small fish following gamefish stocking (Figure 3).

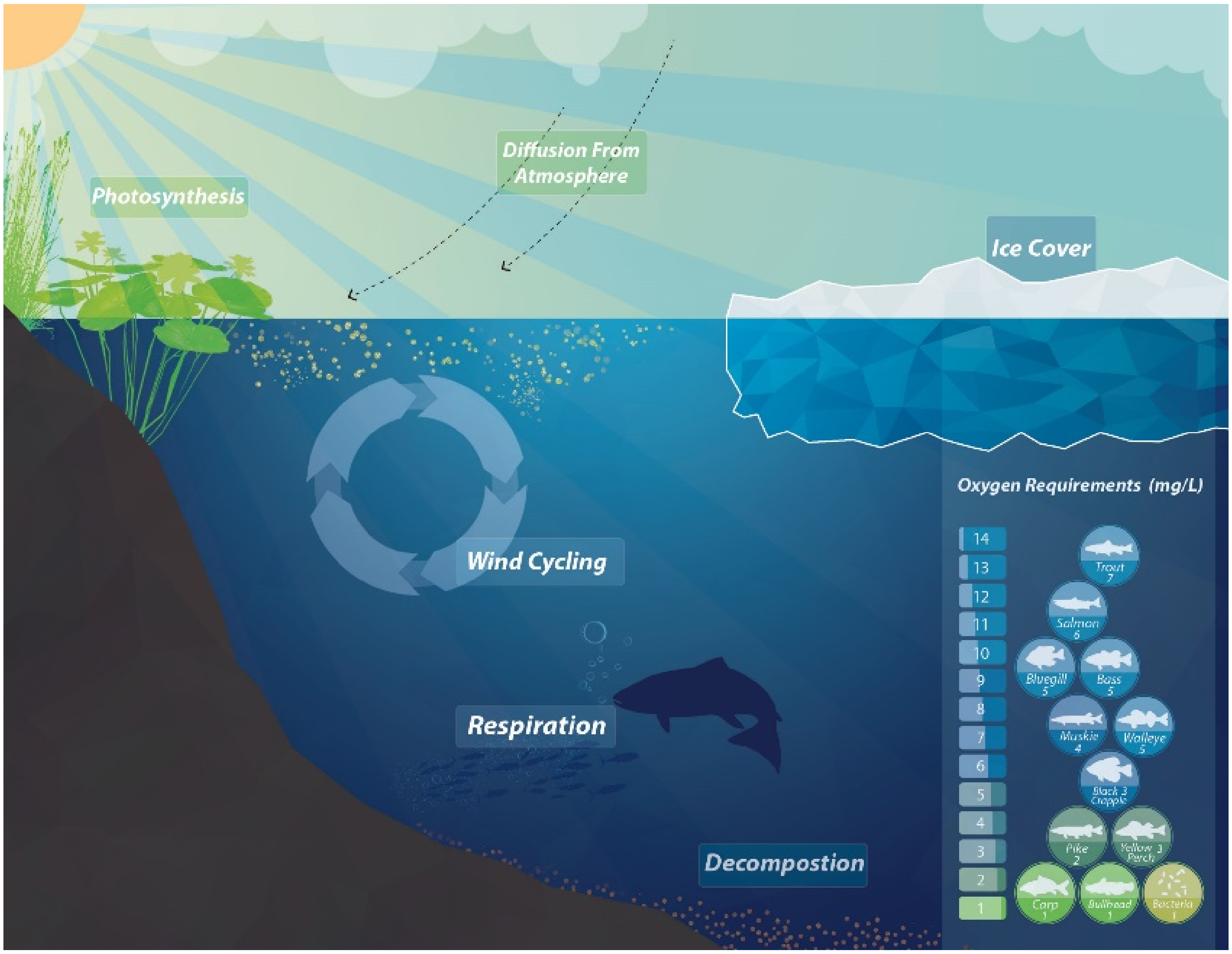


Figure 4. Dissolved oxygen dynamics in shallow lakes

2. BARTLETT LAKE AQUATIC PLANT AND FISH COMMUNITIES

Bartlett Lake (DNR Lake ID 36-0018-0) is a shallow lake located near Northome, MN in Koochiching County. Bartlett Lake has a surface area of 304 acres, a maximum depth of 16 feet and an average depth of 9 feet. The following section describes the aquatic plant and fish communities within the lake.

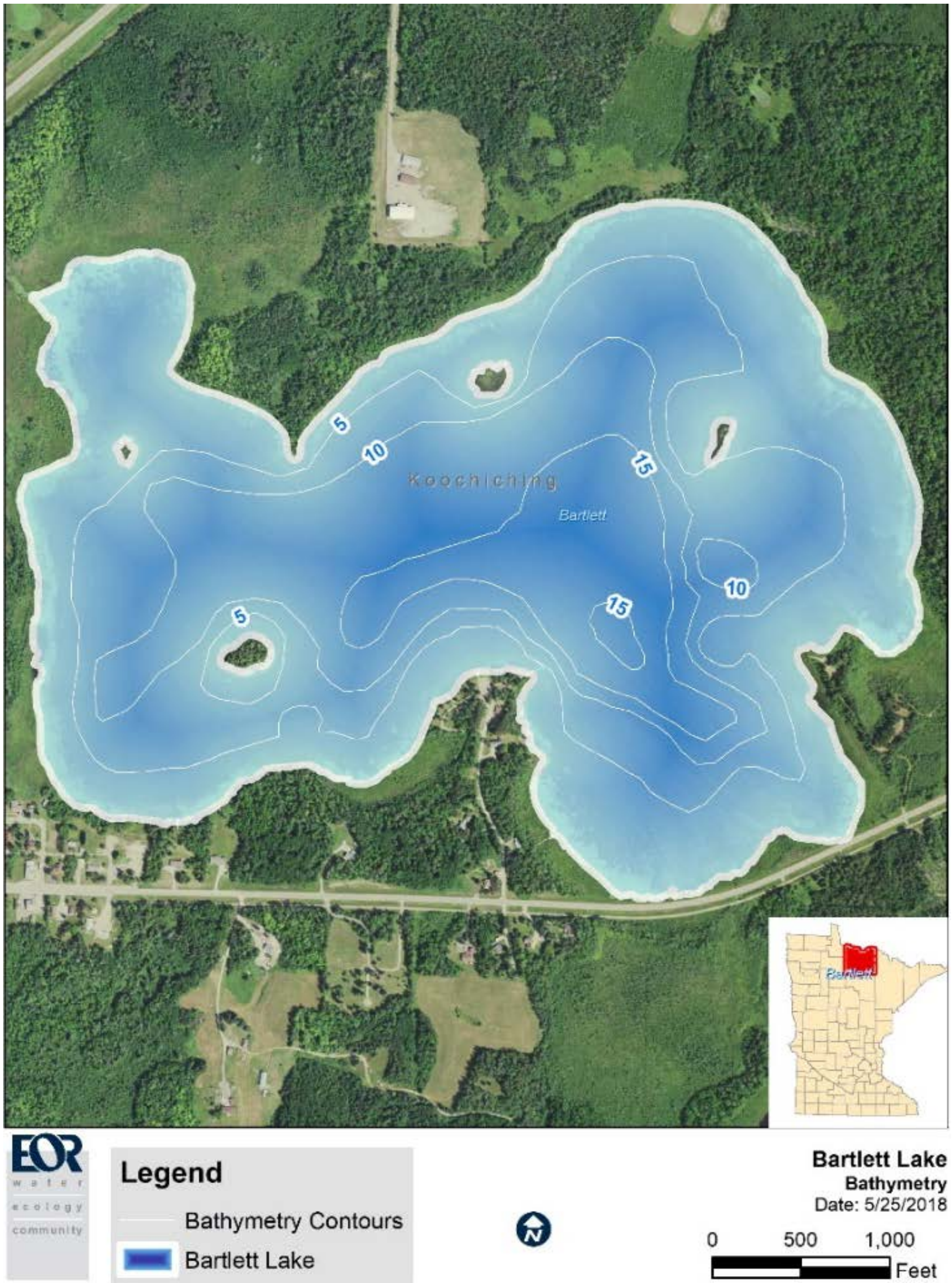


Figure 5. Bartlett Lake bathymetry (water depth) contours

2.1. Aquatic Plant Survey Results

The Minnesota Biological Survey (MBS) conducted an aquatic plant survey on August 21, 2014 on Bartlett Lake. Water clarity during the time of the survey was noted as poor with dark, iron-colored water. The predominant substrates observed were sand and gravel in the main lake with silt and fibrous detritus in bays. Overall, the shoreline was noted as being mostly intact, heavily wooded, with areas of marsh and meadow.

From the MBS 2014 aquatic plant survey data, EOR calculated a Floristic Quality Index (FQI) which was used to measure the diversity and health of the aquatic plant community. The FQI calculation is based on both the quantity of species observed (species richness) as well as the quality of each individual species. Every aquatic plant in the state of Minnesota has been assigned a coefficient of conservatism value (c-value) ranging from 0 to 10. The c-value of all aquatic plants sampled from a lake is used to determine the FQI for a given lake. Species with a c-value of 0 include non-native species such as curly-leaf pondweed (*Potamogeton crispus*) that are indicative of a highly disturbed environment. In comparison, the native species Oakes pondweed (*Potamogeton oakesainus*) has a c-value of 10 because this species is extremely rare and only found in undisturbed, pristine environments.

The results of the Bartlett Lake survey are summarized in Table 1. Included in the table is a list of aquatic plants sampled and their associated c-values. Several species with a c-value of 7 or higher were observed; species with a c-value of 7 or higher are typically correlated with healthy, undisturbed, aquatic plant communities. A healthy, native aquatic plant community represents an important resilience mechanism for deterring the establishment of introduced invasive species such as curly-leaf pondweed and Eurasian watermilfoil. Invasive species are more likely to become established in areas left open by the absence of a healthy, native aquatic plant community.

The average FQI score for Minnesota Lakes is 23.7±8 with a median of 25.2 (Radomski and Perleberg, 2012). The average FQI score for the lakes in the Northern Lakes and Forest (NLF) ecoregion is 28.5±6. The FQI score of 30.0 for Bartlett Lake is reflective of the high quality nature of the aquatic plant community which currently contains no invasive species. The Minnesota DNR recently conducted a review of plant surveys conducted on 3,254 lakes across the state. They concluded that the presence of water marigold (*Bidens beckii*) was a good indicator of a highly diverse aquatic plant community. The presence of water marigold in Bartlett Lake provides additional evidence to suggest that the aquatic plant community is diverse and healthy.

Table 1. Bartlett Lake August 2014 aquatic plant species and Floristic Quality Index c-values

Common Name	Scientific Name	C-Value
Blunt-tipped Sago Pondweed	*Stuckenia filiformis*	8
Bushy Pondweed, Common naiad	*Najas flexilis*	6
Canada waterweed	*Elodea canadensis*	4
Clasping-leaf pondweed	*Potamogeton richardsonii*	5
Crested arrowhead	*Sagittaria cristata*	8
Flatstem pondweed	*Potamogeton zosteriformis*	6
Floating-leaf arrowhead	*Sagittaria cuneata*	6
Floating-leaf pondweed	*Potamogeton natans*	5
Fries pondweed	*Potamogeton friesii*	8
Giant bur-reed	*Sparganium eurycarpum*	5
Hard-stem bulrush	*Schoenoplectus acutus var. acutus*	6
Narrow-leaved cat-tail	*Typha angustifolia*	0
Northern watermilfoil	*Myriophyllum exalbescens*	7
Sago pondweed	*Stuckenia pectinata*	3
Sessile-fruited arrowhead	*Sagittaria rigida*	7
Small Spikerush	*Eleocharis palustris*	5
Variable pondweed	*Potamogeton gramineus*	7
Very Small Pondweed	*Potamogeton pusillus*	7
Water horsetail	*Equisetum fluviatile*	7
Water marigold	*Bidens beckii*	8
Water stargrass	*Heteranthera dubia*	6
White water lily	*Nymphaea odorata*	6
Wild rice	*Zizania palustris*	8
Yellow pond lily	*Nuphar lutea ssp. pumila*	9
Summary Table	**Average C-Value**	6.125
FQI = C*√S	**Number of species**	24
C= Mean coefficient of conservatism value S= Number of species in sample	**FQI**	**30.0**

2.2. Fisheries Survey Results

The DNR has conducted several fisheries assessments of Bartlett Lake dating back to 1946. A comparison of the total biomass of species sampled within Bartlett Lake from 1986 to 2016 is provided in Table 1. As a general rule of thumb, the desired fish composition for shallow lakes is 30-40% piscivores or gamefish (Benndorf 1990).

Results from fisheries surveys conducted in 2007 and 2016 (post-winterkill events in 2004 and 2014) found healthy populations of quality-sized, desirable gamefish species including northern pike, yellow perch, and black crappie. The percentage of piscivore (northern pike) biomass to overall biomass was also highest in the years following winterkill events, indicating northern pike may have been providing top-down (predatory) control over other fish in these years.

While growth rates of desirable gamefish species are exceptional in Bartlett Lake, periodic winterkills have occasionally led to an unbalanced fishery dominated by tolerant species, specifically black bullhead. Black bullheads can tolerate high turbidity, low dissolved oxygen, and a range of temperature conditions that are lethal to most desirable gamefish species. Fisheries population surveys from 1986, 2000, and 2012 are examples of periods of time when the lake's fishery was unbalanced.

Results from the most recent (2016) fishery survey are especially encouraging with northern pike already averaging 4 pounds just two-years after a 2014 winterkill event. Several yellow perch were also captured that survived the 2014 winterkill event, including one individual that exceeded 12 inches. Similarly, northern pike stocked in 2004 and 2005 reached an average weight of 3.56 pounds by 2007, with individuals ranging from 18 to 28 inches in length following a 2004 winterkill event. Black crappie also showed good growth rates with individuals exceeding 8 inches in length by year 2. Black crappie were introduced in 2004. Since their introduction, observed growth rates have been some of the highest on record for the DNR Fisheries International Falls Management Area. Note that the 2007 and 2016 surveys were conducted following winterkill events in 2004 and 2014. Piscivore biomass was highest during these years which followed the change in the focus of fisheries management on Bartlett Lake in 2004.

Table 2. DNR Fisheries Surveys Results 1986-2016

Survey Year	Fish Species	Fish Count	Average Weight per Fish (lbs)	Total Biomass (lbs)	% Piscivorous
1986	Northern Pike	7	1.79	12.5	**20.9%**
	Yellow Perch	106	0.1	10.6	
	Brown Bullhead	99	0.37	36.6	
2000	Northern Pike	1	1.52	1.5	**0.8%**
	Yellow Perch	1,746	0.1	174.6	
	Brown Bullhead	39	0.15	5.9	
	Black bullhead	43	0.18	7.7	

Survey Year	Fish Species	Fish Count	Average Weight per Fish (lbs)	Total Biomass (lbs)	% Piscivorous
2007	Northern Pike	40	3.75	150	38.6%
	Yellow Perch	423	0.15	63.5	
	Black Crappie	343	0.16	54.9	
	Brown Bullhead	89	0.45	40.1	
	Black bullhead	1,143	0.07	80.0	
2012	Northern Pike	45	2.0	90	15.4%
	Yellow Perch	234	0.25	58.5	
	Black Crappie	117	0.65	76.1	
	Brown Bullhead	3	0.69	2.1	
	Black bullhead	1,022	0.35	357.7	
2016	Northern Pike	18	3.5	63	38.7%
	Yellow Perch	82	0.10	8.2	
	Black Crappie	409	0.15	61.4	
	Black bullhead	602	0.05	30.1	

Green shading = Piscivorous species (Feed on fish)

Yellow shading = Omnivorous species (Feed on plankton, insects, and crustaceans)

Brown shading = Rough fish (Omnivorous bottom feeders)

3. IN-LAKE MANAGEMENT RECOMMENDATIONS

To maintain a stable, clear water state in Bartlett Lake, the amount of algae must be controlled through either reduction in phosphorus loading (Figure 2) or management of the biological community (Figure 3). In-lake summer average phosphorus concentrations in the mid 1970's were 100-150 µg/L and have slowly been declining; recent in-lake summer average phosphorus concentrations are just exceeding state standards (30-40 ppb). The most recent DNR standard fish survey was completed on July 11, 2016. At this time, DNR noted that Bartlett Lake is a highly productive lake with a history of frequent winterkill events. But between winterkill events, Bartlett is capable of quickly rebounding to provide fish that are of interest to anglers.

Given the heavy aquatic vegetation, the success of the Northern Pike and Black Crappie fishery following the 2014 winterkill, and the current in-lake phosphorus concentrations near state standards, Bartlett Lake appears to currently be in a clear-water state. However, given the long history of historic phosphorus loading to Bartlett Lake from city sewer and a creamery, the stability of the clear-water state is likely weak. Therefore, at this time, EOR recommends management of the in-lake biological community of Bartlett Lake to support and maintain a clear-water state characterized by low algae, dense aquatic vegetation, and a healthy game fish population.

A summary of in-lake management alternatives, benefits, considerations, and applicability to Bartlett Lake are included in Table 1. In-lake management alternatives recommended for Bartlett Lake are described in more detail below, with a proposed implementation schedule and cost provided in Table 2.

3.1. Mechanical Harvesting of Aquatic Plants

Native aquatic plant biomass typically peaks in July during a period of time when average nutrient concentrations found in aquatic plants are also high. Small amounts of localized mechanical harvesting conducted during the month of July would have a high likelihood for removing a large pool of phosphorus from Bartlett Lake. Mechanical harvesting will not completely offset contributions from internal sources but may help to reduce the means by which the decay of senescing aquatic plants contributes to the internal phosphorus load of Bartlett Lake. Furthermore, mechanical harvesting will increase the usability of Bartlett Lake by providing boaters with easier access to the deeper, open water portions of the lake.

Typical costs for privately contracted mechanical harvesters in Minnesota range from $300 - $600 per acre. A point-intercept aquatic plant survey complete with estimates of aquatic plant biomass at each sampling location should be conducted prior to the survey to prioritize locations for harvesting. Rather than clear-cutting entire weed flats, mechanical harvesting can be used to cut paths within large weed flats which create "edge habitats" that support popular game fish species, including northern pike (Trebitz et. al., 1997). It is important to only cut small amounts of aquatic plants to maintain establishment of aquatic plants throughout the lake and promote clear water conditions.

Aquatic Plant Management Options and Permitting Requirements

Submerged aquatic plants are very important for lake water quality and fish communities. Therefore, DNR has set up conditions for the treatment or removal of aquatic plants. Any aquatic plant harvesting or removal should be done with great care and to the minimum amount practicable.

Treatment options that do not require a Permit:

The DNR has established thresholds for the physical removal of aquatic vegetation which allow lakeshore owners to create or maintain a swimming or boat docking area without a DNR permit under certain conditions. A DNR permit is not needed for the following physical removal activities:

- First, the clearing or removal of **submerged** vegetation up to 2,500 square feet
    - The 2,500 square foot area may also include a boat channel up to 15 feet wide, and as long as necessary to reach open water (the boat channel is in addition to the 2,500 square feet allowed). The cutting or pulling may be done by hand or with hand-operated or powered equipment that does not significantly alter the course, current, or cross-section of the lake bottom.
- Second, the cleared areas must not extend more than 50 feet along the property owner's shoreline or one-half the length of the property owner's shoreline, whichever is less.

Treatment options that require a Permit

- Destruction of any **emergent** vegetation (cattails, bulrushes, etc.)
- Physical removal involving an area exceeding 2,500 square feet
- Applying herbicides or algaecides
- Moving or removing a bog of any size
- Transplanting aquatic plants
- Use of automated aquatic plant control devices.

3.2. DNR Fisheries Management

A Ramco Bubbler aeration system with two, 5-horsepower motors installed in 1985 was not able to maintain sufficient dissolved oxygen concentrations in Bartlett Lake and a substantial winterkill event of stocked walleye was noted while the aerator was in operation (DNR 2017, pers. comm.). The DNR changed the focus of fisheries management on Bartlett Lake in 2004 following a comprehensive planning effort that involved local stakeholders from the City of Northome and the Koochiching County Environmental Services Department. The fisheries management plan now focuses on stocking northern pike and black crappie which are more tolerant of low dissolved oxygen concentrations.

Shallow, productive lakes like Bartlett Lake that contain piscivorous fish species that experience rapid growth rates following winterkill events are known as "boom or bust" fisheries. Stocked gamefish are able to grow rapidly following a winterkill since there are no other piscivores to compete with for forage. At times, these boom and bust fisheries can provide outstanding angling opportunities if environmental conditions are right, such as a period of 2-3 mild winters with reduced snow and ice cover. Results from the post-winterkill fishery surveys conducted in 2007 and 2016 suggest that the current fisheries management approach (boom or bust fishery) is working with outstanding growth rates observed for northern pike, yellow perch, and black crappie. The success of the boom or bust fishery in promoting a clear water state in Bartlett Lake is also evident in the recent low in-lake phosphorus concentrations and clear water.

The DNR has established the following long-range goals for Bartlett Lake:

- Maintain a black crappie and northern pike fishery between winterkill events to provide angling opportunities for the public.
- Black crappie trap net catch rates should be greater than 3.5 fish per set.
- Northern pike gill net catch rates should be between 3 and 8.3 fish per set with mean length at age 4 greater than the International Falls Management Area mean of 23.3 inches.
- Consider stocking largemouth bass to provide additional top-down control over black bullheads.

To meet these long-term goals, the DNR has established an operational plan which begins with checking dissolved oxygen concentrations annually at approximately March 1st to determine if winterkill is likely. If winterkill is suspected, the DNR will set 6 trap nets after ice-out to determine the extent of winterkill. If the trap net catch per unit effort (CPUE) is below 2.0 black crappie per net, 200 mature, black crappie will be stocked for two consecutive years. If trap net CPUE for northern pike is below 3.0 fish per gill-net, the DNR will stock 300 adult northern pike every other year. The northern pike stocking quota is based on a population goal of 0.8 northern pike >24 inches per acre as recommended by DNR Fisheries Research Biologist Rod Pierce. Associated costs for stocking are covered by the International Falls Management Area budget and/or statewide resources because stocking is called out in the approved lake management plan for Bartlett Lake.

We recommend support of DNR's fisheries management approach.

3.3. Landowner Education

In addition, we recommend informing landowners about aquatic plant regulations and the importance of aquatic plants to lake water quality. Often landowners perceive heavy 'weed' growth as indicators of poor water quality, but maintaining the existing submerged aquatic vegetation is critical for supporting a clear-water state in Bartlett Lake.

3.4. Monitoring

Because shallow lake management can sometimes be unpredictable, we recommend additional water quality monitoring and evaluation of the in-lake biological community to determine if and when further management activities are needed. Very little phosphorus and chlorophyll-a (algae) data has been collected in Bartlett Lake (1976-1978 and 2014-2015). To better understand the response of Bartlett Lake to shifts in the biological community (such as before and after a winterkill) we recommend collecting twice monthly water quality samples for phosphorus, chlorophyll-a and Secchi depth transparency in May through September and a point-intercept aquatic vegetation survey every other year. DNR will be conducting fisheries surveys once every five years.

Table 3. In-Lake Management Alternatives: Benefits, Description, Considerations and Applicability to Bartlett Lake

In-lake Management Alternative Benefits	Description	Considerations	Applicable to Bartlett Lake?
Whole-lake Drawdown • Reduce sediment phosphorus loading • Increase water clarity • Re-establish submerged aquatic vegetation • Fish kill	A whole-lake drawdown is the process of passively or actively removing all water in a lake and exposing the entire lake bottom to the air to: a) oxidize and consolidate sediment, b) freeze curlyleaf pondweed turions if present, c) kill all fish, and d) promote re-germination of native plant species. This activity simultaneously achieves all shallow lake key functions.	Lake aesthetics may be moderately impacted, and consideration must be given to downstream discharge of the high phosphorus lake water. An outlet structure system and a downstream resource capable of receiving the drawdown water are needed. Best in fall/winter when runoff low.	**No.** No outlet structure nor downstream resource capable of receiving the drawdown water.
Sediment Alum Treatment • Reduce sediment phosphorus loading • Reduce algae blooms • Increase water clarity	The application of aluminum sulfate as a floc layer at the lake sediment/water interface that can bind with phosphorus released from the sediments for an extended period of time. The aluminum sulfate used in alum treatments strongly binds with phosphorus through a chemical reaction under most lake conditions, prohibiting phosphorus release from the sediments into the lake water. Alum will also strip phosphorus from the water column as it is applied, resulting in immediate improvements in water clarity and algae. When applied at an appropriate dose, alum will prevent internal recycling of phosphorus over 5-10 years.	Usually applied with a buffer, to maintain appropriate lake pH levels. Requires lake access for application pontoons or barges. There are a finite number of alum binding sites in each alum treatment that are used over time as phosphorus is slowly released by the lake sediments. Therefore, additional alum treatments are needed to replenish the amount of available alum binding sites for sediment phosphorus. Best in late fall or early spring, when aquatic plant growth is minimal and water temperatures are above 40 degrees F. Treatment longevity averages 5.7 years in shallow lakes and 21 years in deeper, stratified lakes (Hanson et al. 2017).	**No.** Internal load 75% of total phosphorus load to lake, but heavy aquatic vegetation would interfere with treatment. High cost and short longevity in large, shallow lakes.

In-lake Management Alternative Benefits	Description	Considerations	Applicable to Bartlett Lake?
Sediment Iron Filings • Reduce sediment phosphorus loading	Recent research at the University of Minnesota on lake sediment cores suggests that the application of zero-valent iron metal filings to lake sediments may be a potential phosphorus reduction tool.	The weight of the amount of iron filings needed to treat a large lake may currently be impractical. Few large scale treatments have been completed to test the effectiveness of iron filings to reduce internal phosphorus load at the lake scale.	**No.** Currently cost prohibitive and relatively untested. May be a consideration as a future follow-up treatment.
Sediment Dredging • Reduce sediment phosphorus loading • Increase lake depths	Dredging permanently removes phosphorus laden sediments and increases lake depths.	Disposal of dredge sediment is a difficult/expensive effort due to the water content and weight of the material. Large, nearby drying areas are needed to reduce the water content of the sediment prior to disposal. Dredging will also remove the seedbank within the lake, destroy in-lake habitat and temporarily increase lake turbidity.	**No.** Cost prohibitive and destructive. Accumulated sediment evenly distributed throughout lake.
Algaecides • Reduce algae blooms • Increase water clarity	Temporary chemical treatment of algae to reduce an algae bloom.	Requires regular monitoring throughout the season, and multiple treatments on an as-needed basis. Reactive approach and does not solve root of water quality problem, just a temporary treatment of the symptom.	**No.** Temporary aesthetic treatment.
Hypolimnetic Aeration • Reduce sediment phosphorus loading • Reduce algae blooms • Increase water clarity	Add air to bottom waters (hypolimnion). Goal is to ensure that bottom waters are oxygenated so that phosphorus is not released from sediment. Appropriate for lakes with high sediment internal load that would benefit from oxic bottom waters.	Requires electricity and ongoing maintenance. For lakes with undesired winter fish kill, can also be used in winter to prevent fish kill. Most applicable to deep lake bottom waters, or to very small treatment ponds.	**No.** Lake too large and shallow. Lake does not strongly stratify.

In-lake Management Alternative Benefits	Description	Considerations	Applicable to Bartlett Lake?
Mechanical Harvesting • Manage aquatic invasive plants & heavy plant growth	Cutting and removal of aquatic vegetation. Goal is to remove vegetation from the water to eliminate it as a source of nutrients as the vegetation degrades, and encourage growth of native plants.	Ongoing harvesting needed, minimize harvesting only to areas needed to provide recreational access to the lake.	**Yes.** Can reduce dense mats, enhance recreational value, and remove source of nutrients to the lake.
Herbicides • Manage aquatic invasive plants	Application of chemical herbicides to the littoral area of the lake. Goal is to kill aquatic vegetation to eliminate it as a source of nutrients. Endothall is often used for curly-leaf pondweed control.	Properly applied herbicides generally have little effect on overall native aquatic plants, though can change species abundance. Multiple years of treatment are needed to manage plant growth. Will not eradicate plants. Best in late spring when CLP growing.	**No.** No aquatic invasive plant species present.
Fish Kill • Manage biological community • Reduce algae blooms • Increase water clarity	Kill fish population using pesticide. Goal is to eliminate an unbalanced fish population in order to re-establish a healthy fish population. Allows lake to be "restarted" with fully defined new fish population. Treatment has been able to shift shallow systems to clear water state for a period of time (many years).	Kills all fish, but not usually black bullheads or carp. May also kill zooplankton. May limit use of lake as habitat for wildlife because of lack of available food (fish). Need to rotenone entire watershed to be most effective, or conduct regular treatments. Best in winter when oxygen concentrations are lowest.	**No.** Can support Northern Pike. Manage lake for game fish control of algae.
Fish Stocking • Manage biological community • Reduce algae blooms • Increase water clarity	Alteration of fish population structure. Goal is to alter fish population structure so that fewer planktivorous fish are present, leaving the zooplankton present to reduce the algae population.	May not be effective if high internal load from sediment still present. May take a long time to see full effect of biomanipulation efforts. Best in early spring to allow juvenile fish to grow during warmer summer months.	**Yes.** Can support game fish. Manage lake for boom or bust fishery.

In-lake Management Alternative Benefits	Description	Considerations	Applicable to Bartlett Lake?
Winter Aeration • Prevent winterkill	Maintain a small plume of high oxygen water in the lake. Goal is to eliminate winter fish kills. Increases oxygen to maintain game fish species with minimal energy consumption. Takes away competitive advantage of bullheads and carp under low oxygen conditions.	Requires electricity and ongoing maintenance. Must obtain a permit to install and fence off aerated lake area. Best to begin aeration soon after ice over.	**No.** Past winter aeration systems installed by DNR unable to prevent winterkills. Utilize occurrence of winterkills to promote a boom or bust fishery.

Table 4. Recommended Implementation Schedule and Budget

In-lake Management Activity	Partners	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Mechanical harvesting	DNR		$5,000		$5,000		$5,000		$5,000		$5,000
Aquatic vegetation point-intercept survey			$5,000		X		$5,000		$5,000		$5,000
DNR fisheries standard survey, aquatic vegetation sampling, and lake management plan update	DNR Fisheries - International Fall				X						
Landowner education	Koochiching SWCD	X	X				X	X			
Lake water quality monitoring	Red Lake DNR	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000
TOTAL		**$3,000**	**$13,000**	**$3,000**	**$8,000**	**$3,000**	**$13,000**	**$3,000**	**$13,000**	**$3,000**	**$13,000**

APPENDIX A. REFERENCES CITED

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