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Snake River Watershed Restoration and Protection Project

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CLEAN
WATER
LAND &
LEGACY
AMENDMENT

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Monitoring	Progress of TMDL implementation will be measured through regular monitoring efforts of water quality and total BMPs completed. This will be accomplished through the efforts of several cooperating agencies and groups. *See Section 8.0*	P. 8-1
Implementation	This report sets forth an implementation framework to achieve the TMDL. (A separate more detailed implementation plan will be developed within one year after of EPA's approval of this TMDL report.) *See Section 6.0*	P. 6-1
Public Participation	*See Section 9.0* Public Comment Period: Comments received:	P. 9-1

Acronyms

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

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

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

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses eight impairments in the Snake River watershed, which is an 8 digit Hydrologic Unit (HUC) located in the St Croix River Basin. It includes nutrient impairments in Knife, Quamba, Pokegama and Cross Lakes; *E. coli* impairments for Upper and Lower Mud Creek and Bear Creek; and fish and macroinvertebrate biotic integrity impairments for Upper Mud Creek. The Snake River Watershed covers approximately 1,006 square miles or 643,534 acres and overlies six counties including Aitkin, Kanabec, Mille Lacs, Pine, Chisago and Isanti. The headwaters of the Snake River are located in southeastern Aitkin County. The Snake River flows south to east to its confluence with the St. Croix River in Pine County, MN. The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for nutrients in the lakes, E. coli standards for the three impaired stream reaches, and State Index of Biotic Integrity standards in Upper Mud Creek. This TMDL is established in accordance with Section 303(d) of the Clean Water Act and provides wasteload allocations (WLAs) and load allocations (LAs) for the Snake River Watershed.

Lakes

Pokegama and Cross Lakes are defined as deep lakes for which the North Central Hardwood Forest ecoregion numeric water quality standards are: a summer average total phosphorus concentration of 40 µg/L or less; 14 µg/L chlorophyll-a or less;, and greater than 1.4 meter Secchi depth. Knife and Quamba Lakes are shallow, for which the numeric water quality standards are: a summer average total phosphorus concentration of 60 µg/L or less; 20 µg/L chlorophyll-a or less; and greater than one meter Secchi depth.

Nutrient budgets were developed for all four lakes along with lake response models to set the TMDL and LAs and WLAs. A robust lake and stream monitoring dataset was available and was the basis of the nutrient budget calculations. Total nutrient reductions ranging from 25% to 73% will be necessary to meet state water quality standards. Nutrient reduction implementation strategies for the four lakes should focus on watershed and internal nutrient load reductions and failing septic system upgrades.

Bacteria

Flow and bacteria monitoring data recorded in Upper Mud Creek, Lower Mud Creek and Bear Creek were used to establish load duration curves meeting the *E. coli* numeric standard of no more than 126 organisms per 100 ml as a geometric mean of not less than five samples representative of conditions within any calendar month, nor more than 10% of all samples taken during any calendar month individually exceed 1,260 organisms per 100 ml. A TMDL, WLAs, and LAs were established for five flow categories: very high flow, high flow, mid-range flow, low flow and dry flow conditions. Bacteria reductions ranging from no reduction to 72% during certain flow regimes will be necessary to meet *E. coli* concentration standards. Implementation activities for the *E. coli* impaired reach watersheds should focus on manure and pasture management initiatives during high flows, and limiting cattle access to streams and septic system upgrades during low flow conditions.

Fish and Macroinvertebrates

The MPCA has developed an Index of Biotic Integrity (IBI) to evaluate the biological health of streams in the State. Currently, an IBI has been developed for two biological communities, fish and macroinvertebrates. Upper Mud Creek is impaired based on both fish IBI (F-IBI) and the macroinvertebrate IBI (M-IBI). The fish impairment is not severe, with sites scoring at the fish IBI standard for Northern Headwaters Streams, however the fish assemblage is somewhat degraded compared to other, higher quality sites. One of two sites assessed on Upper Mud Creek scored well below the Northern Forest Streams Glide-Pool macroinvertebrate IBI standard, exhibiting an abundance of tolerant species and species that are indicative of nutrient enrichment.

A Stressor Identification Report was completed by the MPCA in 2012 using the USEPA's Causal Analysis/Diagnosis Decision Information System (CADDIS), which is a methodology for conducting a stepwise analysis of candidate causes of impairment using a "strength of evidence" approach to evaluate candidate causes affecting biotic integrity. Five candidate causes were identified in the Stressor ID – bedded sediment, low dissolved oxygen, riparian habitat degradation, loss of connectivity due to ditching, altered flow due to ditching. The evidence is strongest that lack of benthic habitat due to sedimentation is the primary stressor to aquatic life in Upper Mud Creek. Impacts from riparian degradation and persistent low dissolved oxygen are important co-stressors. The loss of connectivity and altered hydrology due to extensive ditching in the watershed and on the creek itself are plausible stressors and are likely contributing to the impairment, however there is less direct or conflicting evidence of their role.

Further assessment identified stream bank erosion as a primary source of excess sediment. Streambank instability is affected by the type of vegetation maintained in the degraded riparian zone – primarily short pasture grasses. Animals generally enjoy unrestricted access to the stream, which has resulted in stream bank failures and bare or sparsely vegetated banks and riparian area. Occasions of low dissolved oxygen concentrations are likely the result of excessive stream warming due to a lack of tree canopy, lack of reaeration capacity, and nutrient enrichment.

Restoration of eroded streambanks to reduce sediment contribution and restoring native streambank vegetation to stabilize banks would have the greatest impact on improving benthic habitat. Planting wide native buffers and reestablishing a canopy cover should also be completed to reduce nutrient enrichment, decrease stream temperature, and increase dissolved oxygen.

1.0 Introduction

1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses four lake nutrient impairments, three *E. coli* impairments and one fish and macroinvertebrate biotic integrity in the Snake River watershed. The impaired water bodies are located throughout the Snake River watershed as shown in Figure 1-1. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients, *E. coli* and State Index of Biotic Integrity standards in the Ann River. These TMDLs are established in accordance with Section 303(d) of the Clean Water Act and provides wasteload allocations (WLAs) and load allocations (LAs) for the Snake River Watershed impairments.

1.2 PROBLEM IDENTIFICATION

The lakes addressed in this study were first placed on the State of Minnesota's 303(d) list of impaired waters for nutrient (total phosphorus) impairment in 2010 (Table 1-1). The *E. coli* impaired reaches and the fish and macroinvertebrate reach were also placed on the 303(d) list in 2010.

Table 1-1. Waters in the Snake River watershed listed on the MPCA draft 2012 303(d) list of impaired waters covered in this TMDL.

Water Body	Yr Listed	Assessment Unit ID	Affected use	Pollutant or stressor	Target Start // completion
Mud Creek – Headwaters to Quamba Lake	2010	07030004-566	Aquatic life	Fish Bio assessment	2010//2015
Mud Creek – Headwaters to Quamba Lake	NA	07030004-566	Aquatic recreation	*E. coli*	2010//2015
Mud Creek – Quamba Lake to Snake River	2010	07030004-567	Aquatic recreation	*E. coli*	2010//2015
Bear Creek – Headwaters to Snake River	2010	07030004-514	Aquatic recreation	*E. coli*	2010//2015
Knife Lake	2010	33-0028	Aquatic recreation	Excess Nutrients	2010//2015
Quamba Lake	2010	33-0015	Aquatic recreation	Excess Nutrients	2010//2015
Pokegama Lake	2010	58-0142	Aquatic Recreation	Excess Nutrients	2010//2015
Cross Lake	2010	58-0119	Aquatic Recreation	Excess Nutrients	2010//2015

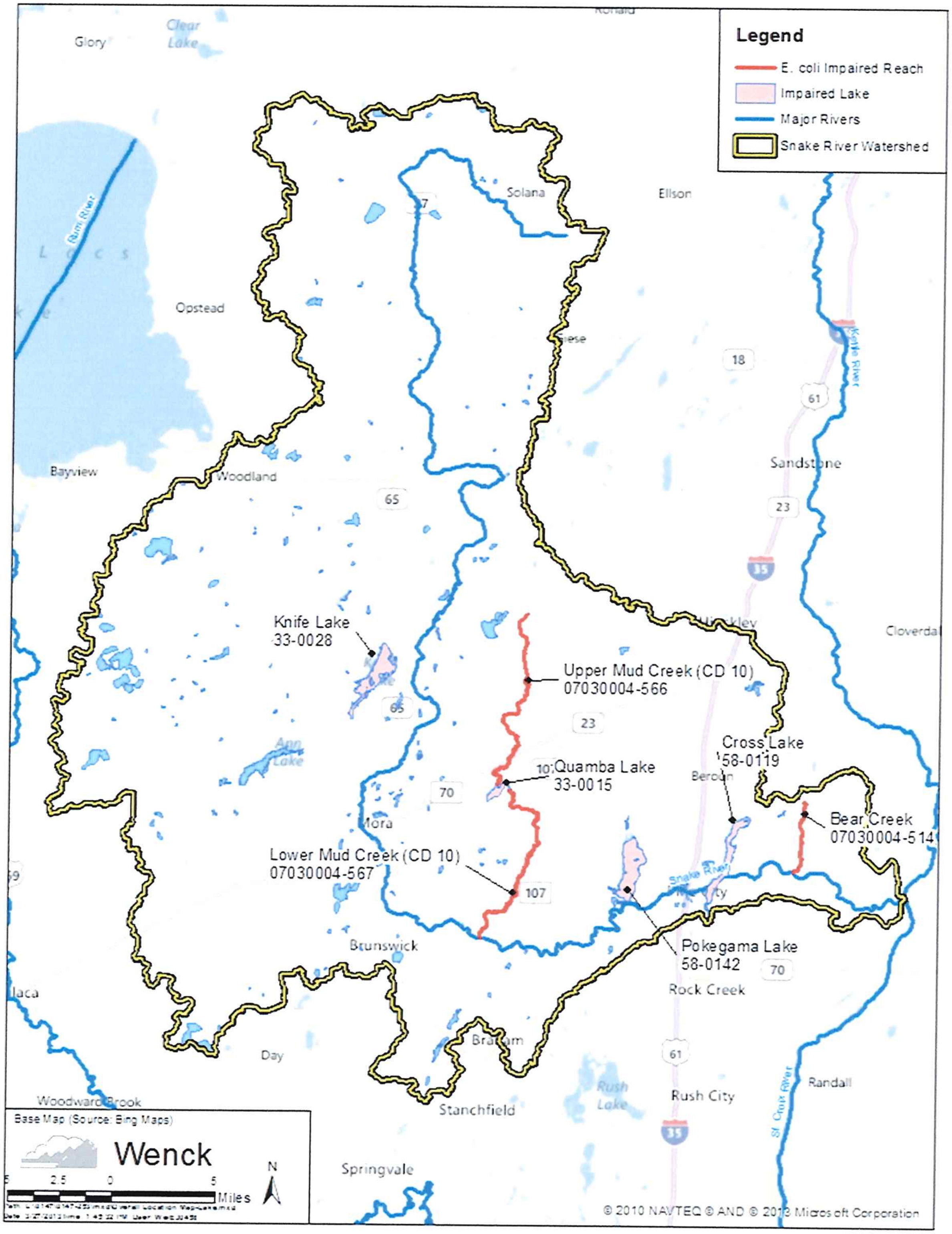


Figure 1.1. Impaired waters in the Snake River watershed.

1.3 IMPAIRED WATERS AND MINNESOTA WATER QUALITY STANDARDS

1.3.1 State of Minnesota Designated Uses

Knife Lake, Quamba Lake, Pokegama Lake, Cross Lake, Bear Creek and Upper and Lower Mud Creeks are all classified as class 2B waters for which aquatic life and recreation are the protected beneficial uses. The MPCA's projected schedule for TMDL completions on the 303(d) impaired waters list implicitly reflects Minnesota's priority ranking of this TMDL, which was scheduled to be initiated in 2010 and completed by 2015. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the water body; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

1.3.2 State of Minnesota Standards and Criteria for Listing

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

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

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

"*E. coli* concentrations are not to exceed 126 colony forming units per 100 milliliters (cfu/100 ml) as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 cfu/100 ml. The standard applies only between April 1 and October 31."

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

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

Nutrients. Minnesota's standards for nutrients limit the quantity of nutrients which may enter surface waters. Minnesota's standards at the time of listing (MR 7050.0150(3)) stated that in all Class 2 waters of the State "...there shall be no material increase in undesirable slime growths or aquatic plants including algae." In accordance with MR 7050.0150(5), to evaluate whether a water body is in an impaired condition the MPCA developed "numeric translators" for the narrative standard for purposes of determining which lakes should be included in the section 303(d) list as being impaired for nutrients. The numeric standards for shallow and deep lakes, adopted in 2008, established numeric thresholds for phosphorus and response variables chlorophyll-a and clarity as measured by Secchi depth (Table 1-2). Regression equations developed by the MPCA (2005) suggest that the two response variables, Secchi depth and chlorophyll-a, should also meet state standards when the necessary phosphorus reductions are made.

Table 1-2. Trophic status thresholds for determination of use support for lakes.

Ecoregion – Lake Type	Numeric Standards		
	303(d) Designation		
	TP (ppb)	Chl-a (ppb)	Secchi (m)
North Central Hardwood Forests (Deep Lake)	< 40	< 14	> 1.4
North Central Hardwood Forests (Shallow Lake[1])	≤60	≤20	≥1.0

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

1.4 ANALYSIS OF IMPAIRMENT

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

Biotic Impairment. Table 1-4 shows the Index of Biotic Integrity scores used to evaluate Upper Mud Creek for biotic impairment.

Table 1-3. Index of Biotic Integrity standards and relevant Mud Creek data.

Station ID	Location	Fish IBI		Macroinvertebrate IBI	
		Standard	Score	Standard*	Score
06SC110	Site 3: CR 5	40	40	52.4	40.7
98SC018	Site 7: 225th Street	40	40	52.4	59.2

Note: Fish-IBI used is Northern Headwaters Streams. Invert-IBI is Northern Forest Glide-Pool.

Nutrients. In 2010, Knife, Quamba, Pokegama and Cross Lake were listed for nutrient impairments due to excess total phosphorus. The lakes also did not meet either chlorophyll-a or Secchi depth standards.

E. coli. In 2010, Bear and Lower Mud Creek were listed as impaired for bacteria. Upper Mud Creek is not currently on the 303(d) list. However, recent samplings in Upper Mud Creek in 2010-2011 indicate this reach will likely be listed as impaired for E. coli during the next listing cycle.

2.0 Watershed and Stream Characterization

2.1 SNAKE RIVER WATERSHED DESCRIPTION

The Snake River watershed is an 8 digit Hydrologic Unity (HUC) located in the St. Croix River Basin. The watershed is approximately 1,006 square miles, or 643,534 acres, in extent and overlies four counties including Aitkin, Kanabec, Mille Lacs, and Pine. The headwaters of the Snake River are located in the southeastern Aitkin County. The Snake River watershed can be broken down into 8 sub-watersheds (Figure 2.1), which include: Upper Snake, Middle Snake, Knife River, Mud Creek, Groundhouse River, Pokegama Creek, Ann River and Lower Snake River. The Snake River flows south to east to its confluence with the St. Croix River in Pine County, MN.

2.2 LAND COVER

Land use and land cover in the Snake River watershed has a large variation of cover ranging from agricultural and urban in the south, to largely forest and wetland in the north (Figure 2.2). Land use for the impaired reach watersheds are presented in Tables 2-1 and 2-2 and were calculated using the 2010 National Agricultural Statistics Service (NASS).

Table 2-1. 2010 Land Cover of the *E. coli* impaired reach watersheds.

Land Cover	Percent of Total		
	[1] Upper Mud Creek	[1] Lower Mud Creek	[1]Bear Creek
Watershed area (acres)	20,353	26,389	6,156
Hay/Pasture	35%	36%	38%
Cropland	2%	8%	16%
Forest	31%	24%	28%
Wetland	27%	28%	15%
Urban/Roads	3%	4%	3%
Open Water	2%	1%	0%

[1] Includes only subwatersheds that drain to impaired reach.

Table 2-2. Land Cover of the impaired lake watersheds.

Land Cover	Percent of Total				
	Knife Lake	Quamba Lake	Pokegama Lake	Cross Lake (Snake)	Cross Lake (Direct)
Watershed area (acres)	59,777	24,350	52,146	428,025	8,027
Hay/Pasture	17%	37%	33%	22%	35%
Cropland	1%	2%	2%	6%	8%
Forest	47%	29%	29%	36%	20%
Wetland	28%	26%	30%	31%	16%
Urban/Roads	2%	3%	3%	3%	8%
Open Water	4%	3%	3%	2%	13%

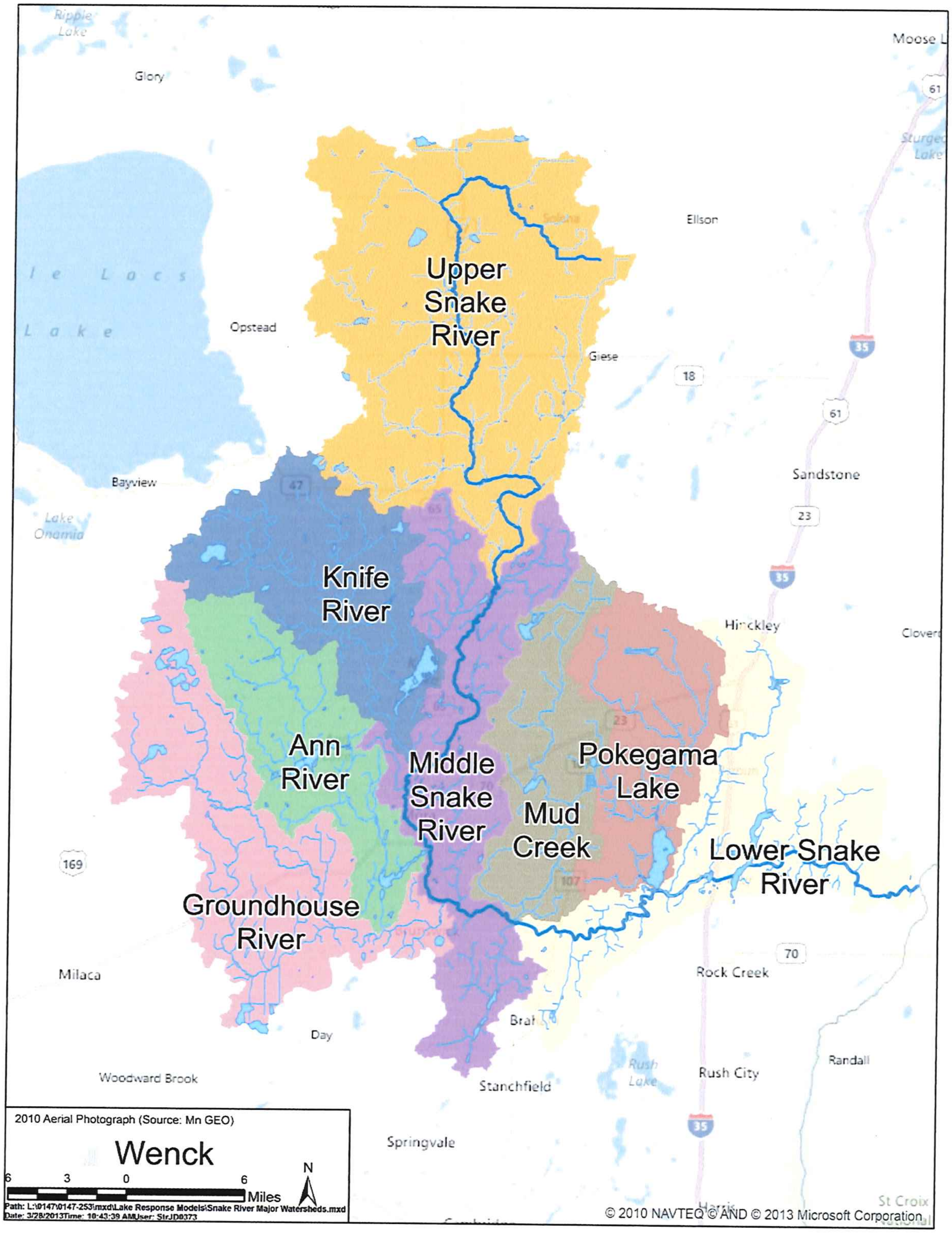


Figure 2.1. Major subwatersheds and drainage pattern in the Snake River watershed.

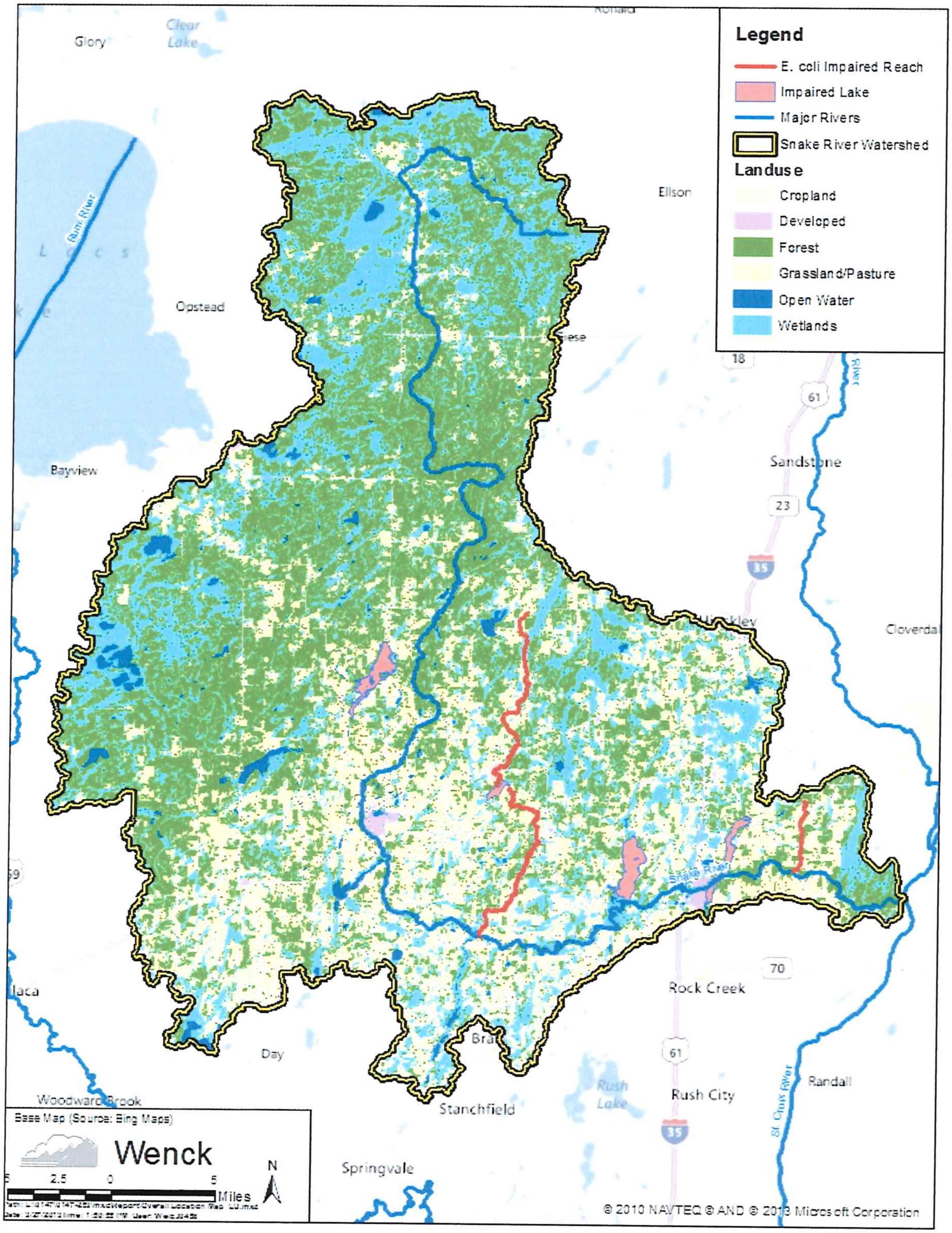


Figure 2.2. Snake River watershed 2010 NASS land cover.

2.3 BIOTIC INTEGRITY IN SNAKE RIVER

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

The impairments were listed on the basis of monitoring conducted in 1996 and 1998 (see Figure 2.3 for monitoring locations.) The fish impairment was designated in 2002 and the macroinvertebrate in 2004. Additional monitoring conducted in 2006-2009 was used to confirm the impairments and prepare a Stressor Identification Study (Stressor ID) in 2012 (Jasperson 2012) for both the fish and macroinvertebrate communities. This TMDL report summarizes the biologic data and IBI results that were evaluated in more detail in that Stressor ID.

While the fish-IBI scores at the two bio monitoring sites on Upper Mud (Site 3 and Site 7, Figure 2.3) were equal to the listing standard for Northern Headwaters Streams, the fish community was found to be dominated by species with high tolerance to habitat degradation and environmental stress. Both sites also scored low on metrics pertaining to lithophilic (gravel-spawning) species and benthic insectivores.

Upper Mud Creek is classified for macroinvertebrate monitoring purposes as a Northern Forest Glide-Pool stream, which typically exhibits a low gradient. Only one of the two biomonitoring sites did not meet the state M-IBI standard – Site 3. The individual metrics indicate the community is dominated by pollution tolerant species with a distinct lack of intolerant species found at other locations on Upper and Lower Mud Creek. The site also was abundant in filter feeders, a trophic trait that often indicates nutrient enrichment and excessive algal production.

2.4 FACTORS INFLUENCING BIOTIC INTEGRITY IN THE SNAKE RIVER

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

Potential candidate causes of the impairments that were ruled out based on a review of available data include: pH; turbidity/TSS; stream temperature; chloride toxicity; pesticides; and heavy metals toxicity. Five stressors that are potential candidate causes were examined in more detail: loss of habitat due to excess deposited and bedded sediment; low dissolved oxygen concentrations; degraded riparian habitat; loss of connectivity and altered flow, both due to ditching in the watershed and on the stream itself. The Mud Creek Stressor Identification Report (Jasperson 2012) is incorporated into this report by reference.

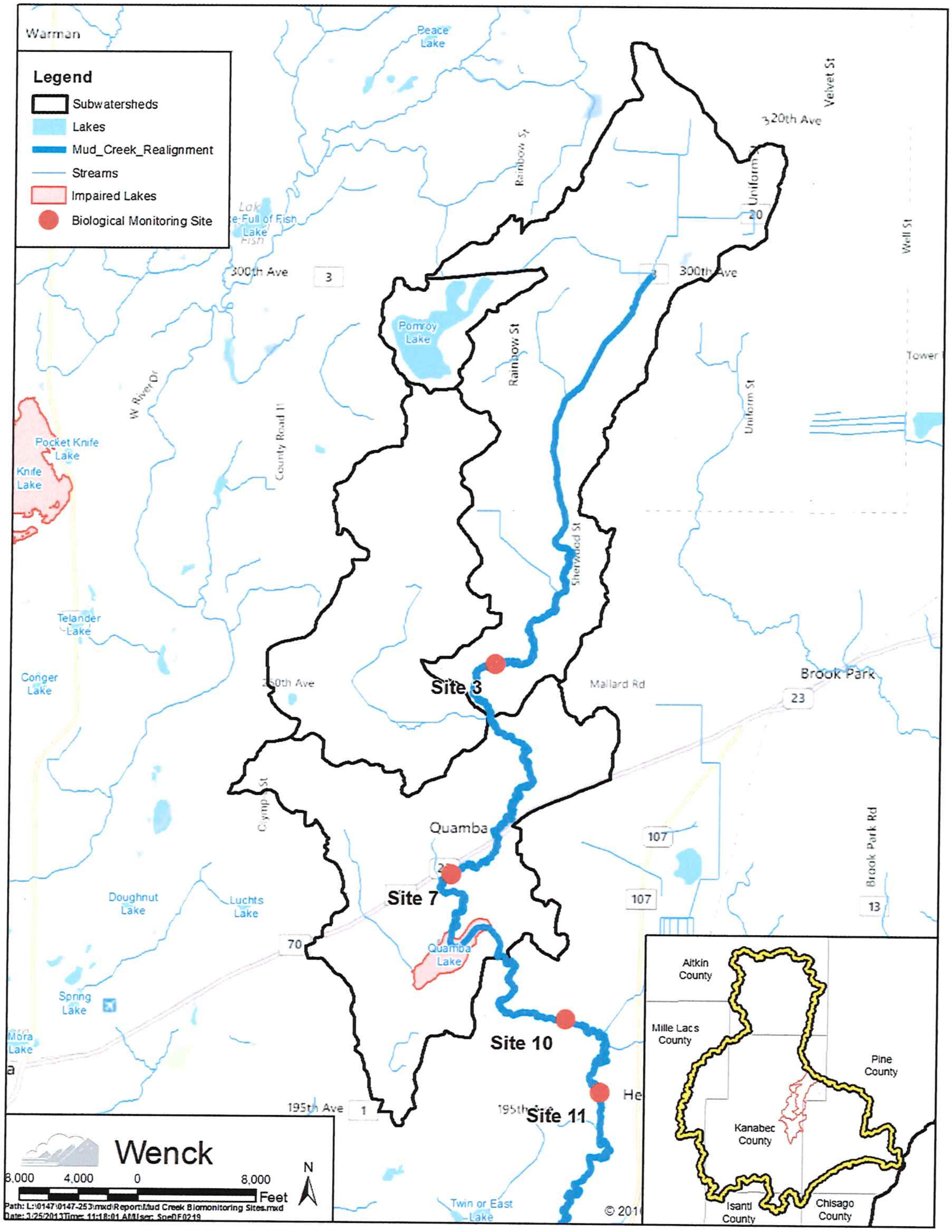


Figure 2.3 Biomonitoring locations from the Stressor Identification Study.

2.4.1 Excess Deposited and Bedded Sediments

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

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

As described in the Stressor ID Report, pebble counts and stream condition assessments found that the stream bottom sediments in Upper Mud Creek were dominated by sand and fine sediments, especially Sites 3 and 6. The Pfankuch Stability Index was used to assess condition and stability of the stream channel. Sites 2, 3, and 6 were rated poor stability, specifically in the metrics relating to scouring and sediment deposition. Agricultural land uses, primarily cattle grazing, are a significant source of sediment delivery in the watershed. Destabilization of stream banks from animal grazing is resulting in segments of destabilized streambanks, which has contributed to sediment loss and delivery downstream. Channel widening, gully formation, and other erosional processes within the stream corridor appear to be contributing higher than normal sediment loads to the river. Excess sediment deposition can reduce pool and riffle habitat quality, and result in a lack of fish and macroinvertebrate species that depend on coarse substrates for feeding and reproduction.

2.4.2 Low Dissolved Oxygen

Living aquatic organisms such as fish and macroinvertebrates require oxygen to sustain life. Decreases in dissolved oxygen (DO) in the water column can cause changes in the types and numbers of fish and aquatic macroinvertebrates in surface waters, and shift the community composition to species that are tolerant of lower levels or wider dial swings in DO. Instantaneous, longitudinal and continuous (diurnal) measurements for dissolved oxygen were conducted at monitoring stations on Upper and Lower Mud Creek during the summers of 2007, 2008 and 2009. Instantaneous data indicates that dissolved oxygen concentrations in both reaches of the creek occasionally drop below the standard of 5 mg/L during mid to late summer months.

Longitudinal surveys in the late summer months found early-morning concentrations less than the 5.0 mg/L standard, but continuous sampling over multiple days in early summer months found concentrations staying consistently above the 5.0 mg/L standard, and an acceptable daily flux. More data is necessary to better establish the extent of potential low dissolved oxygen in both reaches. There is some uncertainty regarding the processes driving this stressor, which may be related to in-line and riparian wetland flushing or possibly to nutrient enrichment from mid-stream Quamba Lake, which is impaired by excess nutrients.

2.4.3 Habitat Loss from Riparian Corridor Disturbance

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

Land cover alterations have reduced the quality of the riparian corridor. Cattle grazing and activity near the stream and removal of natural riparian vegetation have led to destabilized streambanks and reduced overhanging vegetation that provides fish cover, filtering, and habitat.

2.4.4 Loss of Watershed Connectivity Due to Ditching

Connectivity can refer to a number of different pathways that move organisms, energy, and matter. Connectivity can be longitudinal or linear; lateral, or with the floodplain; vertical, to the hyporrheic zone below the stream bed and banks; or temporal. Much of Upper Mud Creek and its tributaries have been channelized, or excavated and straightened to serve as drainage ditches. This can have an immediate effect on biotic integrity by reducing or eliminating natural in-stream habitat structures such as pools, riffles, and backwaters, and it can change how the stream and organisms access the floodplain and other locations upstream and downstream. Limited information is available, but literature suggests ditching in the watershed and on Upper Mud Creek has a negative impact on biotic integrity.

2.4.5 Altered Hydrology

Ditching can also impact hydrology. Ditches are often constructed to control or reduce water levels in wetlands, reducing storage in the watershed and increasing discharge downstream. Limited information is available, but literature suggests ditching in the watershed and on Upper Mud Creek has a negative impact on biotic integrity.

2.5 BACTERIA IN THE SNAKE RIVER

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

2.6 FACTORS INFLUENCING BACTERIA IN SNAKE RIVER WATERSHED

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

2.6.1 Bacteria Loading

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

2.6.2 Streamflow

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

2.7 FACTORS INFLUENCING NUTRIENTS IN SNAKE RIVER WATERSHED

Factors influencing total phosphorus and other nutrient levels in the Snake River watershed impaired lakes are atmospheric nutrient loading, watershed nutrient loading, internal phosphorus loading and loading from failing septic systems and wastewater treatment facilities. These sources are described in detail in Section 4.

3.0 *E. coli* Impairments

3.1 OVERVIEW OF *E. COLI* IMPAIRED REACHES IN THE WATERSHED

This TMDL applies to the *E. coli* bacteria impairment for three reaches in the Snake River Watershed (Figure 1.1). Data from main-stem monitoring stations in the watersheds served as the basis of the impairment determination and were used to support development of the TMDL.

3.2 WATERSHED LAND USE/LAND COVER

Land use for the *E. coli* impaired reach watersheds was calculated using the 2011 National Agricultural Statistics Service (NASS) GIS land cover file (Table 2-1). Land use in these watersheds is primarily a mixture of hay/pasture, forest and wetland with some urban and cropland.

3.3 DATA SOURCES

3.3.1 Water Quality Data

The *E. coli* data used for the development of this TMDL are grab samples collected by the Snake River Watershed Management Board (SRWMB), Kanabec SWCD, Pine SWCD, and the MPCA in 2004 through 2006 and 2008 through 2010 (Table 3-1). Although data prior to this period exists, the more recent data better represent current conditions in the watershed. Mud Creek samples were analyzed for fecal coliform prior to 2006 and since then for *E. coli*. All Bear Creek samples were analyzed for *E. coli*. Fecal coliform data was converted to *E. coli* "equivalents" using the equation discussed in section 1.3.2. Appendices A-C show the location of the monitoring stations at which samples were collected. All data were obtained through Minnesota Pollution Control Agency's EQuIS online database.

Table 3-1. Snake River *E. coli* monitoring sites.

EQuIS ID	Reach ID	Location	Parameter	Number of Samples	Years
S003-533	07030004-567	Lower Mud Creek @ CSAH-5	Fecal Coliform	None	-
			E. coli	2	2009
S005-597	07030004-566	Upper Mud Creek @ 225th Ave	Fecal Coliform	None	-
			E. coli	26	2010 - 2011
S003-533	07030004-566	Upper Mud Creek @ 290th Ave	Fecal Coliform	22	2004 - 2006
			E. coli	40	2008 - 2010
S005-286	07030004-514	Bear Creek @ Crooked River Rd	Fecal Coliform	None	-
			E. coli	63	2005 - 2011
S005-293	07030004-514	Bear Creek @ CSAH 10	Fecal Coliform	None	-
			E. coli	10	2006
S005-292	07030004-514	Tributary to Bear Creek @ Cedar Creek Rd	Fecal Coliform	None	-
			E. coli	11	2006

3.3.2 Streamflow Data

The Upper and Lower Mud Creek impaired reaches have recent continuous flow data (Appendices A-C). These stations were operated during the 2010 to 2011 sampling seasons from April/March through the middle of November. There is also one long-term USGS flow monitoring station located on the Snake River near Pine City (S000-198). This station began operating in 1906 and has operated year around since the early 1990s. Regression relationships between the Mud Creek impaired reach stations and the Snake River USGS station show good correlation (R^2 of 0.65-0.71) and the regression equations were used to fill data gaps and predict all winter and non-monitored flows from 2001-2011.

The Bear Creek impaired reach (S005-286) had three instantaneous flow measurements collected during the 2010 sampling season. A regression relationship (R^2 of 0.97) for Bear Creek was established with station S002-542 (Pokegama Creek at CSAH-14) and used to fill data gaps and predict winter and non-monitored flows from 2001-2011.

3.3.3 Impairment Criteria for the Snake River

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

E. coli and *E. coli* "equivalent" data from each main-stem impaired reach monitoring station were combined into one dataset and analyzed according to the aforementioned MPCA assessment methodology to demonstrate the level of impairment in the impaired reach. Figure 3.2 shows monthly geometric means for each impaired reach during the bacteria index period (April-October). Table 3-2 lists the acute standard exceedances for each impaired reach and months in which exceedances occurred.

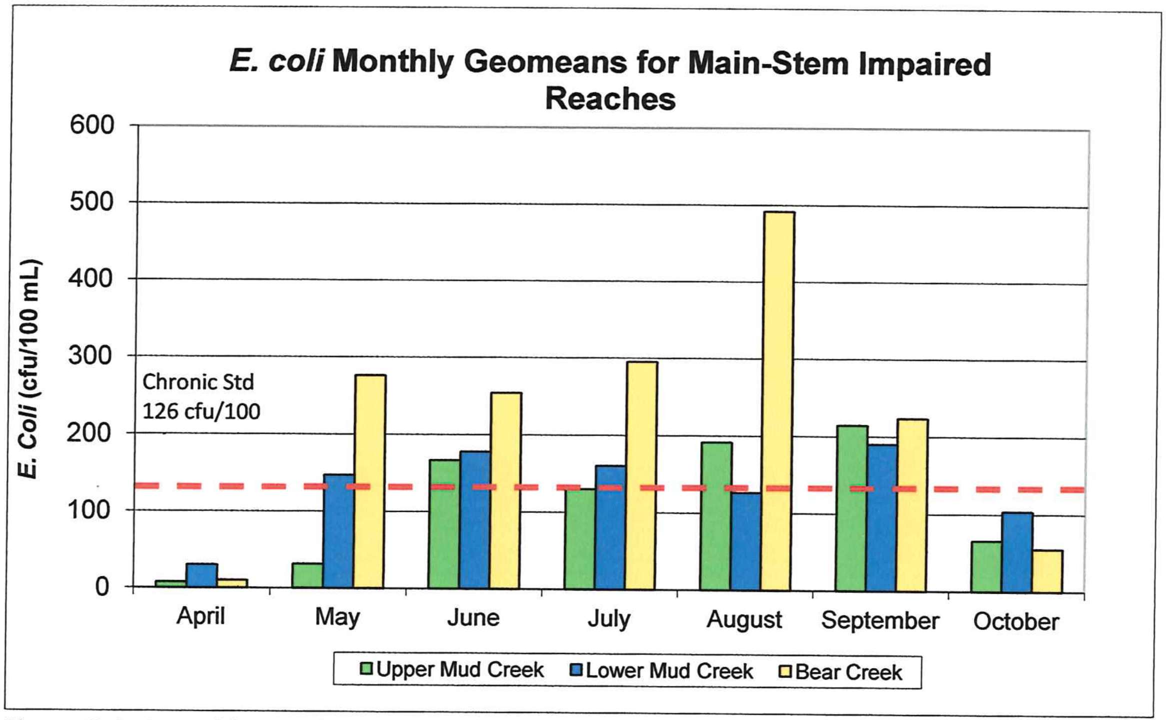


Figure 3.1. Monthly *E. coli* geometric means for each impaired reach for 2004-2006 and 2008-2011. Note: The dotted red lines indicate the *E. coli* chronic (126 cfu/100 ml) state standards.

Table 3-2. Individual *E. coli* acute exceedances in 2004-2006 and 2008-2011 for the impaired reach monitoring stations.

Site	Total Samples	Acute Exceedances	Percent	Months with Acute Exceedances
Upper Mud Creek S003-533	62	4	6%	August (1); September (1); October (2)
Lower Mud Creek S005-597 S005-596	28	0	0%	None
Bear Creek S002-286 S002-293	71	12	17%	June (2); July (3); August (4); September (3)

3.4 ALLOCATION METHODOLOGY

3.4.1 Overview of Load Duration Curve Approach

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

A flow duration curve was developed using 10-yr flow records at the furthest downstream flow station in each impaired reach. The curved line relates mean daily flow to the percent of time those values have been met or exceeded (Figure 3.3). For example, at the 50% exceedance value for S003-533, the river was at 10 cubic feet per second or greater 50% of the time. The 50% exceedance is also the midpoint or median flow value. The curve is then divided into flow zones including very high (0-10%), high (10-40%), mid (40-60%), low (60-90%) and dry (90 to 100%) flow conditions. Subdividing all flow data over the past 10-years into these five categories ensures high-flow and low-flow critical conditions are accounted for in this TMDL study.

To develop a load duration curve, all average daily flow values were multiplied by the 126 cfu/100 ml standard and converted to a daily bacteria load to create a "continuous" load duration curve. Now the line represents the assimilative capacity of the stream for each daily flow. To develop the TMDL, the median load of each flow zone is used to represent the Total Daily Loading Capacity (TDLC) for that flow zone. The TDLC can also be compared to current conditions by plotting the measured load by exceedance for each water quality sampling event (Figures 3.4-3.6). Each value that is above the TDLC line represents an exceedance of the water quality standard while those below the line are below the water quality standard.

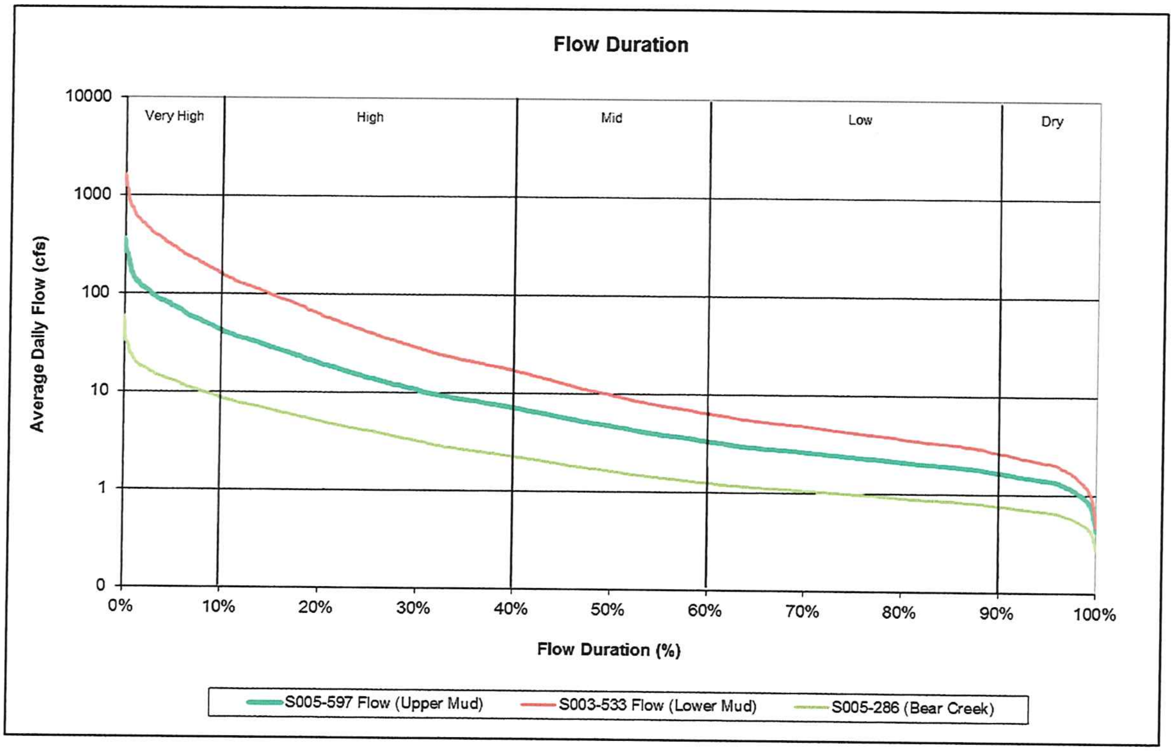


Figure 3.2. Flow duration curve for each impaired reach.

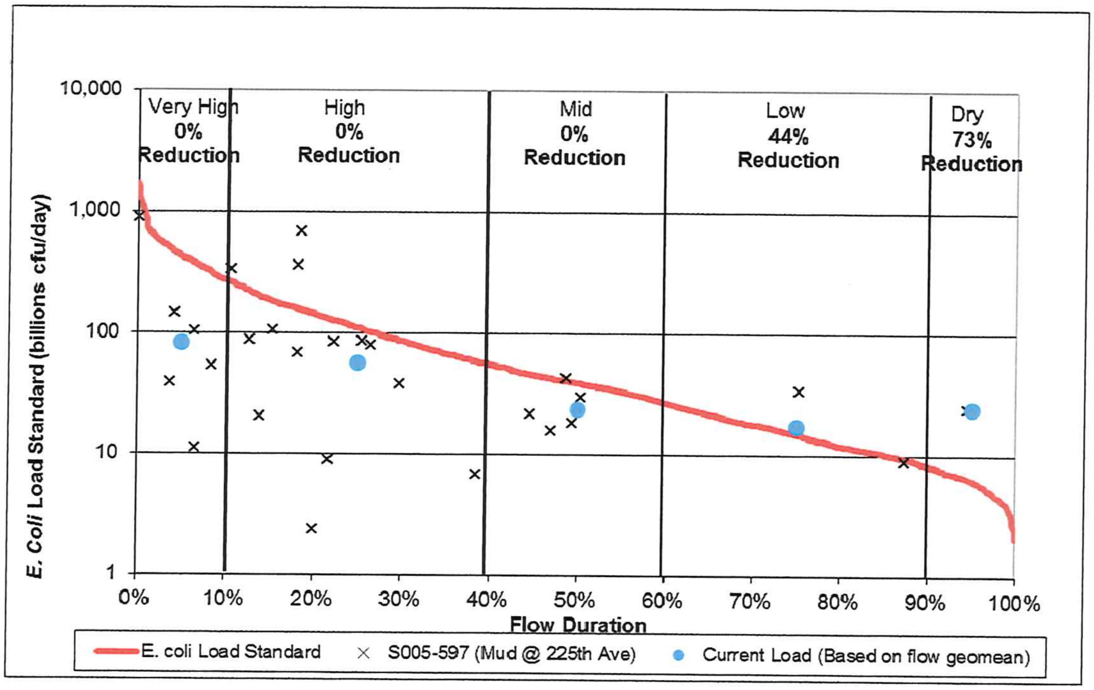


Figure 3.3. Upper Mud Creek *E. coli* load duration curve and required load reductions by flow category.

Note: The red line represents the maximum allowable daily *E. coli* load.

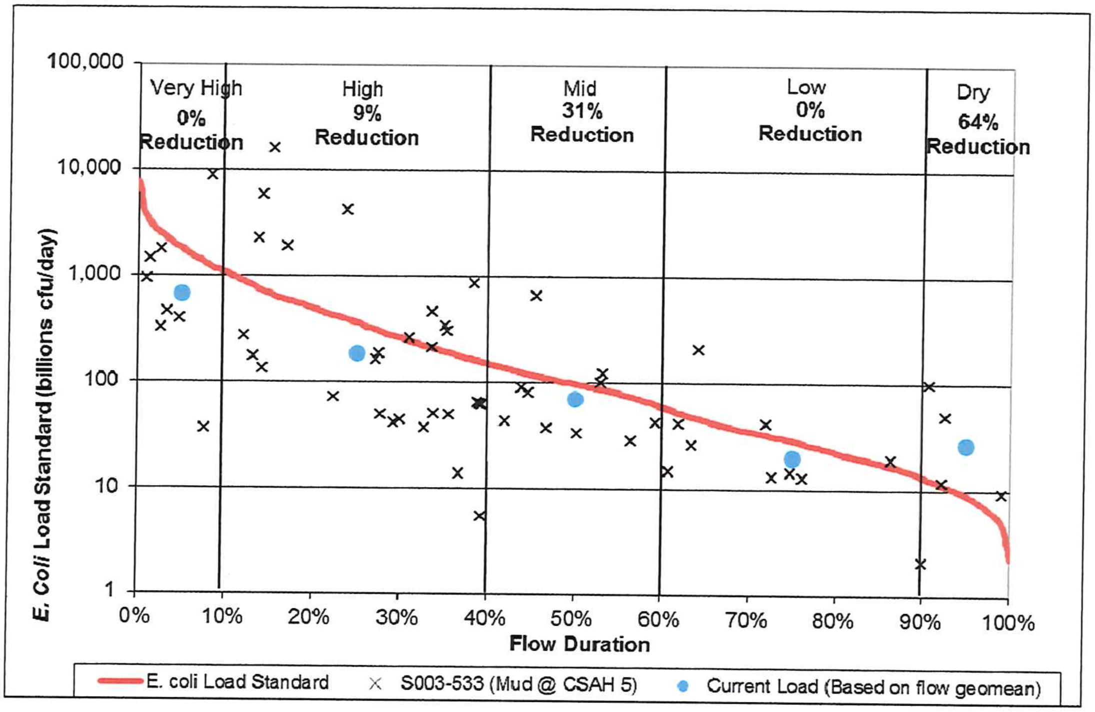


Figure 3.4. Lower Mud Creek *E. coli* load duration curve and required load reductions by flow category.

Note: The red line represents the maximum allowable daily *E. coli* load.

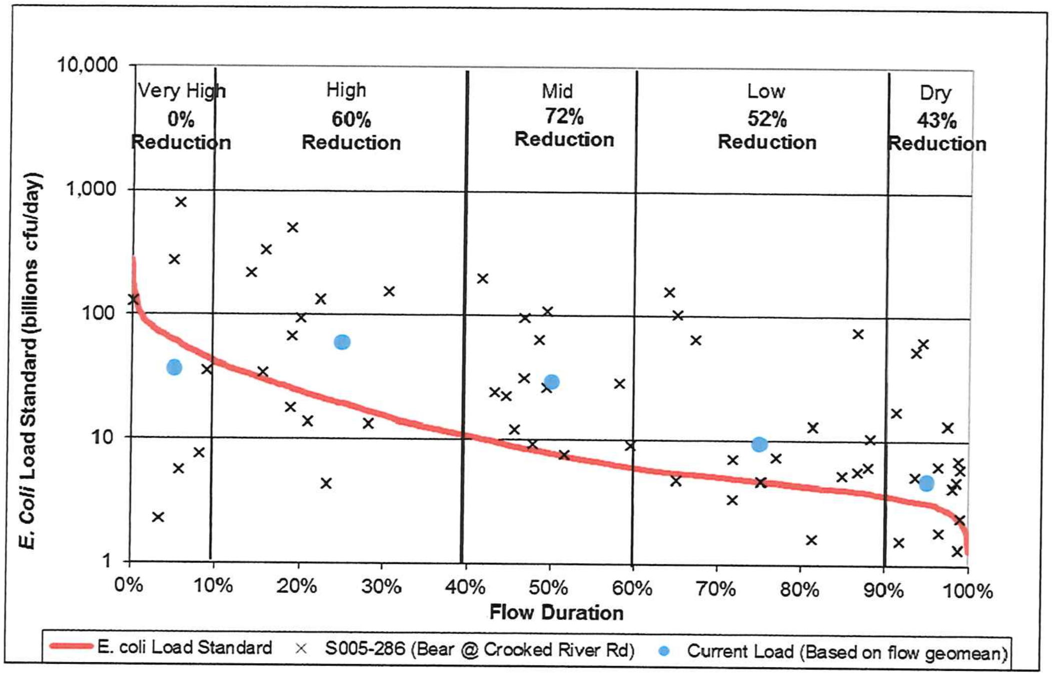


Figure 3.5. Bear Creek *E. coli* load duration curve and required load reductions by flow category.
Note: The red line represents the maximum allowable daily *E. coli* load.

3.4.2 Margin of Safety

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

3.4.3 Wasteload Allocations

Wasteload allocations for bacteria TMDLs are typically divided into three categories: permitted wastewater dischargers, Municipal Separate Storm Sewer Systems (MS4s), and construction and industrial storm water. At the time of this study, the MPCA confirmed there were no active permitted NPDES surface wastewater dischargers or MS4s in the impaired reaches watersheds. Thus, these wasteload categories were given a zero value in each of the impaired reaches *E. coli* allocation tables (Tables 3-3 to 3-5). Industrial facilities and construction sites with storm water permits through the MPCA are not believed to discharge the pollutant of concern and were not given *E. coli* allocations for this TMDL.

3.4.4 Watershed Load Allocations

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

3.5 TOTAL MAXIMUM DAILY LOADS

Tables 3-3 through 3-5 present the total loading capacity, margin of safety, wasteload allocations and the remaining watershed load allocations for the impaired reaches. The table also presents all load allocations in terms of the percent of total loading capacity in each flow category.

Table 3-3. Upper Mud Creek *E. coli* impaired reach TMDL for each flow zone.

Mud Creek 07030004-566		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		E. coli Load (billions of organisms/day)				
Total Daily Loading Capacity		353.2	66.8	22.4	11.0	6.5
Margin of Safety (MOS)		17.7	3.3	1.1	0.6	0.3
Wasteload Allocations	Permitted Point Source Dischargers	0.0	0.0	0.0	0.0	0.0
Load Allocation	[1]Watershed Load	335.5	63.5	21.3	10.4	6.2
Value expressed as percentage of total daily loading capacity						
Total Daily Loading Capacity		100%	100%	100%	100%	100%
Margin of Safety (MOS)		5%	5%	5%	5%	5%
Wasteload Allocation	Permitted Point Source Dischargers	0%	0%	0%	0%	0%
Load Allocation	[1]Watershed Load	95%	95%	95%	95%	95%

[1]Watershed load consists of all non-regulated runoff from forest land, wetlands, rural land, agricultural land and non-regulated MS4 stormwater

Table 3-4. Lower Mud Creek *E. coli* impaired reach TMDL for each flow zone.

Mud Creek 07030004-567		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		E. Coli Load (billions of organisms/day)				
Total Daily Loading Capacity		1,438.3	193.7	46.0	19.5	9.8
Margin of Safety (MOS)		71.9	9.7	2.3	1.0	0.5
Wasteload Allocations	Permitted Point Source Dischargers	0.0	0.0	0.0	0.0	0.0
Load Allocation	[1]Watershed Load	1,366.4	184.0	43.7	18.5	9.3
Value expressed as percentage of total daily loading capacity						
Total Daily Loading Capacity		100%	100%	100%	100%	100%
Margin of Safety (MOS)		5%	5%	5%	5%	5%
Wasteload Allocation	Permitted Point Source Dischargers	0%	0%	0%	0%	0%
Load Allocation	[1]Watershed Load	95%	95%	95%	95%	95%

[1]Watershed load consists of all non-regulated runoff from forest land, wetlands, rural land, agricultural land and non-regulated MS4 stormwater

Table 3-5. Bear Creek *E. coli* impaired reach TMDL for each flow zone.

Bear Creek 07030004-514		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		E. Coli Load (billions of organisms/day)				
Total Daily Loading Capacity		61.5	19.3	7.7	4.6	3.1
Margin of Safety (MOS)		3.1	1.0	0.4	0.2	0.2
Wasteload Allocations	Permitted Point Source Dischargers	0.0	0.0	0.0	0.0	0.0
	MS4 Communities	0.0	0.0	0.0	0.0	0.0
Load Allocation	[1]Watershed Load	58.4	18.3	7.3	4.4	2.9
Value expressed as percentage of total daily loading capacity						
Total Daily Loading Capacity		100%	100%	100%	100%	100%
Margin of Safety (MOS)		5%	5%	5%	5%	5%
Wasteload Allocation	Permitted Point Source Dischargers	0%	0%	0%	0%	0%
Load Allocation	[1]Watershed Load	95%	95%	95%	95%	95%

[1]Watershed load consists of all non-regulated runoff from forest land, wetlands, rural land, agricultural land and non-regulated MS4 stormwater

3.6 IMPACT OF GROWTH ON ALLOCATIONS

3.6.1 Wasteload Allocations

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

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

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

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

3.7 POLLUTANT SOURCE ASSESSMENT

The pollutant source assessment is intended to present information that is helpful in identifying the potential sources of elevated bacteria concentrations in the impaired reach watersheds. The first section of the source assessment is a discussion of background levels of bacteria in streams. The next section addresses seasonal influences and looks at the relationships between elevated bacteria concentrations and flow. The final section contains estimates of the potential sources of bacteria available for transport by source category for the *E. coli* impaired reach watersheds.

3.7.1 *E. coli* Background Conditions

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

The outlet of Quamba Lake represents the upstream boundary of the Lower Mud Creek *E. coli* impaired reach. Even if bacteria inputs to Quamba Lake are high, the lake's volume should provide significant dilution. Thus, it is assumed a majority of the bacteria observed in the Lower Mud Creek impaired reach is produced within the Lower Mud Creek watershed.

3.7.2 Exceedances by Season and Flow Regime

Individual *E. coli* measurements show exceedances during summer and fall and occasionally in the spring (Tables 3-6 to 3-8). April was the month with the lowest bacteria concentrations even though there is little crop canopy cover and there is often significant manure application during this time. This suggests seasonality of bacteria concentrations may be influenced by stream water temperature. More samples should be gathered in April to confirm this. Fecal bacteria are most productive at temperatures similar to their origination environment in animal digestive tracts. Thus, these organisms are expected to be at their highest concentrations during the warmer summer months when stream temperature are highest. High *E. coli* concentrations continue into the late summer and fall which may be attributed to cattle access to stream/tributaries and/or reapplication of manure.

Table 3-6. Chronic *E. coli* exceedances in the Upper Mud Creek impaired reach by season and flow regime.

	Very High/High Flow	Mid Flow	Low/Dry Flow
Spring	0%	NA[1]	NA[1]
Summer	71%	67% (3 samples)	100% (1 sample)
Fall	100%	0% (2 samples)	100% (2 samples)

[1] No samples collected during season and flow regime.

Note: Number of samples only listed if less than 4 samples were taken during season/flow regime.

Table 3-7. Chronic *E. coli* exceedances in the Lower Mud Creek impaired reach by season and flow regime.

	Very High/High Flow	Mid Flow	Low/Dry Flow
Spring	20%	0% (1 sample)	NA[1]
Summer	58%	60%	50%
Fall	23%	75%	100% (2 samples)

[1] No samples taken during season and flow regime.

Note: Number of samples only listed if less than 4 samples were taken during season/flow regime.

Table 3-8. Chronic *E. coli* exceedances in the Bear Creek impaired reach by season and flow regime.

	Very High/High Flow	Mid Flow	Low/Dry Flow
Spring	20%	NA[1]	NA[1]
Summer	100%	100%	78%
Fall	0%	100% (2 samples)	64%

[1] No samples taken during season and flow regime.

Note: Number of samples only listed if less than 4 samples were taken during season/flow regime.

The relationship between flow and bacteria concentrations aids in identifying potential sources of elevated bacteria concentrations. Table 3-9 shows the conceptual relationship between flow and loading sources under various flow conditions. Under low flows, runoff processes are minimal as bacteria concentrations are primarily driven by wastewater treatment plants (if present), failing subsurface sewage treatment systems (SSTS) and animals in or near the receiving water. Conversely, at high flows, runoff from land with bacteria concentrations such as feedlots and pastures, urban areas and cropland often dominate. Exceedances appear to occur across all flow regimes in the bacteria-listed reaches. This suggests that, at times, all of the aforementioned flow-driven sources may contribute to high bacteria concentrations observed throughout each reach.

Table 3-9. Conceptual relationship between flow regime and potential pollutant sources.

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

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

3.7.3 Potential Bacteria Source Inventory

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

3.7.3.1 Livestock Sources

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

Table 3-10 lists the number of feedlots present in the impaired reach watersheds according to the 2012 MPCA database and county surveys. Maps showing the approximate location (as points) and size (total animal units) of each feedlot are shown in Appendices A-C.

Table 3-10. Inventory of Agricultural Animals in the Impaired Reaches Watersheds.

Impaired Reach	# of Feedlots	# of CAFOS Permit #	Total Animal Units	Total Dairy Units	Total Beef Units	Total Swine Units	Total Poultry Units	Total Other Units
Upper Mud Creek 07030004-566	49	0	1,789	0	1,658	13	1	117
Lower Mud Creek 07030004-567	61	0	1,146	72	712	172	0	257
Bear Creek 07030004-514	23	0	1,198	54	1,042	59	0	43

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

3.7.3.1.1 Manure Application

A significant proportion of the cropland throughout Minnesota and the upper Midwest receives some sort of manure application during different times of the year. Most beef manure is applied as a solid while dairy manure is applied as both liquid and solid manure. In most cases, the larger dairy operations have liquid manure pits, while the smaller dairies haul manure as a solid. Most liquid manure is injected into the soil or incorporated within 24 hours. Solid manure is spread on the soil surface where it is not immediately incorporated into the ground. A large portion of manure applications occur in the fall when animal waste pits are emptied out. However, some farmers (especially small dairy farmers) will spread this manure year round. In general, manure that is not incorporated has a higher potential for runoff. Land application of manure within 300 feet of intermittent and perennial streams and all Minnesota DNR protected lakes and wetlands are required to meet MPCA setback requirements (MPCA, 2005).

Beef and dairy cattle and horses, all three of which are considered grazers, are the only agricultural animals in the impaired reach watersheds. For the purposes of this TMDL, it is assumed these animals spend about eight months of the year grazing in pastureland throughout the impaired reaches watersheds. For the other four months, the animals are housed in barns or other confined spaces where their manure is stockpiled. Thus, approximately 33% of the animal manure produced in the watershed is available for spreading on cropland. However, since less than 20% of the total land in each of the watersheds is currently used to grow crops, it is assumed only half (16%) of the stockpiled manure is spread on cropland while the other half is spread on pastureland. It is also assumed that all of the manure spreading in the watershed is surface applied.

3.7.3.1.2 Feedlots and Pastures near Streams

GIS processing suggests that approximately 16% of the pastureland in the Upper and Lower Mud Creek impaired reach watersheds and 20% in the Bear Creek watershed is located within 500 feet of the main-stem or a major tributary. As a result, this TMDL will assume that 16% and 20% of the fecal coliform produced by the agricultural animals in the Mud Creek and Bear Creek watersheds during the eight month grazing period is deposited within 500 feet of streams while the rest is deposited on upstream pastureland. As discussed in the previous section, this TMDL also assumes approximately 50% of the manure stockpile is spread on pastureland when stockpiles are emptied. Pastures, feedlots and open lot cattle and dairy facilities near streams or waterways have a higher likelihood of animal access to the stream and therefore higher likelihood of delivering bacteria to the receiving water.

3.7.3.2 Septic Systems

Failing or nonconforming individual sewage treatment systems (ISTS) can be an important source of bacteria to surface waters. Currently, the exact number and status of ISTSs in the Snake River watershed is unknown. MPCA's 2004 "10 Year Plan to Upgrade and Maintain Minnesota's On-Site Treatment Systems" report to the Minnesota Legislature includes some information regarding the performance of ISTSs in the Snake River watershed (MPCA, 2004). This study provides county annual reports from 2002 that include estimated failure rates for each county in the state of Minnesota. The report differentiates between systems that are generally failing and those that are an imminent threat to public health and safety (ITPHS). Generally failing systems are those that do not provide adequate treatment and may contaminate ground or surface water. For example a generally failing system may have a functioning, intact tank and soil absorption system, but fails to protect ground water by providing a less than sufficient amount of unsaturated soil between where the sewage is discharged and the ground water or bedrock. Systems considered ITPHS are severely failing or were never designed to provide adequate raw sewage treatment. Examples include ISTSs that discharge to the ground surface or directly to surface water bodies such as ditches, streams or lakes.

Total number of generally failing and ITPHS systems in each of the three impaired reach watersheds was estimated in GIS using 2010 Census population data. Rural population that falls outside the boundaries of municipalities with wastewater treatment facilities (WWTFs) was calculated and divided by 3 people per household to estimate the total number of ISTS in each watershed. Next, failing and ITPHS systems were estimated by multiplying the total number of ISTSs by the county failure rates from the 2004 MPCA report (Table 3-11). Finally, annual bacteria load from failing ISTSs was calculated using the University of Minnesota Water Resource Center's 2012 version of the Septic System Improvement Estimator (SSIE). The SSIE is a spreadsheet-based model that uses published literature rates to calculate annual pollutant loads from problematic septic system. The model assumes that approximately 50% of the bacteria from generally failing ISTSs is removed prior to discharge to groundwater/surface water while 0% of the bacteria from ITPHS ISTSs is removed. A complete ISTS bacteria load summary for each impaired reach watershed is provided in Appendices A-C.

Table 3-11. ISTS failure rates by County.

County	Generally Failing ISTSs	ITPHS ISTSs
Aitkin	39%	3%
Isanti	20%	5%
Kanabec	25%	5%
Mille Lacs	40%	3%
Pine	20%	3%

3.7.3.3 Wildlife

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

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

There are currently no waterfowl surveys or data available for watersheds or the surrounding area. A 2011 Waterfowl Breeding Population Survey by the MN DNR and U.S. Fish & Wildlife Service estimated that there are approximately 10 waterfowl (includes both geese and ducks) per square mile throughout the state (Minnesota DNR 2011).

3.7.3.4 Urban Storm Water Runoff

Untreated urban storm water has demonstrated bacteria concentrations high as or higher than grazed pasture runoff, cropland runoff, and feedlot runoff (USEPA 2001, Bannerman et al. 1993, 1996). There is very little urban area in impaired reach watersheds. This TMDL source assessment assumes urban bacteria contributions come from improperly managed waste from dogs and cats. Deer and waterfowl densities in urban areas were assumed to be the same as those discussed in the previous section. Consistent with the methodology outlined in the Southeast Minnesota Regional Bacteria TMDL (MPCA 2002), it was assumed that there were 0.58 dogs/household and 0.73 cats/household in the urban areas.

3.7.4 Snake River Watershed Bacteria Available for Transport

Each bacteria source was assigned a percentage to predict the likelihood of that animal's bacteria reaching the impaired reaches and their tributaries. A summary of these percentages is presented in Appendices A-C. It is important to note that this process assumes that all bacteria produced in the watershed remain in the watershed. The assumptions are approximations that were first developed as part of the Southeast Regional TMDL (MPCA, 2002), then altered to reflect GIS calculations and current conditions within the watershed.

Next, potential fecal coliform runoff loads were estimated for the impaired reaches watersheds (Figures 3.7 to 3.9 and Appendices A-C). Daily fecal coliform production estimates for each agricultural animal unit, cat/dog and wildlife animal were derived from the Southeast Regional TMDL (MPCA 2002).

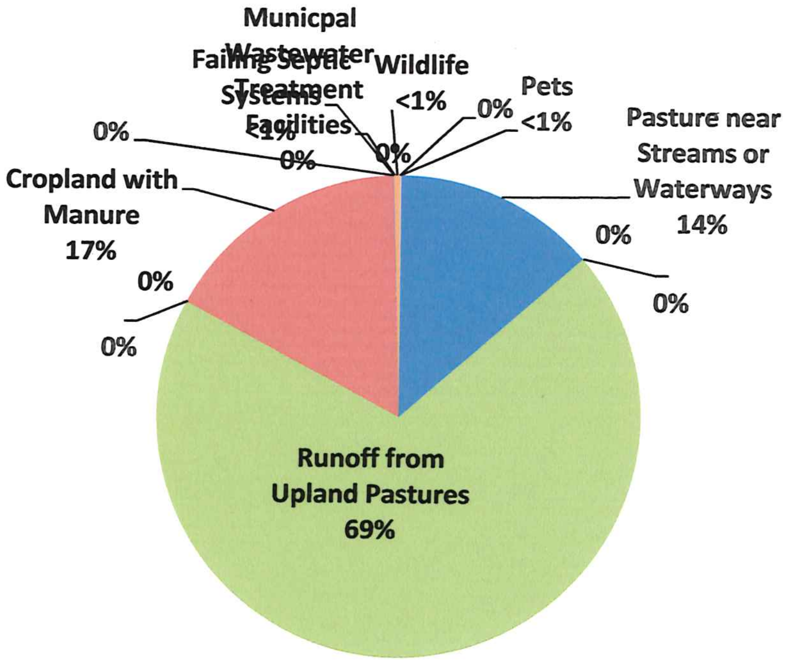


Figure 3.6. Fecal coliform available (by source) for delivery in the Upper Mud Creek impaired reach watershed.

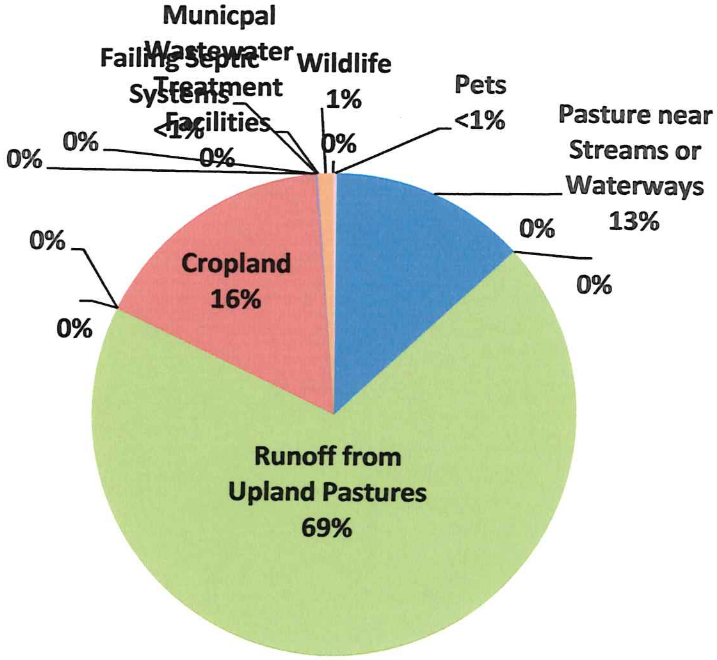


Figure 3.7. Fecal coliform available (by source) for delivery in the Lower Mud Creek impaired reach watershed.

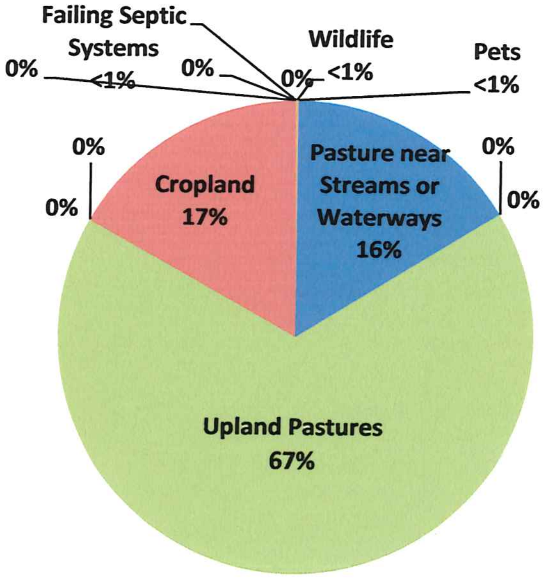


Figure 3.8. Fecal coliform available (by source) for delivery in the Bear Creek impaired reach watershed.

3.7.5 Pollutant Source Assessment Summary

- Livestock are by far the biggest producer of bacteria in the impaired reach watersheds.
- The largest potential sources are those activities associated with pasture management. Implementation activities should focus on limiting cattle access to the impaired reaches and their tributaries, and buffering runoff from pastures near streams and waterways. Secondarily, BMPs for upland pasture land should also be implemented.
- Cropland manure application does not appear to be a top source of bacteria to the impaired reaches since cropland represents only 2-16 percent of the land use throughout the watershed. That said, cropland with high runoff potential and heavy drain tiling and fields located near streams/waterways should be targeted for BMPs.
- Collectively, failing ISTSs appear to be a relatively small source compared to livestock. However, all three reaches, especially Bear Creek, displayed significant *E. coli* violations during dry and low-flow conditions. Thus, depending on their location and level of failure, these systems have the potential to be significant bacteria contributors during these flow conditions.

4.0 Lake Nutrient Impairments

4.1 WATERSHED AND LAKE CHARACTERIZATION

Knife Lake (DNR # 33-0028), Quamba Lake (DNR # 33-0015), Pokegama Lake (DNR # 58-0142) and Cross Lake (DNR # 58-0119) are located in east-central Minnesota in the Snake River watershed (Figure 4.1). Knife and Quamba Lakes are impoundments that discharge to tributaries of the Snake River. Pokegama Lake discharges directly to the Snake River west of Pine City, MN. Cross Lake is located downstream of Knife, Quamba and Pokegama Lakes near the outlet of the Snake River watershed. The south basin of Cross Lake acts as a flow-through basin for the Snake River near Pine City before the river eventually discharges to the St. Croix River.

Knife Lake is a 1,259 acre impoundment on the Knife River in Kanabec County approximately 7 miles north of Mora, MN. Outflow from Knife Lake eventually flows to the Snake River via the Knife River. Knife Lake is a shallow (maximum depth of 15 feet) lake with a short residence time (77 days) meaning that the lake flushes about once every two and a half months (Table 4-1). Knife Lake has a relatively large drainage area (58,518 acres). The Knife River watershed which enters the lake on the southwest end of the lake is approximately 53,000 acres and accounts for a majority of the lake's total watershed. The remainder of the Knife Lake watershed is made up of direct drainage to the lake.

Quamba Lake is a shallow (maximum depth of 11 feet) 226 acre impoundment of Mud Creek about 6 miles northeast of Mora, MN (Table 4-1). Mud Creek enters the lake from the north and outflows through a dam on the east end of the lake. The Mud Creek watershed above Quamba is about 20,354 acres and accounts for a majority of the lake's inflow. Direct drainage to Quamba accounts for about 17% (3,771 acres) of the lake's total watershed. Quamba Lake has very short residence time (22 days). Because it is shallow, Quamba Lake should be expected to have 100% coverage of submerged aquatic vegetation.

Pokegama Lake is a 1,515 acre lake located about three miles east of Pine City, MN. Pokegama Lake is a shallow basin with a maximum depth of 25 feet; however 60% of the lake is 15 feet or less in depth. The lake is connected to the Snake River via a constructed outlet and is subject to extreme water level fluctuations. A large portion of Pokegama Lake's inflow comes from Pokegama Creek which drains approximately 42,811 acres and enters the lake through a wide channel on the north end of the lake. Direct drainage to Pokegama Lake accounts for approximately 15% (7,819 acres) of the lake's total watershed and is made up of various small tributaries that drain directly to the lake.

Table 4-1. Lake morphometry and watershed characteristics.

Parameter	Knife Lake	Quamba Lake	Pokegama Lake
Surface Area (acres)	1,259	226	1,515
Average Depth (ft)	8.5	5.6	11.8
Maximum Depth (ft)	15	11	25
Volume (ac-ft)	10,740	1,264	17,868
Residence Time (years)	0.21	0.06	0.35
Littoral Area (acres)	1,259	226	903
Littoral Area (%)	100%	100%	60%
Watershed (acres)	58,518	24,125	50,630

Cross Lake is a 925 acre lake located on the northeast edge of Pine City, MN. Cross Lake has a long narrow shape, generally running north-south. Cross Lake has three primary basins that display very different physical and limnological characteristics (Table 4-2). Direct drainage to Cross Lake is approximately 7,102 acres and includes Cross Creek, which enters the lake on the north side of the north basin, and several smaller tributaries and intermittent streams. The Snake River, which enters and exits the lake through the south basin, drains approximately 611,704 acres including five upstream nutrient impaired lakes: Knife Lake, Ann Lake, Fish Lake, Quamba Lake and Pokegama Lake. The south basin has a maximum depth of 30 feet and an average depth of 10 feet.

Minnesota Rules Chapter 7050.0150(4)states that in order to be considered a lake/reservoir, a water body must have a hydraulic residence time of at least 14 days which is to be determined using a flow equal to the 122-day ten-year low flow (122Q10) measured June 1st through September 30th. The south basin has a calculated residence time of 9.4 days during 122Q10 flow conditions. Thus, for the purpose of this study, the south basin is considered a wide spot in the river and not a lake/reservoir. The north and central basins, on the other hand have significantly longer residence times (0.8-1.45 years) and function as typical lake systems. It is believed that physical mixing between the central and north basins is minimal due to the flow through nature of the south basin.

Table 4-2. Cross Lake morphometry and watershed characteristics.

Parameter	Cross – All Basins	South Basin	Central Basin	North Basin
Surface Area (acres)	924	311	269	344
Average Depth (ft)	13.8	10.4	15.5	15.7
Maximum Depth (ft)	30	30	22	27
Volume (ac-ft)	12,807	3,238	4,171	5,398
Residence Time (years)	0.02	<0.01	0.80	1.45
Littoral Area (acres)	472	57	198	217
Littoral Area (%)	51%	18%	73%	63%
Watershed (acres)	618,806	613,563	1,470	3,773

4.2 LAKE WATER QUALITY

4.2.1 Introduction

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

Lake water quality samples have been collected at various locations on Knife, Quamba, Pokegama and Cross Lake (Appendices D-G). Lake sampling conducted in 2010 and 2011 was specifically intended to support this TMDL study. The data collected these years represent the most complete and robust dataset for all four lakes since 2000. In general, lake monitoring was conducted bi-weekly from May through September for Secchi depth, total phosphorus (TP) and chlorophyll-a, and temperature and dissolved oxygen measurements. Collection efforts were coordinated and carried out by lake association groups, the Kanabec SWCD, Pine SWCD, and the Minnesota Pollution Control Agency (MPCA).

4.2.2 Temperature and Dissolved Oxygen

Dissolved oxygen profiles for all four lakes were collected at least once per month 2010 and 2011. These profiles show slight stratification and temperature gradients between the surface and bottom waters during the mid-summer months (Appendices D-G). Dissolved oxygen (DO) profiles demonstrate anoxia (DO ≤ 2 mg/L) occasionally occurs in the bottom 1-2 meters of the water column during the warm summer months (July to early September) which suggests the potential for internal loading of phosphorus. It should be noted that Knife and Quamba Lakes are shallow systems with relatively high surface area to depth ratios causing the lakes to be more susceptible to wind-driven mixing events. Pokegama and Cross Lakes are considered deep lakes; however their fetch is long causing their thermoclines to develop relatively deep which minimizes the depth at which anoxic conditions develop. Thus none of the lakes sustain strong thermoclines and large anoxic areas for the entire summer period.

4.2.3 Total Phosphorus

Summer average total phosphorus (TP) concentrations for Knife Lake and Quamba Lake consistently exceeded the 60 µg/L standard for shallow lakes in the North Central Hardwood Forest (NCHF) Ecoregion (Appendices D-G). Similarly, summer average TP concentrations for Pokegama and Cross Lake exceeded the 40 µg/L NCHF deep lake standard in every year monitored since 2001. Total phosphorus was monitored at multiple locations/basins in Knife, Pokegama and Cross Lake in 2010 and 2011. For Knife and Pokegama Lakes, average TP was nearly identical between the two monitored basins, suggesting little spatial variability in TP. For Cross Lake, TP in the north and central basins showed little variability, while the south basin was noticeably higher. The higher concentrations in the south basin reflect TP loading from the Snake River which enters and exits Cross Lake through the south basin.

4.2.4 Chlorophyll-*a*

Since 2001, average chlorophyll-a concentrations in Knife, Quamba and Pokegama have consistently exceeded state standards. Average summer chlorophyll-a concentrations for Knife Lake's central basin have ranged from 11-27 µg, and has exceeded the deep lake standard in 4 of the 5 years sampled since 2001 (Appendices D-G). Chlorophyll-a concentrations that exceed state water quality standards indicate a high incidence of nuisance algae blooms. Chlorophyll-a concentrations were similar between the two Knife Lake and Pokegama Lake basins sampled in 2010 and 2011. For Cross Lake, chlorophyll-a was consistently higher in the north and central basins compared to the south basin, likely due to the south basin's river influence and short residence time.

4.2.5 Secchi Depth

Water clarity (Secchi depth) in general follows the same trend as TP and chlorophyll-a. Since 2001, mean summer Secchi depth in all four lakes has not met state water quality standards (Appendices D-G). The Secchi data for Knife and Pokegama Lake show little variability between basins. Cross Lake Secchi data also indicates little spatial variability between the north, central and south basins. Non-algal turbidity and TSS from the Snake River are likely driving the poor transparency in south basin since chlorophyll-a concentrations are consistently low in this basin.

4.2.6 Lake Water Quality Conclusions

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

4.3 LAKE ECOLOGY

4.3.1 Fish Populations and Fish Health

Fish survey reports for Knife, Quamba, Pokegama and Cross Lake were provided by the DNR Area Fisheries Office in Hinckley, Minnesota. The first DNR fish surveys for these lakes were conducted in 1979 (Knife) and 1981 (Quamba, Pokegama and Cross). Standard survey methods used by the DNR include gill net and trap nets. These sampling methods do have some sampling bias, including focusing on game management species (i.e., northern pike and walleye), under representing small minnow and darter species presence/abundance, and under representing certain management species such as largemouth bass. The current methods also likely under represent carp populations in the lakes. However, in our experience, when carp are present in the lakes, the sampling methods do capture some of the population. So, although carp density is likely under represented, the methods do provide a reasonable year to year comparison.

There have been 34 species collected during the Knife, Quamba, Pokegama and Cross Lake DNR surveys:

- black bullhead
- black crappie
- bluegill
- bowfin
- brown bullhead
- channel catfish
- chestnut lamprey
- common carp
- common shiner
- creek chub
- freshwater drum
- largemouth bass
- muskellunge
- northern pike
- pumpkinseed
- quillback
- river redhorse
- rock bass
- shorthead redhorse
- shovelnose sturgeon
- silver redhorse
- smallmouth bass

- golden redhorse
- golden shiner
- greater redhorse
- hog sucker
- hybrid sunfish (Ann Lake only)
- lake sturgeon
- walleye
- white bass
- white crappie
- white sucker
- yellow bullhead
- yellow perch

Fish community data for each lake was summarized by trophic groups. Appendices D-G provide a complete trophic summary for each survey year both in terms total fish caught and biomass. Species within a trophic group serve the same ecological process in the lake (i.e., panfish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community then analyzing individual species trends.

Rough fish, particularly common carp, have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. Carp and other rough fish have been sampled in all four lakes, however rough fish size and numbers have declined significantly since the early surveys in the 1980s. Rough fish management in Knife Lake has been particularly effective since common carp entered the lake in 1972 when flooding caused the lake's outlet structure to wash out. Knife Lake was treated with rotenone in 1989 and no carp have been noted in the DNR surveys since 1988. At least one common carp was captured in the recent DNR surveys for Quamba, Pokegama and Cross Lakes. However, common carp and other rough fish currently account for only a small portion each lake's total fish population and total biomass.

4.3.2 Aquatic Plants

The littoral zone is defined as that portion of the lake that is less than 15 feet in depth and is where the majority of the aquatic plants are found. The littoral zone of the lake also provides the essential spawning habitat for most warm water fishes (e.g. bass, walleye, and panfish). Knife Lake and Quamba Lake are both shallow lakes with maximum depths less than 15 feet meaning both lakes should support a healthy rooted aquatic plant community. Though they are considered deep lakes, Pokegama Lake and Cross Lake have large littoral areas which should also support a healthy rooted aquatic plant community. The key for these lakes is fostering a diverse population of rooted aquatic plants that is dominated by native (non-invasive) species.

Aquatic plants are beneficial to lake ecosystems, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. However, in high abundance and density they limit recreation activities, such as boating and swimming, and may reduce aesthetic value. Excess nutrients in lakes can lead to non-native, invasive aquatic plants taking over a lake. Some exotics can lead to special problems in lakes. For example, under the right conditions, Eurasian water milfoil can reduce plant biodiversity in a lake because it grows in great densities and out-competes all the other plants. Ultimately, this can lead to a shift in the fish community because these high densities favor panfish over larger game fish.

Another non-native plant species, curly-leaf pondweed, can cause very specific problems by changing the dynamics of internal phosphorus loading. Curly-leaf pondweed is a perennial submersed aquatic plant that was first noted in Minnesota around 1910 (Moyle and Hotchkiss, 1945). Curly-leaf pondweed sprouts in the fall from vegetative structures called turions, and can grow slowly throughout the winter, even under thick ice and snow cover. Thus by the time other species start growing in the spring, curly-leaf plants are large enough to block light penetration to the bottom. By late spring, curly-leaf pondweed can form dense surface mats which interfere with recreation activities. By mid-summer these dense mats senesce and die back, releasing nutrients that can contribute to undesirable algae blooms. Before curly-leaf pondweed plants die back, they form hardened stem tips called turions, which serve the function of vegetative reproduction. These turions sprout in the fall and begin the plant's cycle again.

The DNR has conducted qualitative plant surveys during most of the fish surveys since the late 1970's and early 1980's. These surveys indicate all four lakes support moderately diverse aquatic plant communities that include a mixture of emergent, floating leaf and submerged plant species. These surveys also revealed all four lakes contain undesirable species such curly-leaf pondweed. Recently, the DNR has begun conducting more quantitative plant surveys for Knife, Quamba, Pokegama and Cross Lakes in May and June to assess the early season plant community and map curly-leaf pondweed problem areas (Table 4-3). These surveys indicate curly-leaf pondweed currently has a stronghold in all four lakes and is the most common species during the early summer months. Chemical and mechanical treatments to control curly-leaf pondweed in Knife Lake and Pokegama Lake have taken place since the 1990s; however the DNR has begun issuing more individual and multi-party permits in recent years. More point-intercept plant survey data should be collected on these lakes to continue to monitor curly-leaf pondweed abundance and analyze the effectiveness of chemical treatments.

Table 4-3. Curly-leaf Pondweed abundance Knife, Quamba, Pokegama and Cross Lakes.

Lake	Recent Survey Month-Year	Curly-leaf Pondweed % of points sampled	Other Submerged Species % of points sampled
Knife	[1]May-2009	17%	10%
Quamba	[2]June-2003	30%	19%
Pokegama	[3]May-2009	93%	28%
Cross	[4]June-2006	Present	Present

[1]Only points less than 7 feet deep surveyed
[2]All depths surveyed (11 foot maximum depth)
[3]Only points less than 5 feet deep surveyed
[4]Curly-leaf pondweed mapped, but not surveyed using point-intercept methodology

4.4 NUTRIENT SOURCES

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

4.4.1 Watershed Load

Kanabec, Mille Lacs and Pine SWCDs and MPCA staff and various lake association personnel have collected total and ortho-phosphorus grab samples at various main-stem river and tributary monitoring stations upstream of the four impaired lakes over the past 10 years. Continuous flow has been measured by the MPCA at several monitoring stations throughout the Snake River watershed in recent years. Total phosphorus data shows TP concentrations from certain sites are relatively high and occasionally exceed the proposed state stream TP standard of 100 µg/L. Total phosphorus loads for four continuous flow monitoring stations were estimated using the Flux32 Load Estimation Software supplied by the U.S. Army Corps of Engineers (Walker, 1999). FLUX uses TP sample concentration data and continuous flow measurements to calculate mass discharges (loadings) using five estimation methods. Average daily flow data gaps for each station were filled using regression equations with the Snake River USGS station (S000-198) which has operated year around since1992. Phosphorus loading for subwatersheds with TP data but no continuous flow data was calculated by multiplying the flow weighted mean TP concentration by the runoff depth of the closest continuous flow monitoring station. A complete summary of the continuous flow and phosphorus monitoring data and FLUX load estimates, methods and assumptions is presented in Appendices D-G.

In order to assess TP loading between different land uses and subwatersheds, a Generalized Watershed Loading Function (GWLF) model was developed for the Knife, Quamba, Pokegama, and Cross Lake drainage areas. GWLF is a GIS-based continuous simulation model which uses daily weather data to calculate water balance and simulate runoff, sediment and nutrient loading (Evans et al. 2008). The GWLF models were established using the following GIS layers: daily temperatures and rainfall, subwatershed boundaries, DNR ditch/stream network, 30 meter digital elevation model (DEM), Soil Survey Geographic (SSURGO) database and 2010 National Agricultural Statistics Service (NASS) land-use. Once the models were setup in GIS, runoff curve numbers and phosphorus runoff rates were adjusted to match observed annual water yields and FLUX calculated TP loads. Appendices D-G provides a complete summary of GWLF model performance and model predicted TP loading rates for each subwatershed in the Knife, Quamba, Pokegama and Cross Lake watersheds. Table 4-4 summarizes watershed TP loading by land use for each lake watershed modeled using GWLF. The models indicate a majority of the watershed TP runoff for each lake comes from land uses associated with animal agricultural. Thus, implementing pasture and manure management BMPs will be critical in meeting the watershed load reductions required in this TMDL.

Table 4-4. GWLF predicted TP load as a percent of the total watershed runoff load.

Loading Source	Knife Lake Watershed	Quamba Lake Watershed	Pokegama Lake Watershed	Cross Lake Watershed (Snake)	Cross Lake Watershed (Direct)
Hay/Pasture	80%	89%	80%	65%	79%
Cropland	7%	6%	9%	30%	19%
Forest	4%	1%	1%	1%	<1%
Wetland	8%	3%	9%	3%	<1%
Urban/Roads	1%	1%	1%	1%	1%

4.4.2 Upstream Lakes

Cross Lake has five major upstream impaired lakes that contribute flow and TP load to the Snake River: Ann Lake (DNR Lake # 33-0040), Fish Lake (DNR Lake # 33-0036), Knife Lake, Quamba Lake and Pokegama Lake. These upstream lakes drain approximately 191,700 acres and account for about 31% of Cross Lake's total drainage area. Discharge volume from these lakes was calculated using annual runoff depths from the continuous flow station located in each impaired lake watershed (Appendices D-G). Phosphorus loads from each upstream lake were calculated by multiplying each lake's flow weighted mean TP concentration by the estimated outflow volume. Knife, Quamba and Pokegama Lakes have no major upstream lakes located in their drainage basin.

4.4.3 Failing Septic Systems

Failing or nonconforming individual sewage treatment systems (ISTS) can be an important source of phosphorus to surface waters. Currently, knowledge of the exact number and status of ISTSs in the

Snake River watershed is unclear. MPCA's 2004 "10 Year Plan to upgrade and Maintain Minnesota's On-site Treatment Systems" report to the Minnesota Legislature includes some information regarding the performance of ISTSs in the Snake River watershed (MPCA, 2004). This study provides county annual reports from 2002 that include estimated failure rates for each county in the state of Minnesota. The report differentiates between systems that are generally failing and those that are imminent threat to public health and safety (ITPHS). Generally failing systems are those that do not provide adequate treatment and may contaminate ground or surface water. For example a generally failing system may have a functioning, intact tank and soil absorption system, but fails to protect ground water by providing a less than sufficient amount of unsaturated soil between where the sewage is discharged and the ground water or bedrock. Systems considered ITPHS are severely failing or were never designed to provide adequate raw sewage treatment. Examples include ISTSs that discharge to the ground surface or directly to surface water bodies such as ditches, streams or lakes.

Total number of generally failing and ITPHS systems in each of the four lake watersheds was estimated in GIS using 2010 Census population data. Rural population that falls outside the boundaries of municipalities with wastewater treatment facilities (WWTFs) was calculated and divided by 3 people per household to estimate the total number of ISTS for each lake watershed. Next, failing and ITPHS systems were estimated by multiplying the total number of ISTSs by the county failure rates from the 2004 MPCA report (Table 4.5). Finally, annual phosphorus loading from failing ISTSs was calculated using the University of Minnesota Water Resource Center's 2012 version of the Septic System Improvement Estimator (SSIE). The SSIE is a spreadsheet-based model that uses published literature rates to calculate annual pollutant loads from problematic septic system. The model assumes that approximately 50% of the phosphorus from generally failing ISTSs is removed prior to discharge to groundwater/surface water while 0% of the phosphorus from ITPHS ISTSs is removed. A complete ISTS phosphorus load summary for each lake watershed is provided in Appendices D-G.

Table 4-5. ISTS failure rates by County.

County	Generally Failing ISTSs	ITPHS ISTSs
Aitkin	39%	3%
Isanti	20%	5%
Kanabec	25%	5%
Mille Lacs	40%	3%
Pine	20%	3%

4.4.4 Wastewater Treatment Facilities

There are no National Pollutant Discharge Elimination System (NPDES) permitted point source discharges located in the Quamba Lake and Pokegama Lake watersheds. There are five active point sources in the Knife Lake and Cross Lake watersheds: Wahkon WWTF (MN0047066), Isle WWTF (MN0023809), Ogilvie WWTF (MN0021997), Mora WWTF (MN0021156) and Grasston WWTF (MN0025691). Wahkon WWTF and Isle WWTF are located in the Knife Lake watershed and discharge to tributaries and wetlands near the headwaters of the Knife River (Appendix D). Ogilvie WWTF, Mora WWTF and Grasston WWTF are located in the Snake River watershed and discharge directly to the Snake River or a major tributary of the Snake River upstream of Cross Lake's south basin. Table 4-6 summarizes current permit limits and effluent flow and TP loads based on discharge monitoring reports (DMRs) supplied by the MPCA. It should be noted that Grasston WWTF does not currently discharge effluent to surface waters through its surface discharge control structure. The only water that leaves this facility is to evaporation and groundwater recharge from the facility's primary cell. At this time, all facilities are currently permitted for wet weather design flow and several water quality parameters, however not TP.

Table 4-6. WWTFs in the Knife and Cross Lake Watersheds.

Facility	Lake Watershed	Receiving Water	Permitted Wet Weather Design Flow (mgd)	Current Effluent Flow (mgd)[1]	Current Effluent TP Load (TP/year)[1]	Current Effluent TP Conc. (µg/L)[1]
Wahkon WWTF	Knife	Unnamed dry run	0.121	0.075	100	434
Isle WWTF	Knife	Unnamed wetland	0.200	0.123	204	546
Ogilvie WWTF	Cross	Groundhouse River	0.230	0.139	701	1,660
Mora WWTF	Cross	Snake River	0.800	0.511	4,489	3,144
Grasston WWTF[2]	Cross	Snake River	0.038	NA	NA	NA

[1] Effluent flow and TP calculated based on annual average of the 2010-2011 MPCA discharge monitoring reports
[2] Grasston WWTF does not currently discharge to surface water

4.4.5 Internal Load

Internal phosphorus loading from lake sediments has been demonstrated to be an important part of the phosphorus budgets of lakes. However, measuring or estimating internal loads can be difficult, especially in shallow lakes and lakes with long fetch that periodically or constantly mix throughout the year.

To estimate internal loading, an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, is estimated from dissolved oxygen profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor is then used along with a sediment release rate to estimate the total phosphorus load from the sediments. Oxic and anoxic phosphorus release rates were estimated individually for all four lakes by collecting sediment cores and incubating them in the lab under oxic and anoxic conditions (James, 2012; Appendix H).

For all four lakes, dissolved oxygen and temperature profiles were collected at least once per month in 2010 and 2011. However; little anoxia (DO less than 2.0 mg/L) was observed in all four lakes. Even in lakes considered "deep" basins, Pokegama and Cross, anoxia was recorded only in the bottom 1-3 meters during one or two of the site visits each summer. It is important to note that shallow lakes (Knife and Quamba) and medium depth lakes with long fetch (Pokegama and Cross) can often demonstrate short periods of anoxia due to instability of stratification which is often missed by periodic measurements. So, for all four lakes, an equation was used (Nürnberg 2005) to estimate the anoxic factor. Once the anoxic factor was estimated, the next step is to identify the rate at which sediments release phosphorus under both anoxic and oxic conditions. The laboratory measured rate of phosphorus release from anoxic and oxic sediments for each lake are presented in Table 4-7. These rates were then multiplied by the total area of each lake to estimate gross internal loading in each system (Nürnburg 2004).

Table 4-7. Internal load estimates.

Lake	Oxic Release ($mg/m^2/day$)	Anoxic Release ($mg/m^2/day$)	Anoxic Factor (days)	Total Internal Load (lbs/year)
Knife	0.7	9.5	54	6,764
Quamba	0.4	11.1	56	1,347
Pokegama	0.5	16.3	56	13,203
Cross - North	0.5	17.8	50	3,212
Cross – Central	1.8	31.1	51	5,196
Cross – South	NA	18.8	56	3,612

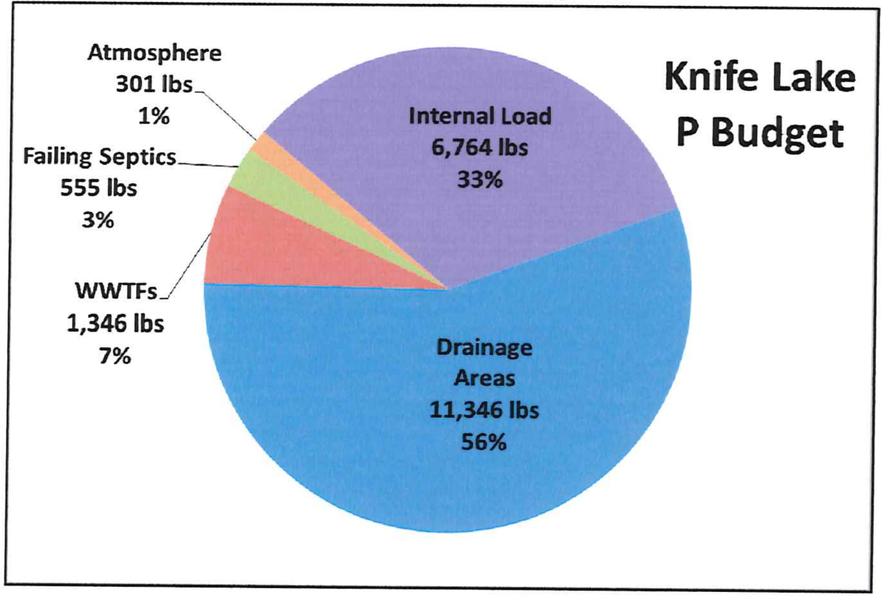
4.4.6 Atmospheric Load

The atmospheric load refers to the load applied directly to the surface of the lake through atmospheric deposition. Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report "Detailed Assessment of Phosphorus Sources to Minnesota Watersheds" (Barr Engineering 2004), and are based on annual precipitation. The values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre-year for dry, average, and wet years, respectively.

4.4.7 Lake Nutrient Budgets

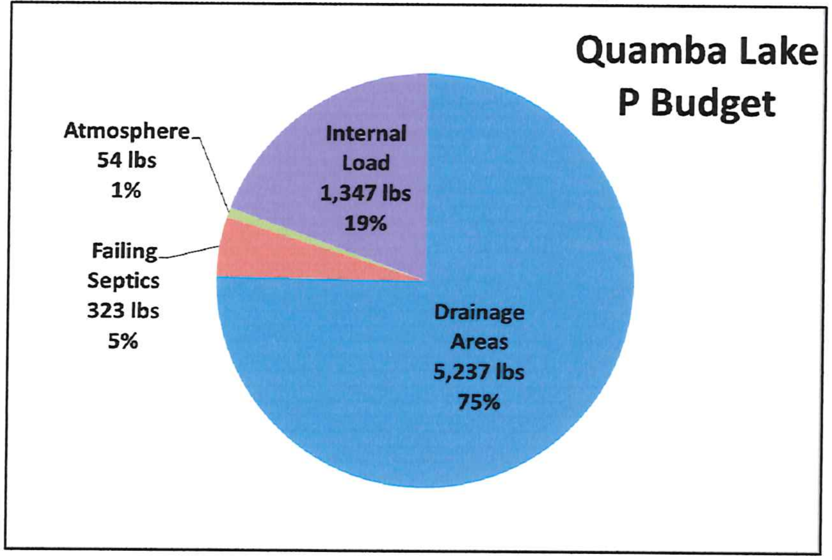
Knife Lake's phosphorus budget for model years 2010 and 2011 is presented in Figure 4.1. Loading from Knife Lake's drainage area, particularly Knife River, represents a majority of the annual TP load to the lake. Internal load from Knife Lake sediments represents the second largest source of TP. Internal load can play a significant role during the warm summer months when TP load from the watershed is low and primary production is high. The Wahkon and Isle WWTFs currently only account for about 7% of the annual TP budget while failing septics and atmospheric inputs account for 3% and 1%, respectively.

Figure 4.1. Knife Lake average annual TP budget.



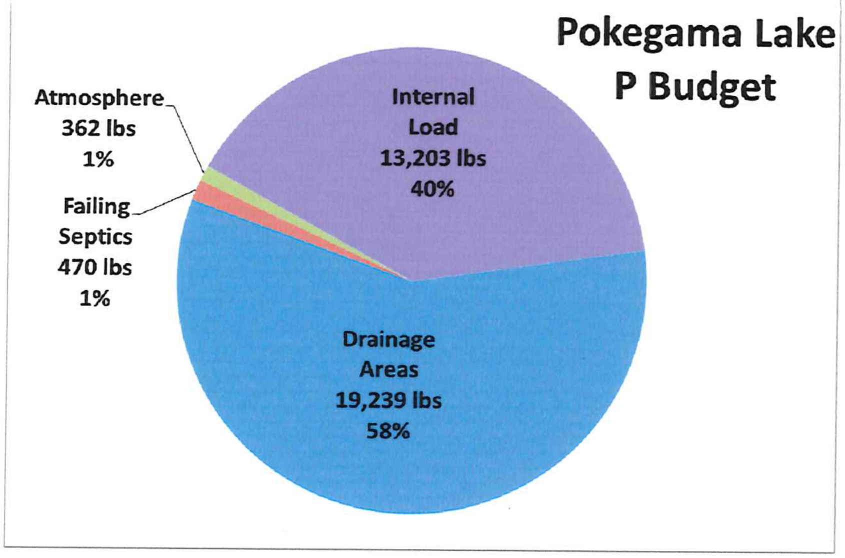
Phosphorus loading to Quamba Lake is dominated by inputs from Upper Mud Creek and the lake's direct watershed (Figure 4.2). Similar to Knife Lake, the internal loading from Quamba Lake's sediment represent the next largest source of TP to the lake and plays an important role during the warm, dry summer months. Failing septics and atmospheric loading are not major nutrient sources to Quamba Lake compared to watershed and internal sources.

Figure 4.2. Quamba Lake average annual TP budget.



Compared to Quamba Lake, TP loading to Pokegama Lake is split more evenly between watershed runoff and internal loading. Phosphorus loading from Pokegama's direct watershed accounts for about half of the watershed TP runoff. Monitored TP runoff concentrations for the direct watershed were extremely high (336-499 µg/L) and above the proposed TP standard of 100 µg/L. Pokegama Creek accounts for more than half of the drainage area water budget for Pokegama Lake, however monitored TP concentrations for Pokegama Creek were significantly lower (89 µg/L average TP) than the direct watershed. Pokegama Lake has a very high measured internal P release rate (16.3 mg/m^2/day) and internal load is responsible for approximately 40% of the lake's P budget. Only about 5% of the TP load to Pokegama Lake comes from failing ISTSs while atmospheric deposition accounts for only 1% of the lake's TP budget.

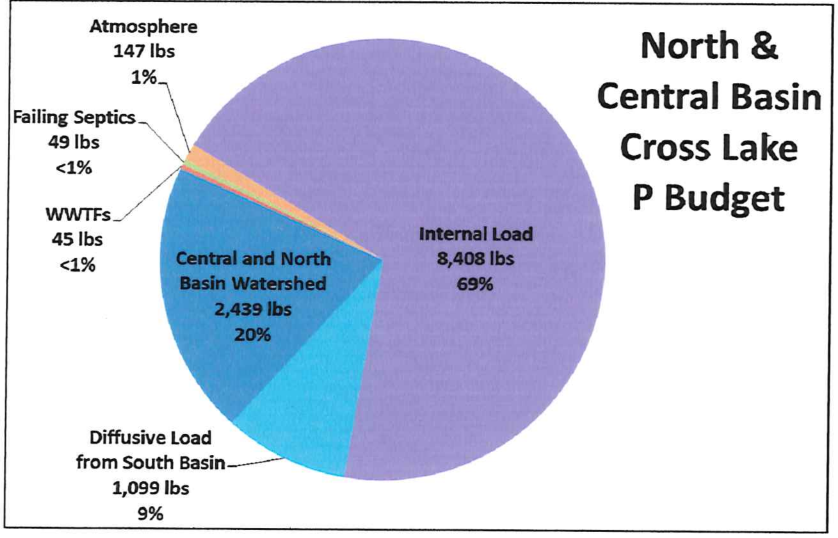
Figure 4.3. Pokegama average annual TP budget.



Cross Lake's south basin, which is dominated by flow from the Snake River, is considered a wide spot in the Snake River according to Minnesota Rules, Chapter 7050, Part 0150 Subp. 4. S. The Snake River inflow to the Cross Lake's south basin currently meets the State of Minnesota's 100 µg/L proposed river and stream TP eutrophication standard. As a result, this study will only focus on TMDL allocations for Cross Lake's central and north basins. Figure 4.4 shows average annual loading to the north and central basin. Appendix G contains a complete summary of annual TP loading to each individual basin. Results indicate the diffusive flux of phosphorus from the south basin to the central and north basins is relatively small (9%) compared to other loading sources. Direct runoff from the central and north basin watersheds also accounts for a relatively small portion of the overall phosphorus budget, however monitored TP runoff concentrations are very high (120-321 µg/L average TP) and are consistently above the proposed 100 µg/L river and stream TP standard. Internal load accounts for about 69% of the total phosphorus load to Cross Lake's central and north basins and plays a significant role in the growing season phosphorus budget due to these basin's long residence times and high internal P release rates.

There are no wastewater treatment facilities in the central and north basin watersheds. The facilities discussed in section 4.4.4 discharge to the Snake River upstream of the south basin and do not directly impact the central and north basin. These facilities do have the potential to contribute phosphorus indirectly via the south basin diffusive flux. Wastewater treatment facility diffusive input was estimated by calculating the WWTFs percent of the total phosphorus load to the south basin and then multiplying this percentage by the total diffusive flux from the south basin. This analysis demonstrates the WWTFs contribute only 45 pounds of phosphorus to the central and north basins each year. Atmospheric inputs and failing septics in the central and north basin are also small and individually account for less than 2% of the TP load.

Figure 4.4. Cross Lake average annual TP budget.



4.5 LAKE RESPONSE MODELS

Once the nutrient budget for a lake has been developed, the response of the lake to those nutrient loads must be established. Lake response to nutrient loading was modeled using the BATHTUB suite of models and the monitored data available for the impaired lakes. BATHTUB is a series of empirical eutrophication models that predict the response to phosphorus inputs for morphologically complex lakes and reservoirs (Walker 1999). Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict the lake response to total phosphorus loads. The Canfield-Bachmann model estimates the lake phosphorus sedimentation rate, which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom, and is used in concert with lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake phosphorus concentrations. These model predictions are compared to measured data to evaluate how well the model describes the lake system. Once a model is well calibrated, the resulting relationship between phosphorus load and in-lake water quality is used to determine the assimilative capacity. Lake response model inputs, performance and results for all four impaired lakes are included in Appendices D-G.

4.6 TMDL ALLOCATIONS

The numerical TMDL for Knife, Quamba, Pokegama and Cross Lakes was calculated as the sum of the Wasteload Allocation, Load Allocation and the Margin of Safety (MOS) expressed as phosphorus mass per unit time. Nutrient loads in this TMDL are set for phosphorus, since this is typically the limiting nutrient for nuisance aquatic algae. These TMDLs are written to solve the TMDL equation for a numeric target of 60 μg/L (Knife and Quamba) and 40 μg/L (Pokegama and Cross) of total phosphorus as a summer growing season average.

4.6.1 Total Loading Capacity

The first step in developing an excess nutrient TMDL for lakes is to determine the total nutrient loading capacity for the lake. To determine the total loading capacity, the average annual nutrient budgets and lake response models for each lake were used as the starting point. The nutrient inputs were then systematically reduced until the model predicted that the lakes met the appropriate total phosphorus standard as a growing season mean. The reductions were applied first to the internal load and then the watershed sources. The TMDL loading capacities for each lake are presented in Table 4-8 to 4-11.

4.6.2 Wasteload Allocations

Wasteload allocations for lakes are typically divided into three categories: NPDES surface wastewater discharges, construction and industrial storm water and Municipal Separate Storm Sewer Systems (MS4s). Currently, there are no MS4s located anywhere in the Snake River watershed. At the time of this study, the MPCA confirmed there were no active permitted NPDES surface wastewater dischargers in the Quamba and Pokegama Lake watersheds. As discussed in Section 4.4.4 there are currently five permitted NPDES wastewater dischargers in the Knife and Cross Lake watershed: Wahkon WWTF, Isle WWTF, Ogilvie WWTF, Mora WWTF and Grasston WWTF.

Load allocations for NPDES wastewater dischargers are set by multiplying the facility's wet whether design flow by their permitted pollutant (in this case TP) concentration limit. While all five of the permitted WWTFs in this study monitor effluent TP concentrations, none of the facilities currently have TP concentration or loading limits in their disposal system (SDS) permits. While these facilities account for a relatively small portion of the Knife and Cross Lake TP budgets, some of the facilities discharge at concentrations well over 1,000 µg/L (Table 4-6). The recently approved Lake St. Croix Nutrient Total Maximum Daily Load assigned individual and aggregate load cap WLAs to all municipal WWTFs in the Snake River watershed (MPCA, 2012). This study assigned individual WLAs that require a 1,000 µg/L TP concentration limit to all facilities whose wet weather design flow is between 0.2-1.0 mgd. Facilities with wet whether design flows below 0.2 mgd were assigned an aggregate load cap that calls for a 2,000 µg/L TP concentration limit for controlled discharges. It was determined these WLAs were reasonable for inclusion in this TMDL since the Knife and Cross Lake BATHTUB models responded favorably when these concentration limits were applied. The Wahkon and Isle WWTFs currently discharge below the Lake St. Croix aggregate load cap concentration limit of 2,000 µg/L and will not require reductions for in the Knife Lake TMDL. The Ogilvie and Mora WWTFs consistently discharge above their 1,000 µg/L TP concentration and will require wasteload reductions.

The St. Croix TMDL WLAs described above require overall phosphorus load reductions of approximately 0.2% for Ogilvie WWTF and about a 50% for Mora WWTF. Grasston WWTF will not provide any load reduction since this facility does not currently discharge its effluent to surface waters. Implementing the Lake St Croix TMDL aggregate load cap WLAs to the WWTFs in the Snake River watershed should have a direct benefit on water quality in Cross Lake's south basin and indirect benefits on water quality for Cross Lake's central and north basins. Current condition WWTF loading estimates to the central and north basin is described in section 4.4.7. It is estimated that the WWTF reductions required in the St. Croix TMDL will result in a diffusive load reduction of approximately 16 pounds to Cross Lake's north and central basins.

At the time of this study, there were 53 active NPDES construction permits in the four impaired reach watersheds. To account for these facilities and future growth in the watershed (reserve capacity), construction storm water allocations in each TMDL are set to one percent of the total drainage area load allocation. Also at the time of this study, there were 3 active industrial storm water permits in the impaired reach watersheds. To account for these permits and future growth (reserve capacity), allocations for industrial storm water in the TMDL are set at a half percent of the total drainage area load allocation.

For Cross Lake, construction and industrial stormwater from the south basin's direct watershed and Snake River via diffusive flux from the south basin was estimated similar to WWTF allocations using the following equation:

$$\text{C\&I WLA} = (\text{WAL}_{\text{total}} * 0.015) / \text{South}_{\text{total}} * \text{Diff}_{\text{total}}$$

Where:

C&I WLA = construction and industrial stormwater WLA from the south basin via diffusion
$\text{WAL}_{\text{total}}$ = Total watershed phosphorus load to the south basin
$\text{South}_{\text{total}}$ = Total phosphorus load to the south basin
$\text{Diff}_{\text{total}}$ = Total diffusive phosphorus flux from the south basin to the north and central basins

4.6.3 Load Allocation

The Load Allocation includes all non-permitted watershed loads such as inflow from upstream wetlands and lakes, runoff from forest land, rural agricultural land and storm water runoff not covered by a state or federal permit. The Load Allocation also includes atmospheric deposition and internal loading. One of the first steps in determining the allowable phosphorus loads to the lakes is setting the appropriate internal load release rate. Measured release rates in Knife, Quamba, Pokegama and Cross were compared to expected release rates for mesotrophic lakes (Nürnberg 1997). Mesotrophic lakes demonstrate internal phosphorus release rates ranging from 0 to 12 mg/m^2-day with a median release rate around 4 mg/m^2-day. Although the median is 4 mg/m^2-day, there is a broad range of internal loads in mesotrophic lakes which makes selecting an appropriate number difficult. Furthermore, all of these lakes are considered shallow or are over 50% littoral and should be expected to release little or no phosphorus when maintained in a healthy state. For example, anoxic release rates in Oneka Lake, a shallow, submerged aquatic vegetation dominated lake located in Anoka County, were below detection. Oneka Lake is the only healthy shallow lake with release measurements near the Snake River watershed. Therefore, release rates in healthy, plant dominated lakes could arguably be zero.

Internal release rates for all four lakes were high and considered eutrophic to hyper-eutrophic. The lake response models for each lake indicated achieving state standards would be impossible without significant internal load reductions. To meet state standards, internal release rates for Knife, Quamba, Pokegama and Cross need to be reduced to 1.0 mg/m^2/day or below. Oxic release of phosphorus was also measured in all four lakes. These rates were not adjusted assuming that the release is a result of the natural breakdown of sediment in the lakes.

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

To determine the allowable watershed phosphorus load, the lake response models were updated with the selected allowable internal load as determined in the previous section. Next, current estimated watershed loading in the lake response models was reduced until the models predicted in-lake phosphorus concentration to meet state standards. In addition to failing SSTS upgrades (zero load contribution), significant watershed load reductions (13%-89%) will be needed for each lake to meet state standards. No changes were expected for atmospheric deposition because this source is impossible to control.

4.6.4 Margin of Safety

The MOS is intended to ensure achievement of the water quality goals in the face of inevitable scientific uncertainties. This TMDL has a robust dataset that includes lake water quality monitoring over multiple years and basins, extensive tributary flow and load monitoring and lab measured internal phosphorus release rates. An explicit margin of safety of 5% of the load has been set aside for the Knife, Quamba, Pokegama and Cross Lake TMDLs. The 5% MOS was considered reasonable given each lake's robust dataset and lake response model performance.

4.6.5 Reserve Capacity

In the Snake River watershed and the St. Croix River basin, reserve capacity (RC) is only available to establish wasteload allocations for the conversion of existing phosphorus loads; it is not intended to provide wasteload allocations for new and expanding industrial or municipal discharges. In Minnesota, RC is established for projects that address failing or nonconforming septic systems and "unsewered" communities and will be made available only to new WWTPs or existing WWTPs that provide service to existing populations with failing or nonconforming systems. The determination of the RC for lakes with WWTPs located in their watersheds, Knife and Cross Lake, was done according to methodology set forth in the Lake St. Croix TMDL (MPCA 2012) and is described below.

The reserve capacities for ISTSs were estimated based on the septic system populations provided in Appendices D-G. MPCA staff experience indicates around 10 percent of all ISTS systems in a given area ultimately convert to surface discharge. A per capita phosphorus rate of 0.16 kg phosphorus/cap-yr was applied to 10 percent of the septic population in each impaired lake watershed to calculate the reserve capacity. This per capita rate was estimated by applying an assumed 80 percent reduction through wastewater treatment to an MPCA raw-wastewater loading guideline of 0.80 kg phosphorus/cap-yr (or 1.76 lb phosphorus/cap-yr). The allotting of reserve capacity for future ISTS conversions will be made on the basis of this 0.16-kg phosphorus/cap-yr rate. For Cross Lake's north and central basins, the RC only includes the estimated RC for the Snake River watershed that flows to the south basin and was therefore removed from the south basin diffusive flux load allocation.

4.6.6 Summary of TMDL Allocations

The numerical TMDL for each lake was calculated as the sum of the Wasteload Allocation, Load Allocation, and the Margin of Safety (MOS) expressed as phosphorus mass per unit time. Tables 4-8 to 4-11 present the TMDL equations for each lake. Annual and summer load allocations were rounded to the nearest whole number. Daily load allocations were rounded to the nearest tenth of a pound.

Table 4-8. Knife Lake Total Maximum Daily Load allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations		Load Reduction	
		(lbs/year)	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)[3]	%
Wasteload Allocation	Construction & Industrial Storm water	115	0.3	115	0.3	0	0%
	Wahkon WWTF	737	2.0	737	2.0	0	0%
	Isle WWTF	609	1.7	609	1.7	0	0%
Load Allocation	Watershed Load[4]	11,200	30.7	7,222	19.8	3,978	35%
	Failing Septics	555	1.5	0	0.0	555	100%
	Internal	6,764	18.5	1,299	3.6	5,465	81%
	Atmosphere	301	0.8	301	0.8	0	0%
Reserve Capacity		--	--	47	0.1		
MOS		--	--	544	1.5	--	--
TOTAL		**20,281**	**55.5**	**10,874**	**29.8**	**9,998**	**46%**

[1] Existing load is the average for the years 2010 and 2011.

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

[3] Net reduction from current load to TMDL is 9,407 lbs/yr; but gross load reduction from all sources must accommodate the Reserve Capacity and MOS as well, and hence is 9,407 + 47 + 544 = 9,998 lbs/yr.

[4] Watershed load consists of all non-regulated runoff from forest land, wetlands, rural land, agricultural land, and non- regulated MS4 stormwater.

Table 4-9. Quamba Lake Total Maximum Daily Load allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations		Load Reduction	
		(lbs/year)	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)[3]	%
Wasteload Allocation	Construction & Industrial Storm water	55	0.2	55	0.2	0	0%
Load Allocation	Watershed Load[4]	5,182	14.2	3,516	9.6	1,666	32%
	Failing Septics	323	0.9	0	0.0	323	100%
	Internal	1,347	3.7	113	0.3	1,234	92%
	Atmosphere	54	0.1	54	0.1	0	0%
MOS		--	--	197	0.5	--	--
TOTAL		**6,961**	**19.1**	**3,935**	**11.8**	**3,223**	**43%**

[1] Existing load is the average for the years 2010 and 2011.

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

[3] Net reduction from current load to TMDL is 3,026 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 3,026 + 197 = 3,223 lbs/yr.

[4] Watershed load consists of all non-regulated runoff from forest land, wetlands, rural land, agricultural land, and non-regulated MS4 stormwater.

Table 4-10. Pokegama Lake Total Maximum Daily Load allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations		Load Reduction	
		(lbs/year)	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)[3]	%
Wasteload Allocation	Construction & Industrial Storm water	108	0.3	108	0.3	0	0%
Load Allocation	Pokegama Brook Watershed Load[4]	9,886	27.1	5,777	15.8	4,109	42%
	Direct Watershed Load[4]	9,246	25.3	1,055	2.9	8,191	89%
	Failing Septics	470	1.3	0	0.0	470	100%
	Internal	13,203	36.1	1,356	3.7	11,847	90%
	Atmosphere	362	1.0	362	1.0	0	0%
MOS		--	--	456	1.2	--	--
TOTAL		**33,275**	**91.1**	**9,114**	**24.9**	**24,617**	**73%**

[1] Existing load is the average for the years 2001, 2002, 2008 and 2010.

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

[3] Net reduction from current load to TMDL is 24,161 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 24,161 + 456 = 24,617 lbs/yr.

[4] Watershed loads consist of all non-regulated runoff from forest land, wetlands, rural land, agricultural land, and non-regulated MS4 stormwater.

Table 4-11. Cross Lake North and Central Basin Total Maximum Daily Load allocations.

Allocation	Source	Existing TP Load [1]		TP Allocations		Load Reduction	
		(lbs/year	(lbs/day)[2]	(lbs/year)	(lbs/day)[2]	(lbs/year)[3]	%
Wasteload Allocation	North & Central Basin Watershed Construction & Industrial Stormwater	21	<0.1	21	<0.1	0	0%
	South Basin Diffusive Flux Construction & Industrial Stormwater	21	<0.1	21	<0.1	0	0%
	Ogilvie WWTF	6	<0.1	6	<0.1	<1	<1%
	Mora WWTF	39	0.1	19	<0.1	20	50%
	Grasston WWTF[4]	0	0.0	4	<0.1	(+)4	--
Load Allocation	South Basin Diffusive Flux	1,078	3.0	1,947	5.3	(+)869	--
	Direct Watershed Load[5]	2,418	6.6	1,220	3.3	1,198	50%
	Failing Septics	49	0.1	0	0.0	49	100%
	Internal	8,408	23.0	3,053	8.4	5,355	64%
	Atmosphere	147	0.4	147	0.4	0	0%
Reserve Capacity		--	--	7	<0.1	--	--
MOS		--	--	339	0.9	--	--
TOTAL		**12,187**	**33.4**	**6,784**	**18.6**	**5,749**	**44%**

[1] Existing load is the average for the years 2010 and 2011.

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

[3] Net reduction from current load to TMDL is 5,403 lbs/yr; but gross load reduction from all sources must accommodate the Reserve Capacity and MOS as well, and hence is 5,403 + 7 + 339 = 5,749 lbs/yr.

[4] Grasston WWTF does not currently discharge effluent to surface water

[5] Watershed loads consist of all non-regulated runoff from forest land, wetlands, rural land, agricultural land, and non-regulated MS4 stormwater.

4.6.7 Lake Response Variables

In developing the lake nutrient standards for Minnesota lakes (Minn. Rule 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's Eco regions (Heiskary and Lindon, 2005). Clear relationships were established between the causal factor total phosphorus and the response variables chlorophyll-a and Secchi disk. Based on these relationships it is expected that the allocations set forth in this TMDL to meet the phosphorus targets of 60 µg/L and 40 µg/ for shallow and deep lakes, the chlorophyll-a and Secchi standards will likewise be met.

4.6.8 Seasonal and Annual Variation

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