Elm Creek Watershed Management Commission Watershed Total Maximum Daily Load

A strategy for restoring a watershed in transition

Minnesota Pollution Control Agency

December 2016

wq-iw11-04e

Authors and Contributors

Rich Brasch, Three Rivers Park District

Brooke Asleson, Minnesota Pollution Control Agency

John Erdmann, Minnesota Pollution Control Agency

Kim Laing, Minnesota Pollution Control Agency

Randy Lehr, Ph.D., Sigurd Olson Environmental Institute, Northland College

Amy Timm, Three Rivers Park District

Brian Vlach, Three Rivers Park District

Justin Valenty, Three Rivers Park District

Marylee Murphy, Three Rivers Park District (former employee)

Table of Contents

TABLES

FIGURES

TMDL Summary Table

EPA/MPCA Required Elements	Summary	TMDL Page #
Location	Located within northern Hennepin County in both the Elm Creek Watershed and the North Fork Crow River Watershed in the upper Mississippi River Basin.	1
303(d) Listing Information	(see table below)	2

Waterbody	HUC/Lake I.D.	Pollutant/ Stressor	Listing Year
Diamond Creek	07010206-525	*E. coli*, Low DO, Fish & Macro-invertebrate bioassessment	2010, 2010, 2014, 2014
Rush Creek	07010206-528	*E. coli*, low DO, Fish & Macro-invertebrate bioassessment	2010, 2010, 2002, 2014
Rush Creek, S. Fork	07010206-732	*E. coli*, Fish & Macroinvertebrate bioassessment, chloride	2010, 2014, 2014, 2014
Rush Creek, S. Fork	07010206-760	Fish & Macro-invertebrate bioassessment	2014, 2014
Elm Creek	07010206-508	*E. coli*, low DO, Fish & Macro-invertebrate bioassessment, chloride	2010, 2004, 2014, 2014, 2014
Cowley Lake	27-0169	Nutrients	2010
Diamond Lake	27-0125	Nutrients	2006
Fish Lake	27-0118	Nutrients	2008
Henry Lake	27-0175	Nutrients	2008
Rice Lake - Main	27-0116-01	Nutrients	2010
Sylvan Lake	27-0171	Nutrients	These lakes are Not yet listed on the state's 303(d) list of impaired waters; however data indicate that these lakes qualify for inclusio on the list for nutrients due to impaired recreatio
Goose Lake	27-0122	Nutrients	

See Section 1.2 for remaining listing information; See Appendix I for list of MS4s receiving WLAs for each impaired water

<table>
<tr><td>Applicable Water Quality Standards/ Numeric Targets</td><td>Criteria set forth in Minn. R. 7050.0150 (3) and (6) (biotic integrity), 7050.0150 (5) and 7050.0222 (TP (TP) and E. coli), and 7050.0150 (subp. 2, 3, 4, 5. subp. 4) (low DO).

<table>
<tr><th>Waterbody</th><th>Numeric Target</th></tr>
<tr><td>Bacteria Impairments</td><td>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</td></tr>
<tr><td>DO Impairments</td><td>No more than 10% of suitable samples are less than 5 mg/l DO</td></tr>
<tr><td>Fish bioassessment</td><td>Index of Biotic Integrity (IBI) threshold for fish of 40 for Northern Headwaters streams.</td></tr>
<tr><td>Macro-invertebrate bioassessment</td><td>IBI threshold for Macroinvertebrates of 46.8 for streams in the Southern Forest GP</td></tr>
<tr><td>Lake Nutrient Impairments</td><td>TP of 60 ug/l or less</td></tr>
</table></td><td>5</td></tr>
<tr><td>Loading Capacity (expressed as daily load)</td><td>Bacteria: See Section 4.1.1
Lake Nutrients: See Section 4.2.1
Biotic Integrity: See Section 4.3</td><td>29</td></tr>
<tr><td>Wasteload Allocation (WLA)</td><td>Bacteria: See Section 4.1.2
Lake Nutrients: See Section 4.2.2
Biotic Integrity: See Section 4.3</td><td>33</td></tr>
<tr><td>Load Allocation (LA)</td><td>Bacteria: See Section 4.1.3
Lake Nutrients: See Section 4.2.3
Biotic Integrity: See Section 4.3</td><td>34</td></tr>
<tr><td>Margin of Safety (MOS)</td><td>Bacteria: An explicit figure of 5% of the loading capacity for each flow regime was used to represent the MOS. See Section 4.1.4.
Lake Nutrients: Explicit MOS of 5% of the loading capacity of each lake. See Section 4.2.4
Biotic Integrity: An explicit 5% of loading capacity for pollutant stressors total suspended solids and TP. See Section 4.3.</td><td>34</td></tr>
<tr><td>Seasonal Variation</td><td>Bacteria: Load duration curve (LDC) methodology accounts for seasonal variations. See Section 4.1.5.
Lake Nutrients: See Section 4.2.5.</td><td>34</td></tr>
</table>

	Biotic Integrity: LDC methodology accounts for seasonal variations in the pollutant stressors of total suspended solids and TP. See Section 4.3.	
Reasonable Assurance	TMDL implementation will be carried out on an iterative basis so that implementation course corrections based on periodic monitoring can be made to adjust the strategy to meet the applicable standard. See Section 5.	66
Monitoring	Progress in implementing the TMDL will be measured through regular monitoring efforts of water quality and total best management practices (BMPs) completed and estimates of the load reduction associated with those BMPs where appropriate. This will be accomplished through the efforts of several cooperating organizations. See Section 6.	70
Implementation	This report sets forth an implementation framework to achieve the TMDL. See Section 7.1. The cost of compliance with the TMDL is included for the one permitted point source affected, and an estimated cost range for the overall effort to meet the TMDL based on various assumptions is also included. See Section 7.5.	72
Public Participation	See Section 8.0 Public comment period: July 5, 2016 to August 4, 2016	80

Acronyms

AUID	Assessment Unit ID
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
CADDIS	Causal Analysis/Diagnosis Decision Information System
CAFO	Concentrated Animal Feeding Operation
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
CBOD	Carbonaceous Biochemical Oxygen Demand
CLPW	Curly Leaf Pondweed
DO	Dissolved Oxygen
DNR	Minnesota Department of Natural Resources
E. coli	*Escherichia Coli*
ECWMC	Elm Creek Watershed Management Commission
EPA	Environmental Protection Agency
EQuIS	Environmental Quality Information System
GW	Groundwater
IBI	Index of Biotic Integrity
ISTS	Individual Sewage Treatment Systems
in/yr	inches per year
km^2	square kilometer
LA	Load Allocation
Lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LDC	Load Duration Curve
LGU	Local Government Unit
m	meter
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day
mL	milliliter

MID	Minimal Impacts Design
MOS	Margin of Safety
MnDOT	Minnesota Department of Transportation
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
MUSA	Metropolitan Urban Service Area
NBOD	Nitrogenous Biochemical Oxygen Demand
NCHF	North Central Hardwood Forest
NPDES	National Pollutant Discharge Elimination System
RR	Release rate
SID	Stressor Identification
SOD	Sediment Oxygen Demand
TAC	Technical Advisory Committee
TDLC	Total Daily Loading Capacity
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	Total Suspended Solids
USGS	U.S. Geological Survey
µg/L	microgram per liter
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategy
WWTF	Wastewater Treatment Facility

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses 22 impairments in the Elm Creek Watershed and 2 impairments in the Crow River Watershed, both of which are HUC-8 watersheds located in the upper Mississippi River Basin. Those in the Elm Creek Watershed include nutrient impairments in Fish Lake, Rice Lake, Diamond Lake, Goose Lake, and Henry Lake; *Escherichia Coli (E. coli)* bacteria impairments in Rush Creek-South Fork, Rush Creek mainstem, Diamond Creek, and Elm Creek; low dissolved oxygen (DO) impairments in Rush Creek mainstem, Diamond Creek, and Elm Creek; and both fish and Macroinvertebrate biotic integrity impairments for upper and lower reaches of the Rush Creek-South Fork, Rush Creek mainstem, Diamond Creek, and Elm Creek. The TMDL also includes nutrient impairments in Cowley Lake and Sylvan Lake in the Crow River Watershed.

All impaired water bodies lay within the jurisdictional limits of the Elm Creek Watershed Management Commission (ECWMC), who partnered with Minnesota Pollution Control Agency (MPCA) on this effort. The area within the jurisdictional limits of the ECWMC is about 83,600 acres (of which about 66,400 acres is the Elm Creek Watershed) and located in northwestern Hennepin County, Minnesota. The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for the impaired lakes and streams. 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 water bodies included.

Bacteria

Flow and bacteria monitoring data in Rush Creek-South Fork, Rush Creek mainstem, Diamond Creek, and Elm Creek were used to establish load duration curves (LDCs) to define the reductions necessary to meet the *E. coli* numeric standard. The TMDL, WLAs, and LAs were established for five flow categories: very high, high, mid-range, low and dry flow conditions. The necessary bacteria reductions range from no reduction to a 66% reduction during certain flow regimes to meet *E. coli* concentration standards. Implementation activities for the *E. coli*-impaired subwatersheds should focus on manure and pasture management initiatives, limiting livestock access to streams, septic system upgrades or hook-ups to regional sanitary collection and treatment facilities, and pet waste control measures.

Lakes

Nutrient budgets were developed for all seven lakes along with lake response models to set the WLAs and the Las for the TMDLs. Total nutrient reductions required to meet the lake water quality standards range from about 14% for Fish Lake (a deep lake) to between 73% and 89% to meet the shallow lake standards in the other six lakes. Nutrient reduction implementation strategies for all lakes should focus on both watershed and internal load reductions.

Fish/Macroinvertebrates and Low DO

The MPCA has developed an IBI to evaluate the biological health of streams in the state. There are IBIs for both fish and macroinvertebrates. Three stream reaches in the Rush Creek Subwatershed, as well as one reach each on Diamond Creek and Elm Creek, were listed as impaired for both fish and macroinvertebrate IBI. Impairment of the biological communities was most severe in the three stream reaches in the Rush Creek Subwatershed (Including the South Fork Subwatershed), moderate in Diamond Creek, and moderate to low in the Elm Creek, depending on the reach. In general, the analyses suggest that multiple factors appear to be impacting fish communities, while the macroinvertebrate communities are impacted by a narrower range of stressors.

A stressor identification (SID) report was completed by Lehr (2015) based on the U.S. Environmental Protection Agency's (EPA's) Causal Analysis/Diagnosis Decision Information System (CADDIS) approach. The outcome of the SID process provided guidance to address the non-pollutant stressors of altered hydrology and altered physical habitat and established the need to prepare TMDLs using a LDC approach to address the pollutant stressors of total suspended solids (TSS) and total phosphorus (TP). Recently adopted stream water quality standards for TSS and TP were used to determine which stream reaches required TMDLs, with Diamond Creek and Elm Creek (but not Rush Creek) showing moderate exceedances of the TSS standard and all five stream reaches showing significant exceedances of the TP standard. The frequency and magnitude of exceedances for both parameters were generally highest in the upper reaches of each of the affected streams, where rural and agricultural land uses currently dominate.

Multiple implementation elements to address impairments are presented. These include the following:

- Application of stringent stormwater mitigations standards adopted by the ECWMC. The standards are based in part on the MPCA's Minimal Impacts Design (MIDs) project, which establish an initial abstraction of 1.1 inches of runoff from new impervious surfaces as the basis for achieving the performance objective. The ECWMC will apply those standards to development projects submitted for review after January 1, 2015. Application of these standards will significantly reduce existing TP, TSS, and other pollutant loadings from landscapes where intensive agricultural uses are replaced with urban uses meeting the mitigation standards. It will also hold to "no net increase" pollutant loads from low-export pre-development land uses that are converted to urban land uses
- Adoption and execution of standards governing the siting and management of new non-production livestock operations, such as those often associated with "hobby" farms.
- Outreach to existing agricultural operations to identify and implement projects to reduce winter spreading of manure, limit access of livestock to riparian areas, install buffer strips between cropland and/or livestock holding areas and water bodies, and promote fertilizer applications to cropland based on soil test results and crop nutrient needs.
- Education of urban residents on good housekeeping practices, such as use of no-phosphorus fertilizers were appropriate, proper disposal of pet waste, and establishing un-maintained buffer strips adjacent to water bodies.
- Promoting projects to enhance physical stream habitat, promote infiltration to reduce surface water runoff and enhance stream baseflows, and address internal loading affecting lakes where needed through management of roughfish, curly-leaf pondweed, and enriched sediments.

1. Project Overview

1.1 Purpose

This TMDL study is one component of an overall Watershed Restoration and Protection Strategy (WRAPS) designed to protect and restore key water resources within the Elm Creek Watershed as well as within the jurisdictional limits of the ECWMC. This TMDL study addresses *E. coli* impairments in four stream reaches, nutrient impairments in seven lakes, low DO impairments in three stream reaches, and impairments for both fish and Macroinvertebrate biotic integrity in five stream reaches.

Figure 1 shows the hydrologic boundary of the Elm Creek Watershed, the jurisdictional limits of the ECWMC, key water features that will be addressed in this document, the municipalities that are included within the project area, and key cultural features. The Elm Creek Watershed covers an area of approximately 104 square miles (66,400 acres) and is located in the northwest part of the Minneapolis-St. Paul seven county Metro Area. The subwatershed is drained by Elm Creek and its major tributaries, Diamond Creek and Rush Creek. Water movement in the watershed is generally from the west and south to the north and east, with Elm Creek discharging to the Mississippi River in the city of Champlin. The area within the jurisdictional limits of the ECWMC is approximately 130.6 square miles (83,600 acres). The watershed includes all or part of seven municipalities: Champlin, Corcoran, Dayton, Maple Grove, Medina, Plymouth, and Rogers.

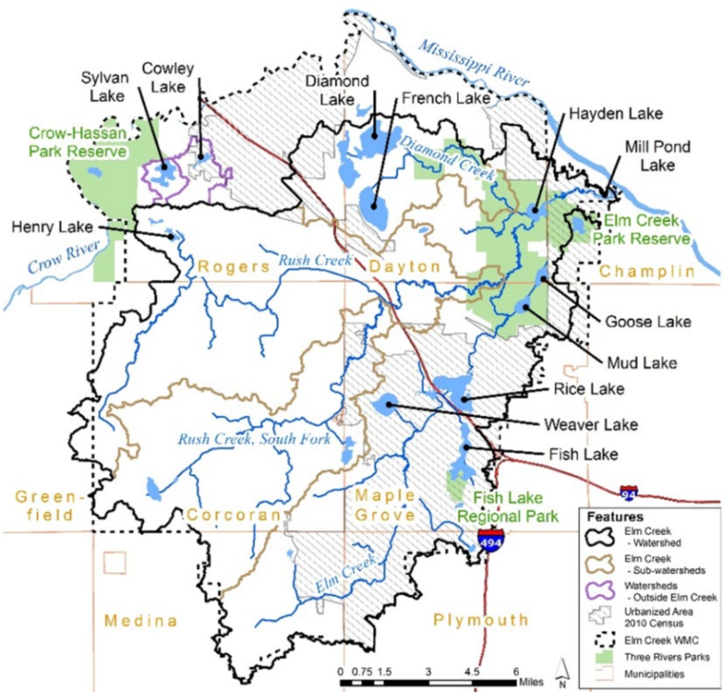


Figure 1. Elm Creek Watershed Location, Northwest Twin Cities Metro Area

All but two of the impaired waters that will be addressed in this document lie within the hydrologic boundary of the Elm Creek Watershed. The exceptions are Cowley Lake and Sylvan Lake, both of which lie to the northwest of the Elm Creek hydrologic boundary in the Crow River Watershed within the city of Rogers. The impairments for both lakes are addressed in this document because they lie within the jurisdictional boundaries of the ECWMC. Cowley Lake was listed as impaired for nutrients on the state's 303(d) list in 2010, while Sylvan Lake is expected to be listed as impaired for nutrients based on in-lake data collected as part of this project. Both the Commission and the MPCA felt it was important to address all current and reasonably expected impairments within the Commission's jurisdictional limits as part of this TMDL effort.

Figure 1 and Figure 2 shows the location of the Elm Creek Watershed in the state of Minnesota as well as within the state's ecoregions. The watershed is located entirely within the North Central Hardwood Forest (NCHF) Ecoregion.

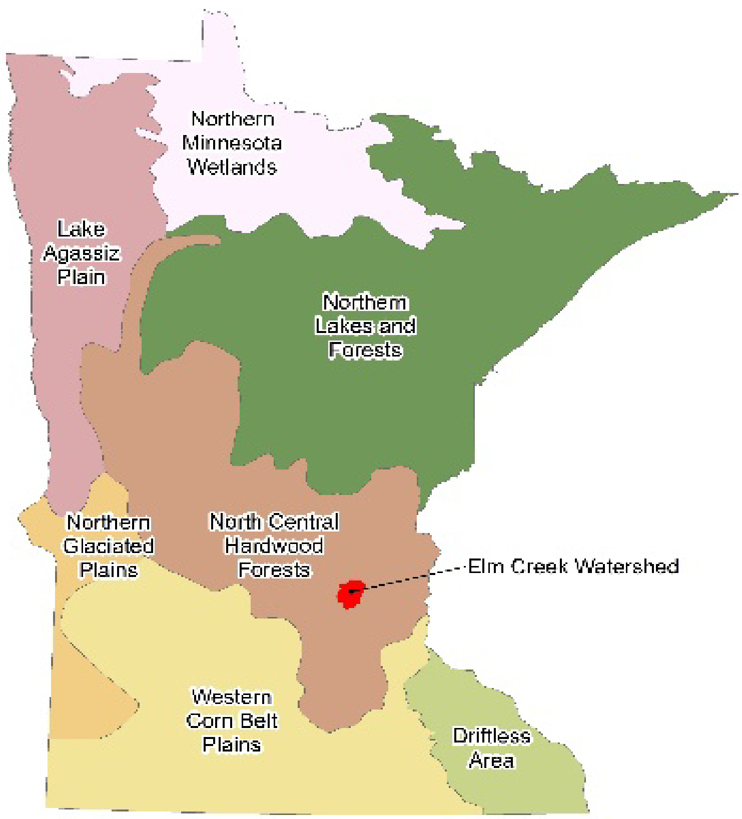


Figure 2. Location of Elm Creek Watershed within North Central Hardwood Forest Ecoregion

1.2 Identification of Waterbodies

Numerous chemical and biotic impairments have been identified based on monitoring data collected by the MPCA, the ECWMC, and others during the 10-year period between 2003 and 2012.

Table 1 summarizes the current impairment listings for the watershed. With the exception of the chloride impairment for Elm Creek and Rush Creek, South Fork (07010206-732), all the impairments in Table 1 will be addressed in this report. The chloride impairment for Elm Creek and Rush Creek, South Fork are addressed in the Twin Cities Metropolitan Area (TCMA) Chloride TMDL.

Table 1. Listed Impaired Waters in the Elm Creek Watershed

Listed Stream Name (Reach Description) or Lake Name	Year Listed	Assessment Unit ID (AUID)	Affected Use	Pollutant or Stressor	303(d) List Scheduled Start/Completion dates
Diamond Cr.	2010	07010206-525	Aquatic recreation	*E. coli*	2009//2014
Diamond Cr.	2010, 2014, 2014	07010206-525	Aquatic life	Low DO, Fish Bioassessment, Macroinvertebrate Bioassessment	2009//2014
Rush Cr.	2010	07010206-528	Aquatic recreation	*E. coli*	2009//2014
Rush Cr.	2010, 2002, 2014	07010206-528	Aquatic life	Low DO, Fish Bioassessment, Macroinvertebrate Bioassessment	2009//2014 (2009/2013 for Fish Bioassessment only)
Rush Cr., S. Fork	2010	07010206-732	Aquatic recreation	*E. coli*	2009//2014
Rush Cr., S. Fork	2014, 2014, 2014	07010206-732	Aquatic life	Fish bioassessment, Macroinvertebrate bioassessment, chloride	2009//2014 (2009/2015 for chloride only)
S. Fork Rush Cr.	2014, 2014	07010206-760	Aquatic life	Fish bioassessment, Macroinvertebrate bioassessment	2009//2014
Elm Cr. – Headwaters	2010	07010206-508	Aquatic recreation	*E. coli*	2009//2014
Elm Cr. – Headwaters	2004, 2014, 2014, 2014	07010206-508	Aquatic life	Low DO, Fish bioassessment, Macroinvertebrate bioassessment, chloride	2009//2014 (2009/2015 for chloride only)
Cowley Lake	2010	27-0169	Aquatic Recreation	Nutrients	2009//2014
Diamond Lake	2006	27-0125	Aquatic Recreation	Nutrients	2009//2014
Fish Lake	2008	27-0118	Aquatic Recreation	Nutrients	2009//2014
Henry Lake	2008	27-0175	Aquatic Recreation	Nutrients	2009//2014
Rice Lake – Main	2010	27-0116-01	Aquatic Recreation	Nutrients	2009//2014
Sylvan Lake	Anticipated 2016*	27-0171	Aquatic Recreation	Nutrients	(2016//2018)
Goose Lake	Anticipated 2016*	27-0122	Aquatic Recreation	Nutrients	(2016//2018)

*Recent local water quality data indicates multiple exceedances of the standard. A formal assessment and listing process will be conducted when the data are received.

1.3 Priority Ranking

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

2. Applicable Water Quality Standards and Numeric Water Quality Targets

2.1 State of Minnesota Designated Uses

All waters listed in Table 1 are classified as class 2B waters for which aquatic life and recreation are the protected beneficial uses.

2.2 State of Minnesota Standards and Criteria for Listing

Following is a brief summary of the numerical water quality standards adopted by the state of Minnesota for the impairments that are addressed in this document.

E. coli. With the revisions of Minnesota's water quality rules in 2008, the state has now changed from a fecal coliform standard to an *E. coli* standard because of the latter's superior potential as an indicator of illness risk and lower cost for analysis (MPCA 2007). The revised standard now states:

> "*E. coli* concentrations are not to exceed 126 colony forming units per 100 milliliters (cfu/100ml) as a geometric mean of not less than five samples representative of conditions within any given calendar month, nor shall more than 10% 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."

Nutrients. Minnesota's standards for nutrients limit the quantity of nutrients which may be found in surface waters. Minnesota's standards at the time of listing (Minn. R. 7050.0150, subp. 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 Minn. R. 7050.0150, subp. 5, to evaluate whether a water body is in an impaired condition, the MPCA has 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 translators established numeric thresholds for phosphorus, chlorophyll-a (Chl-*a*), and water clarity as measured by Secchi depth.

Minnesota adopted lake water quality standards in 2008 that differentiate between "deep" lakes and "shallow" lakes. 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 or submergent rooted aquatic plants (littoral zone). Conversely, deep lakes are defined as those with maximum depths over 15 feet and as having less than 80% of the lake area as littoral zone. This TMDL addresses impairments for both deep and shallow lakes. The numeric eutrophication standards that apply to each type of lake for the NCHF Ecoregion are presented in Table 2. In developing the lake nutrient standards for Minnesota lakes (Minn. R. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (MPCA 2005). Clear relationships were established between the causal factor TP and the response variables Chl-*a* and Secchi transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the Chl-*a* and Secchi standards will likewise be met.

Table 2. Numeric Eutrophication Standards for Shallow and Deep Lakes within the NCHF Ecoregion

Parameters	Shallow Lakes[1]	Deep Lakes[1]
TP concentration (µg/L)	60	40
Chl-a concentration (µg/L)	20	14
Secchi disk transparency (meters)	>1.0	>1.4

[1] Numeric standards are June 1 – September 30 mean values

Low DO. Minnesota's water quality standard for DO for Class 2 waters is set forth in Minn. R. 7050.0222, subps. 2, 3, 4, and 5. Minn. R. 7050.0222, subp. 4, of this section address Class 2B surface waters as follows:

> "The quality of Class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable.
>
> *DO 5.0 mg/l as a daily minimum*
>
> This DO standard may be modified on a site-specific basis according to subpart 8, except that no site-specific standard shall be less than 5 mg/l as a daily average and 4 mg/l as a daily minimum. Compliance with this standard is required 50% of the days at which the flow of the receiving water is equal to the lowest weekly flow with a once in 10-year recurrence interval (7Q10). . . " **.**

High stream phosphorus levels are implicated later in this report as a significant cause of low DO conditions that contribute to degraded stream biologic communities throughout the Elm Creek Watershed. The Elm Creek Watershed project area is located within the Central River Region as identified in the technical support document for stream phosphorus standards (MPCA 2013). Streams within the Central River Region are considered impaired if the mean summertime (June through September) values are greater than 100 ug/l.

Biotic Integrity. Minnesota's standard for biotic integrity is stated in Minn. R. 7050.0150, subps. 3 and 6. The standard uses an IBI which evaluates and integrates multiple attributes of the aquatic community, or metrics, to evaluate a complex biological system. Each metric is based on 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 to 100, with 100 reflecting the healthiest biotic community possible. The MPCA has evaluated fish and macroinvertebrate communities at numerous reference sites across Minnesota that has been minimally impacted by human activity, and has established IBI impairment thresholds based on stream drainage area, ecoregion, and major drainage basin. A stream's biota is considered to be impaired when the IBI falls below the threshold established for that category of stream. High stream TSS levels are implicated later in this report as a significant stressor to biologic communities in several stream reaches in the Elm Creek Watershed. The Elm Creek Watershed project area is located within the Central River region as identified in the technical support document for stream TSS standards (MPCA 2014). A stream within the Central River region is considered impaired for TSS if more than 10% of the April through September samples exceed 30 mg/l.

3. Watershed and Waterbody Characterization

3.1 Lakes

Table 3 shows basin morphometric data and watershed information for each of the seven lake impairments that will be addressed in this document.

Table 3. Key Information for Elm Creek Watershed Project Area Lakes Listed as Impaired

	Cowley	Diamond	Fish	Henry	Rice (Main)	Sylvan	Goose
DNR ID	27-0169	27-0125	27-0118	27-0175	27-0166-01	27-0171	27-0122
Surface Area (ac)	32.9	388.7	238.3	47.0	330.2	148.1	64.4
Max Depth (ft)	8	7.4	60.8	8.2	11	15	6.6
Mean depth (ft)	4.8	4	18.8	2.8	7.0	7.0	4.2
Volume (ac-ft)	155	1516	4364	121.2	2153	1021	270
Residence Time (yrs)	0.33	0.64	4.3	0.31	0.16	4.9	2.4
Littoral area (ac)	32.9	388.7	89.6	47.0	330.2	148.1	64.4
Littoral area (%)	100%	100%	38.6%	100%	100%	100%	100%
Watershed area (ac)	827	2,579	1616	812	17,461	320	240
Watershed area: lake area ratio	25.5 : 1	6.6 : 1	6.8 : 1	17.3 : 1	53 : 1	2.2: 1	3.7: 1
Municipalities in watershed	Rogers	Dayton, Rogers	Maple Grove, Plymouth	Rogers	Maple Grove, Plymouth, Medina, Corcoran	Rogers	Dayton, Champlin

Note that of the seven lakes identified in Table 3 and Table 4, all but Fish Lake are considered “shallow” lakes. In addition, Cowley, Henry, and Rice lakes all have moderate to very large watersheds draining to them relative to each lake’s surface area. Generally, shallow lakes with large contributing watersheds relative to their lake area present significant challenges in achieving in-lake water quality goals.

3.2 Streams

Table 3 presents information for each of the stream reaches listed as impaired and that will be addressed in this document.

Table 4. Key Information for Elm Creek Watershed Stream Reaches Listed as Impaired

	Elm Creek	**Rush Creek**	**Rush Creek-South Fork**	**Rush Creek-South Fork**	**Diamond Creek**
Reach AUID	07010206-508	07010206-528	07010206-732	07010206-760	07010206-525
Reach Length (mi)	21.1	16.9	4.2	0.5	5.9
Impairment listings	Fish and Macroinvertebrate IBI, *E. coli*, DO, chloride[1]	Fish and Macroinvertebrate IBI, *E. coli*, DO	Fish and Macroinvertebrate IBI, *E. coli*, chloride[1]	Fish and Macroinvertebrate IBI	Fish and Macroinvertebrate IBI, *E. coli*, DO
Watershed Area (ac) at bottom of reach	66,400	32,600	13,700 (2,240 between top and bottom of AUID)	6,750 (230 between top and bottom of AUID)	6,750
Municipalities in Watershed	Champlin, Dayton, Rogers, Maple Grove, Corcoran, Plymouth, Medina	Dayton, Rogers, Maple Grove, Corcoran, Medina	Maple Grove, Corcoran	Corcoran	Dayton, Rogers

[1]Note that the chloride impairments for Elm Creek and Rush Creek, South Fork (-732) will not be covered in this document but rather as part of the TCMA Chloride TMDL (MPCA 2016).

Figure 3 shows the locations of, and labels for, stream monitoring stations in the Elm Creek Watershed. Also shown are the municipal boundaries, the impairments for each of the stream reaches that will be addressed in this document, and AUID designations for each reach.

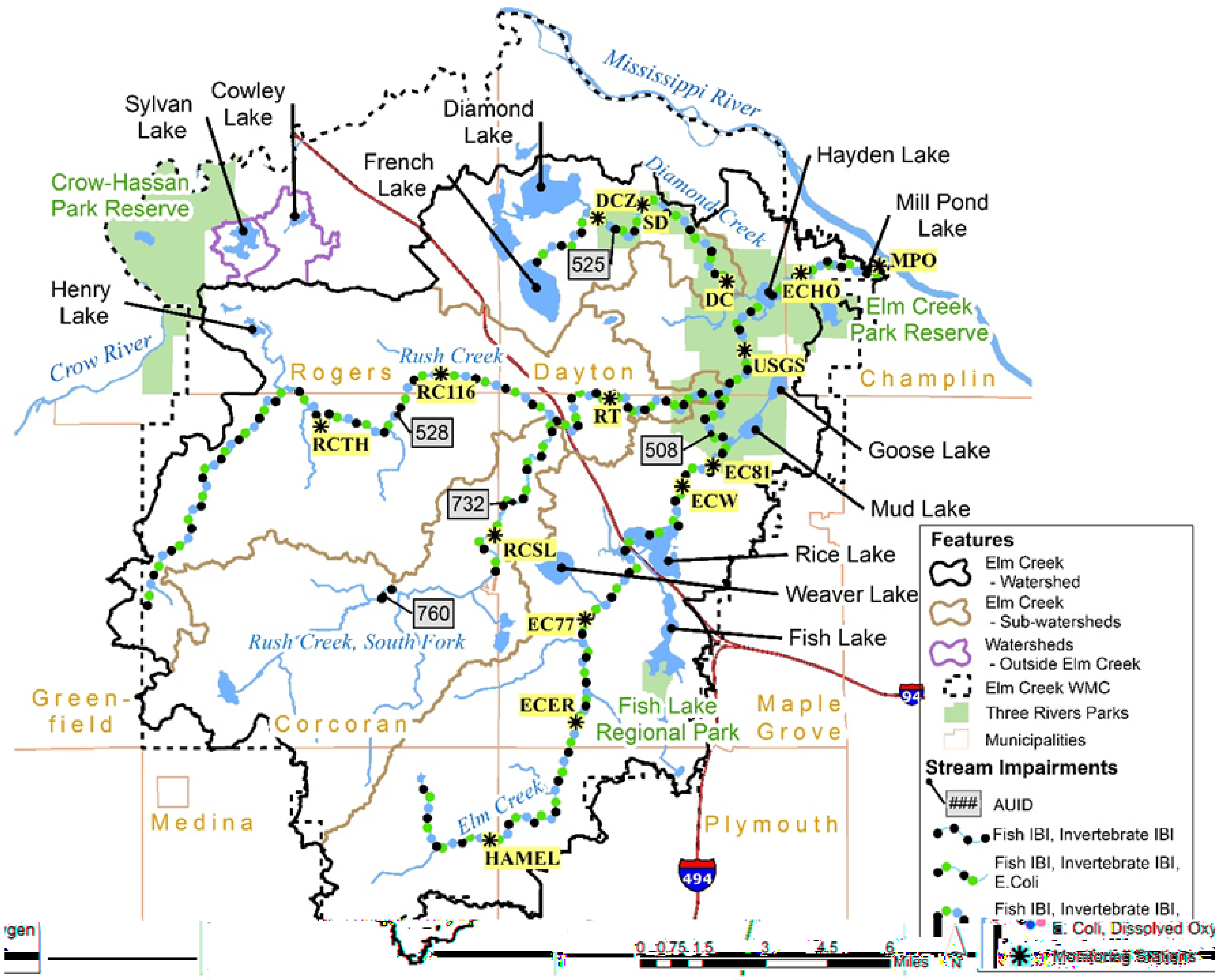


Figure 3. Stream Impairments and Monitoring Stations for Elm Creek Watershed

3.3 Land Use and Subwatersheds

Figure 4 shows 2010 land cover for the Elm Creek Watershed project area based on Metropolitan Council data and Table 5 summarizes land cover in the watershed by major land cover category. As noted in Section 1.1, Cowley and Sylvan Lakes are the only water bodies to be addressed in this document that lie outside the hydrologic boundary of the Elm Creek Watershed. Both Table 4 and Table 5 show the land cover characteristics of the Elm Creek Watershed as a whole in the far left-hand column, then separate land use data for the Rush Creek and Diamond Creek Tributary Subwatersheds, respectively, in the columns in the middle of the table. Land use data for the Sylvan Lake and Cowley Lake Subwatersheds are presented separately in the far right-hand columns.

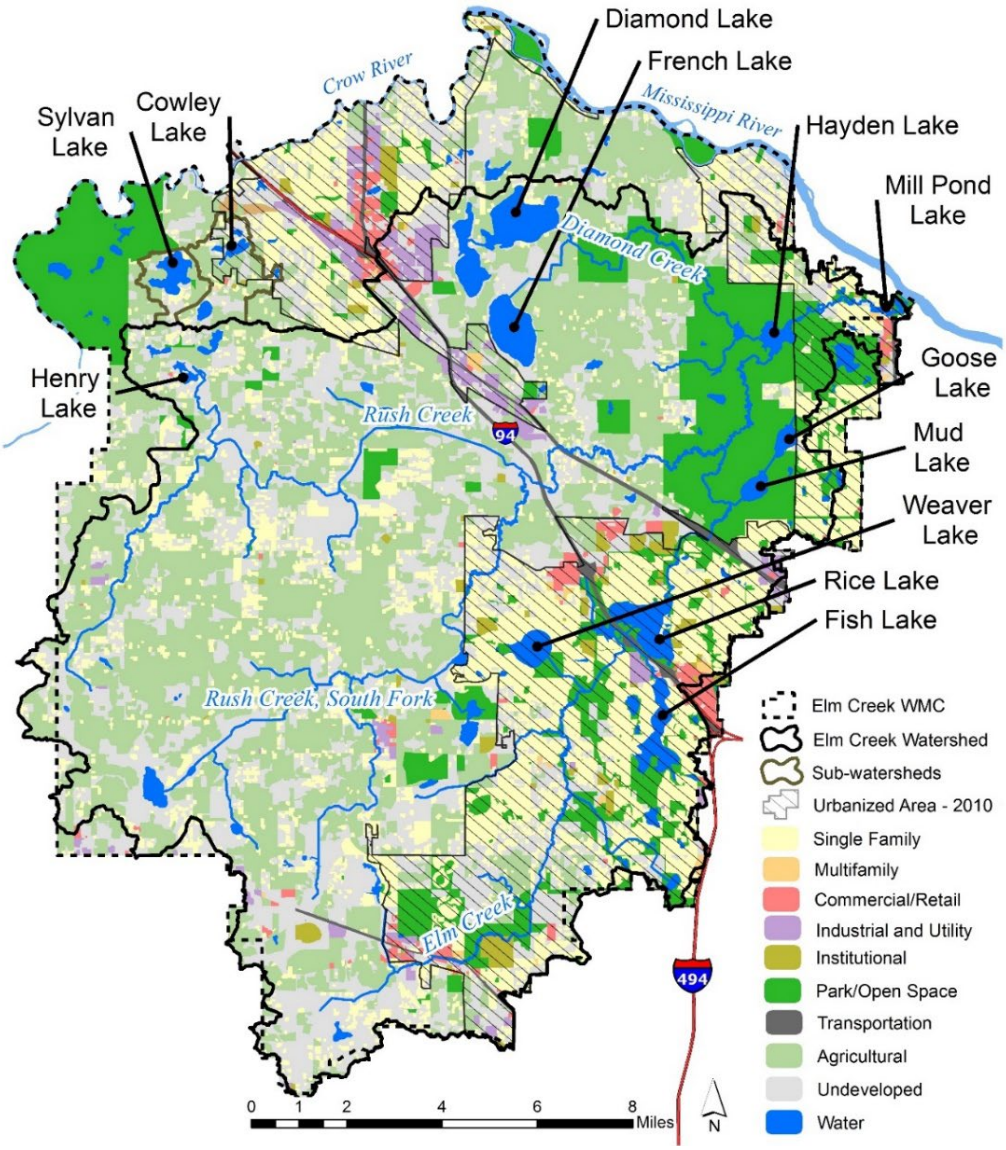


Figure 4. 2010 Land Cover in the Elm Creek, Cowley Lake, and Sylvan Lake Watersheds

Table 5. Summary of 2010 Land Cover in the Elm Creek, Cowley Lake, and Sylvan Lake Watersheds

Land Cover	Elm Creek Watershed[1]		Rush Creek sub-watershed		Diamond Creek sub-watershed		Cowley Lake sub-watershed[2]		Sylvan Lake sub-watershed[2]	
	Area (ac.)	%	Area (ac.)	%	Area (ac.)	%	Area (ac.)	%	Area (ac.)	%
Agricultural	21,309	32.1 %	15,359	47.5 %	2,379	36.2%	401	48.4%	170	53.3 %
Undeveloped	18,089	27.2 %	10,624	32.9 %	1,538	23.4%	259	31.4%	83	25.8 %
Park and Open Space	8,509	12.8 %	1,038	3.2%	1,057	16.1%	1	0.1%	9	2.8 %
Single Family	12,531	18.9 %	4,108	12.7 %	293	4.5%	98	11.8%	58	18.1 %
Multifamily	217	0.3%	32	0.1%	47	0.7%	4	0.5%	0	0.0 %
Retail/Commercial	739	1.1%	93	0.3%	103	1.6%	4	0.5%	0	0.0 %
Industrial/Utility	1,057	1.6%	370	1.1%	390	5.9%	0	0.0%	0	0.0 %
Institutional	822	1.2%	135	0.4%	30	0.5%	7	0.8%	0	0.0 %
Transportation	763	1.1%	225	0.7%	81	1.2%	0	0.0%	0	0.0 %
Water	2,347	3.5%	332	1.0%	654	10.0%	53	6.4%	0	0.0 %
Total	**66,382**		**32,315**		**6,571**		**827**		**320**	

1 Includes land areas for Rush Creek and Diamond Creek Subwatersheds, but not Cowley Lake and Sylvan Lake (since both lie outside the Elm Creek Watershed hydrologic boundary)

2 Excludes area of lake itself

Land use information of interest for this project includes the following:

1. The dominant land use in 2010, in the project area was agricultural, comprising about 32% of the Elm Creek Watershed, and 47% and 39% of the subwatershed area for Cowley Lake and Sylvan Lake, respectively. Cropland and pasture together make up most of this land use category.
2. Only about 25% of the Elm Creek Watershed is developed clustered in the eastern part of the watershed and along the Interstate 94 corridor. Less than 15% of the subwatershed area for Cowley Lake and Sylvan Lake are developed.
3. Undeveloped, a category which includes undevelopable wetlands in addition to lands that are currently vacant and developable is about 27% of the Elm Creek Watershed area.
4. Based on a review of the comprehensive land use plans prepared by each community within the project area, approximately 27,000 acres (about 40% of the area of the Elm Creek Watershed) are

expected to change land use between 2010 and 2030. For the Cowley Lake and Sylvan Lake Subwatersheds, the expected change is even larger, at 60% and 79%, respectively.

5. About 29% of the Elm Creek Watershed is designated as being within the Urbanized Area as defined by the 2010 census. Most of the area comprising the Rush Creek Subwatershed lies outside the 2010 Urbanized Area.
6. Similarly, about 53% of the watershed is within the Metropolitan Urban Service Area (MUSA). This relatively high percentage reflects the anticipation by regional and local governments of significant urban development in the future.

The 2010 census population of the watershed was about 93,000 persons in 33,600 households.

3.4 Current/Historic Water Quality

3.4.1 *E. coli*

A stream reach is placed on the 303(d) list of waters impaired for *E. coli* if the geometric mean of the aggregated monthly *E. coli* concentrations for one or more months exceeds 126 organisms per 100 ml (the "chronic" standard). A geometric mean is used to describe the central tendency of a set of data by dampening the effect of very high or very low numbers and is preferable to the arithmetic mean for analyzing bacteria data. A reach is also considered impaired if more than 10% of the individual samples within a month exceed the "acute" standard of 1,260 organisms per 100 ml.

Table 6 shows the monthly geomeans for April through October for all sample stations within the four *E. coli* impaired reaches in the Elm Creek Watershed. The data presented include the geometric means at each station in an upstream to downstream order for each impaired reach, the total number of samples, and the percentage of samples exceeding the acute standard of 1,260 organisms per 100 ml. Exceedances of the chronic and acute standard are highlighted in red. Data used are from the time period 2003 through 2012.

The data presented indicate that the most severe exceedances of the *E. coli* standard lie in the upper portions of the impaired stream reaches and in the areas of the Elm Creek Watershed that are dominated by rural and agricultural land uses. None of the data for monitoring stations below Station EC81 on Elm Creek show exceedances of either the acute or chronic *E. coli* standard in any month.

Table 6. Monthly Geometric Mean Values for *E. coli* - Impaired Stream Reaches

AUID 07010206-508 (Elm Creek)		**April**			**May**			**June**			**July**			**August**			**September**			**October**			**All Months**		
Site	Data Years	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260
Hamel	2007-2012	15	74	7%	22	141	18%	22	263	9%	24	165	8%	25	180	12%	23	85	22%	26	129	12%	157	141	13%
ECER	2007-2012	11	31	0%	23	117	0%	22	185	5%	24	135	4%	21	220	10%	23	174	13%	20	165	10%	144	142	6%
EC77	2007-2012	12	33	0%	24	56	4%	22	157	5%	24	249	4%	25	207	4%	24	235	4%	24	125	8%	155	137	5%
ECW	2009-2012	10	6	0%	18	25	0%	18	36	0%	18	22	0%	19	44	0%	13	83	0%	9	24	11%	105	29	1%
EC81	2009-2012	12	15	0%	18	70	6%	19	132	0%	18	143	6%	19	182	5%	16	197	6%	18	99	11%	120	103	5%
USGS	2009-2012	11	30	0%	18	58	0%	18	91	0%	19	61	0%	19	109	5%	16	98	0%	19	60	0%	120	70	1%
ECHO	2009-2012	11	12	0%	19	25	0%	18	65	0%	18	56	0%	19	78	0%	17	114	0%	18	126	6%	120	57	1%
MPO	2009-2012	11	16	0%	14	42	0%	14	52	7%	18	37	6%	19	14	0%	16	21	0%	18	55	0%	110	30	2%

AUID 07010206-528 (Rush Creek)		**April**			**May**			**June**			**July**			**August**			**September**			**October**			**All Months**		
Site	Data Years	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260
RCTH	2007-2012	12	9	0%	24	28	0%	23	113	4%	18	185	0%	17	295	12%	7	85	14%	13	110	15%	114	79	5%
RC116	2007-2012	12	10	0%	24	39	0%	22	151	9%	24	239	17%	24	202	21%	20	105	15%	19	51	11%	145	91	11%
RT	2007-2012	12	25	0%	23	30	0%	22	43	0%	25	52	0%	25	51	4%	22	47	0%	20	94	5%	149	46	1%

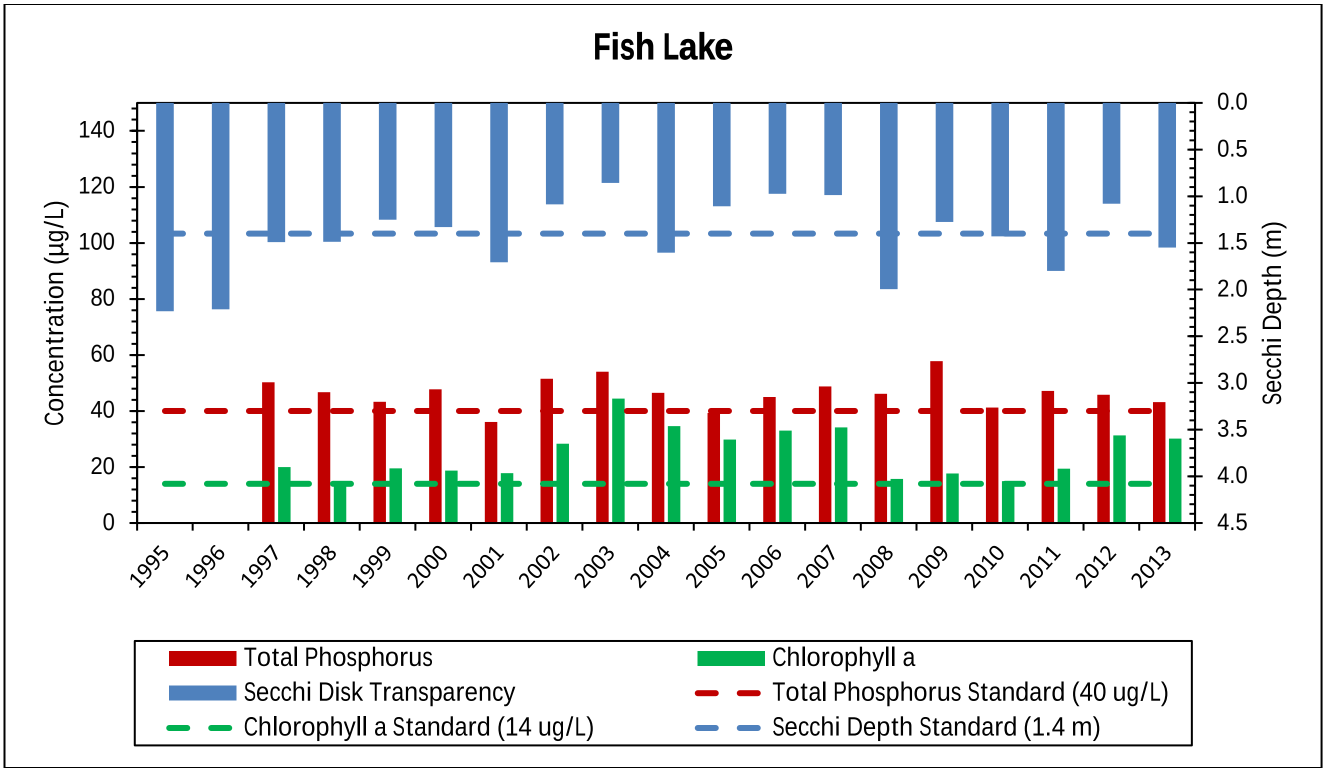
AUID 07010206-732 (Rush Creek South Fork)		**April**			**May**			**June**			**July**			**August**			**September**			**October**			**All Months**		
Site	Data Years	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260
RCSL	2007-2012	13	53	0%	23	79	9%	23	129	0%	22	151	5%	25	141	8%	19	308	21%	18	342	28%	143	145	10%

AUID 07010206-525 (Diamond Creek)		**April**			**May**			**June**			**July**			**August**			**September**			**October**			**All Months**		
Site	Data Years	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260	n	Geo	%n > 1260
DCZ	2007-2012	12	125	0%	23	125	9%	22	89	5%	21	225	24%	23	374	22%	20	136	10%	23	149	13%	144	160	13%
SD	2009, 2012	0			7	106	0%	9	182	22%	10	134	0%	8	175	0%	5	219	0%	5	113	0%	44	150	5%
DC	2007-2012	13	10	0%	23	40	0%	23	46	4%	23	94	0%	25	213	8%	20	202	0%	21	166	14%	148	84	4%

Notes: n = number of samples
Geo = Geometric mean in MPN/100 ml
Values in red indicate violation of standard

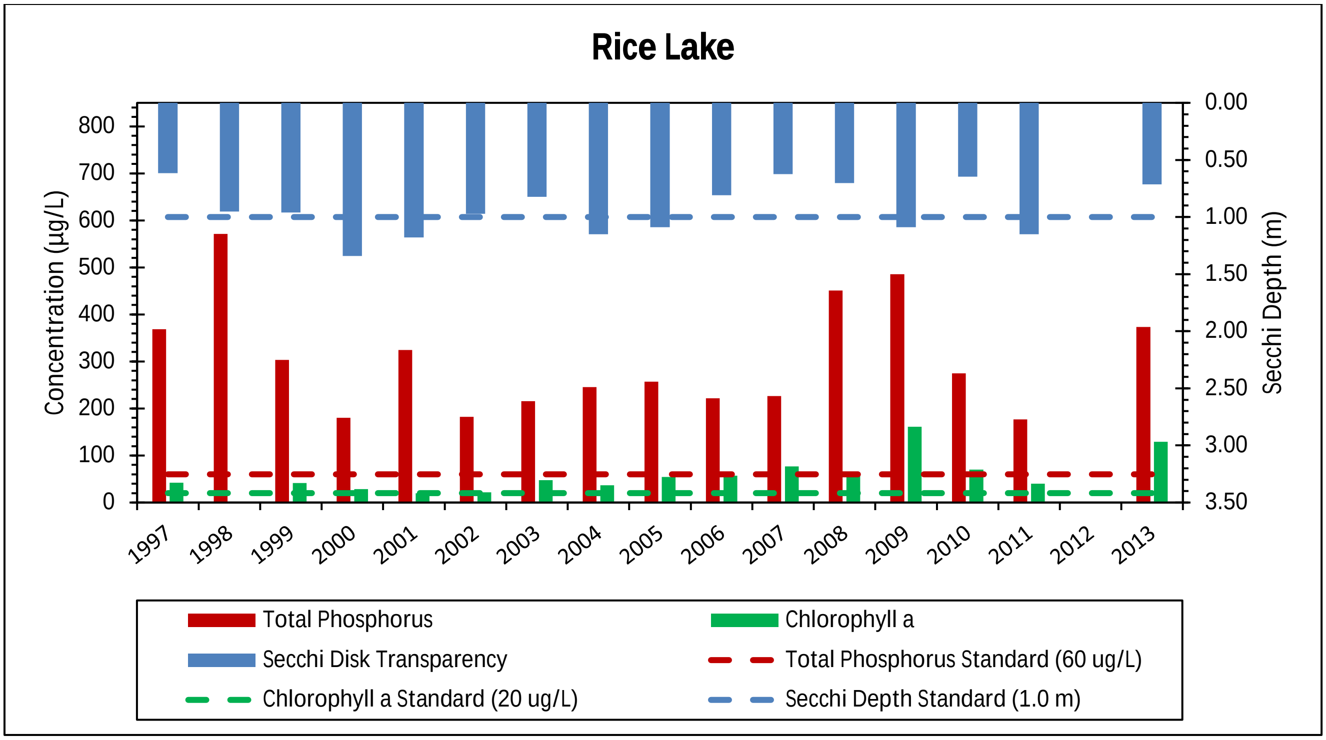
3.4.2 Nutrients (Lakes)

Historical surface water quality data for TP, Chl-*a*, and water clarity for all seven lakes addressed in this report are summarized in Figure 5. Where data are available, the data presented in the figures extend back to mid-1990, though the focus for this TMDL is the 10-year period between 2003 and 2012. The data presented are mean values over the June through September period for each year. Dashed colored lines on each graph reflect the standard for a particular parameter (red for TP, green for Chl-*a*, and blue for Secchi disk transparency) for the NCHF ecoregion. Only Fish Lake is classified as a deep lake, therefore the eutrophication standards denoted on graph for Fish Lake are those for deep lakes. The remaining six lakes are all classified as shallow lakes and the graphs for each reflect those standards.



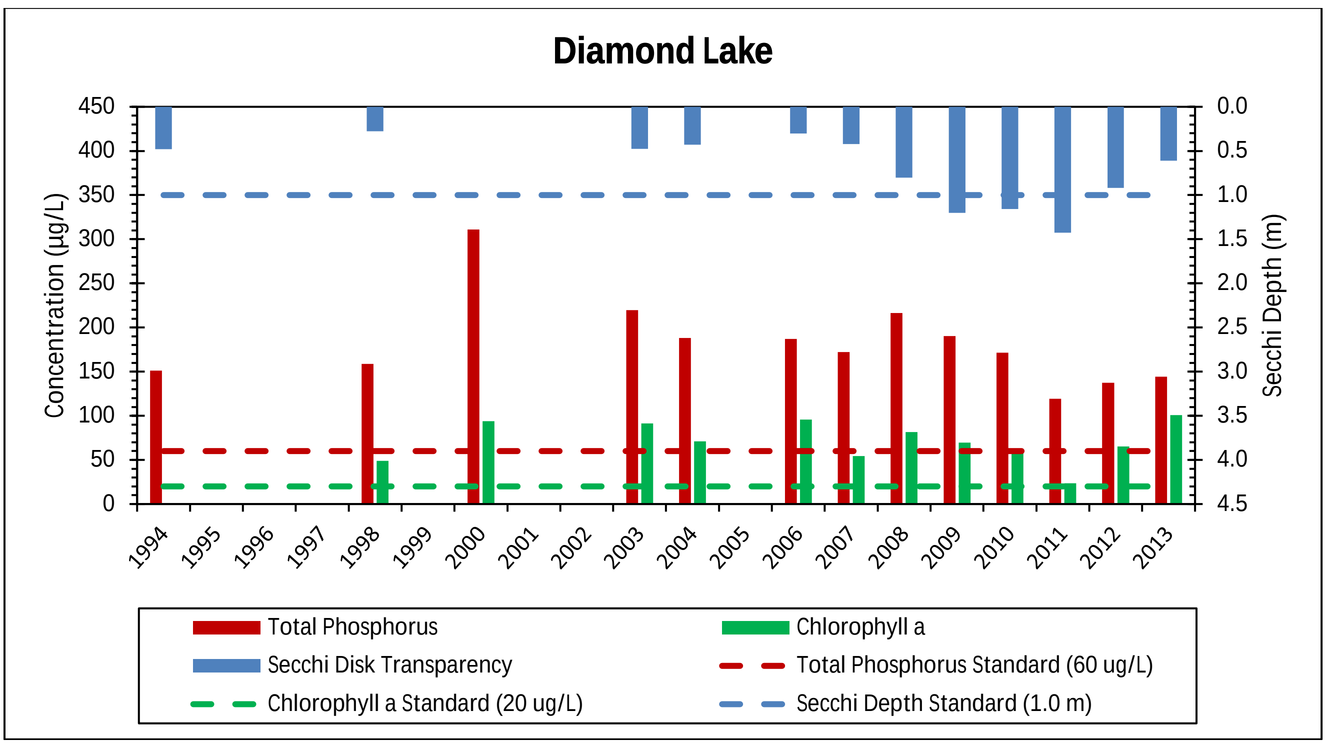
MPCA assessment period for listing determination 1998-2007.

Figure 5. Fish Lake Summer Average (June - September) Water Quality Data



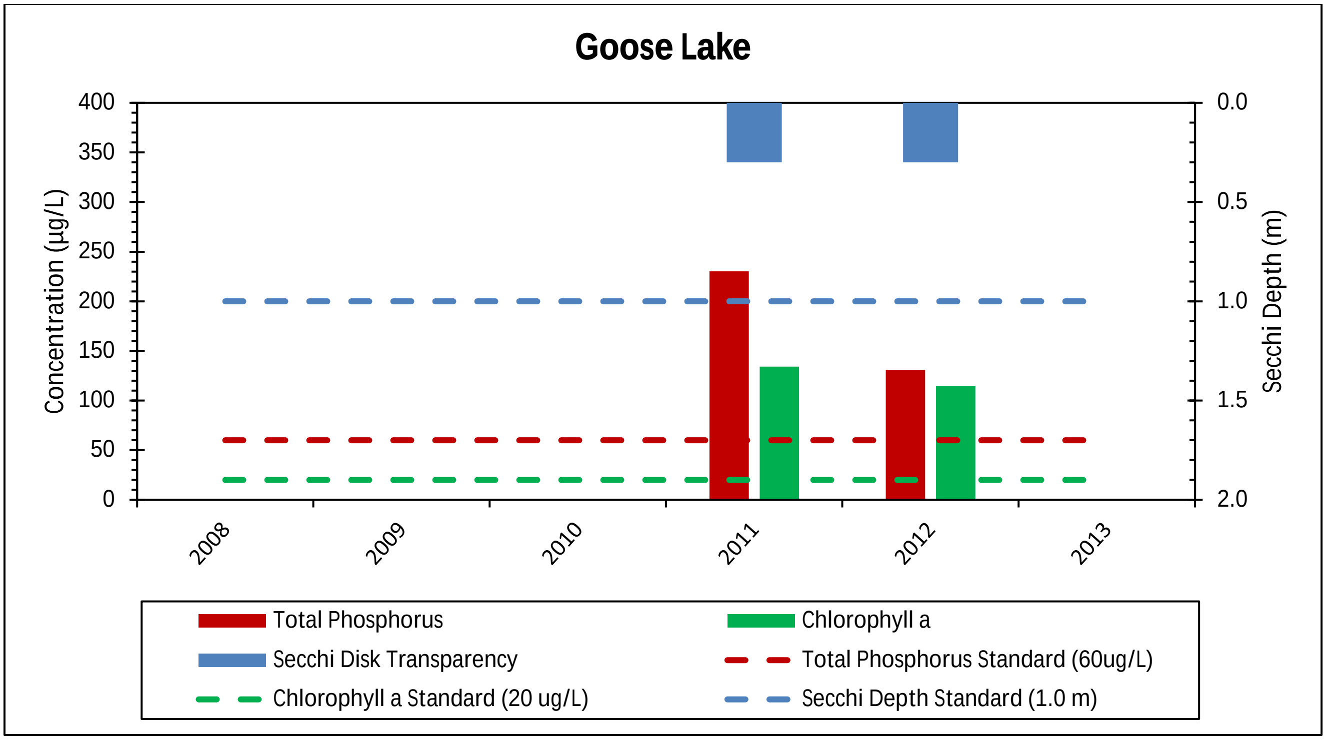
MPCA assessment period for listing determination 2000-2009.

Figure 6. Rice Lake Summer Average (June - September) Water Quality Data



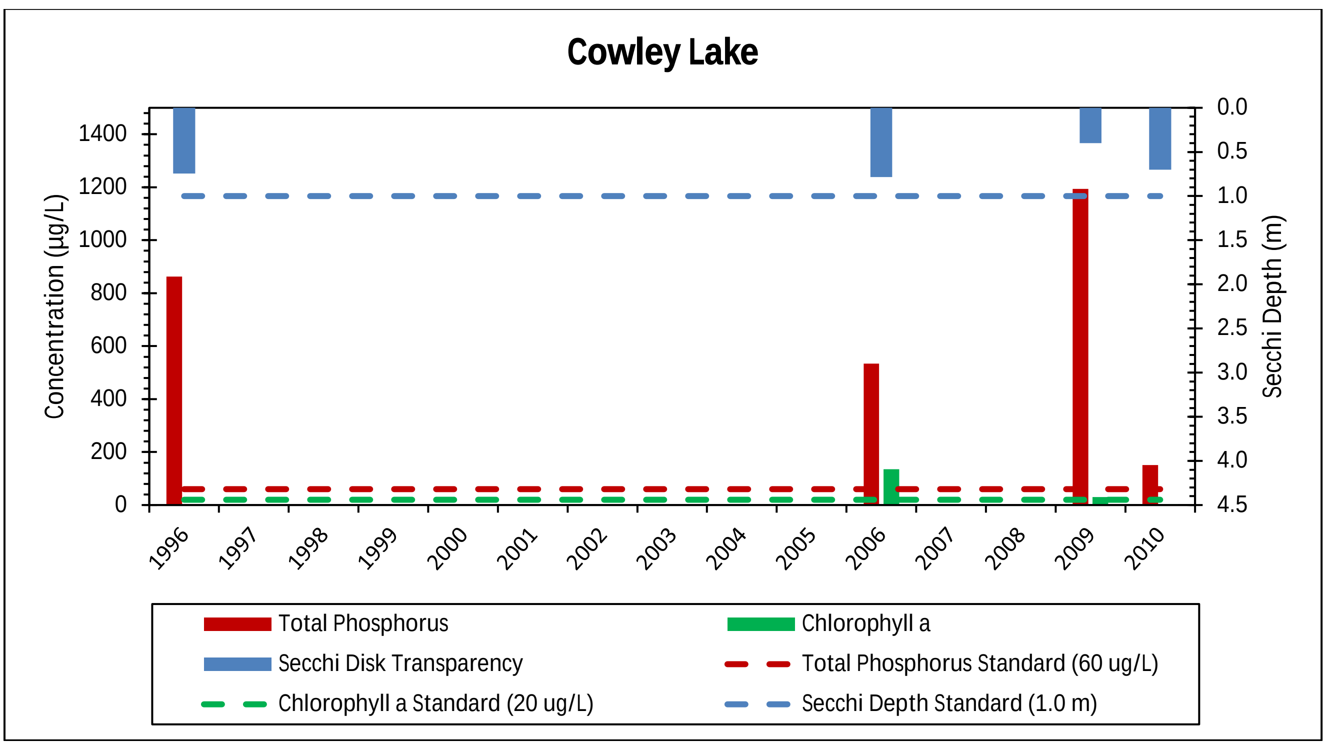
MPCA assessment period for listing determination 1996-2005.

Figure 7. Diamond Lake Summer Average (June - September) Water Quality Data



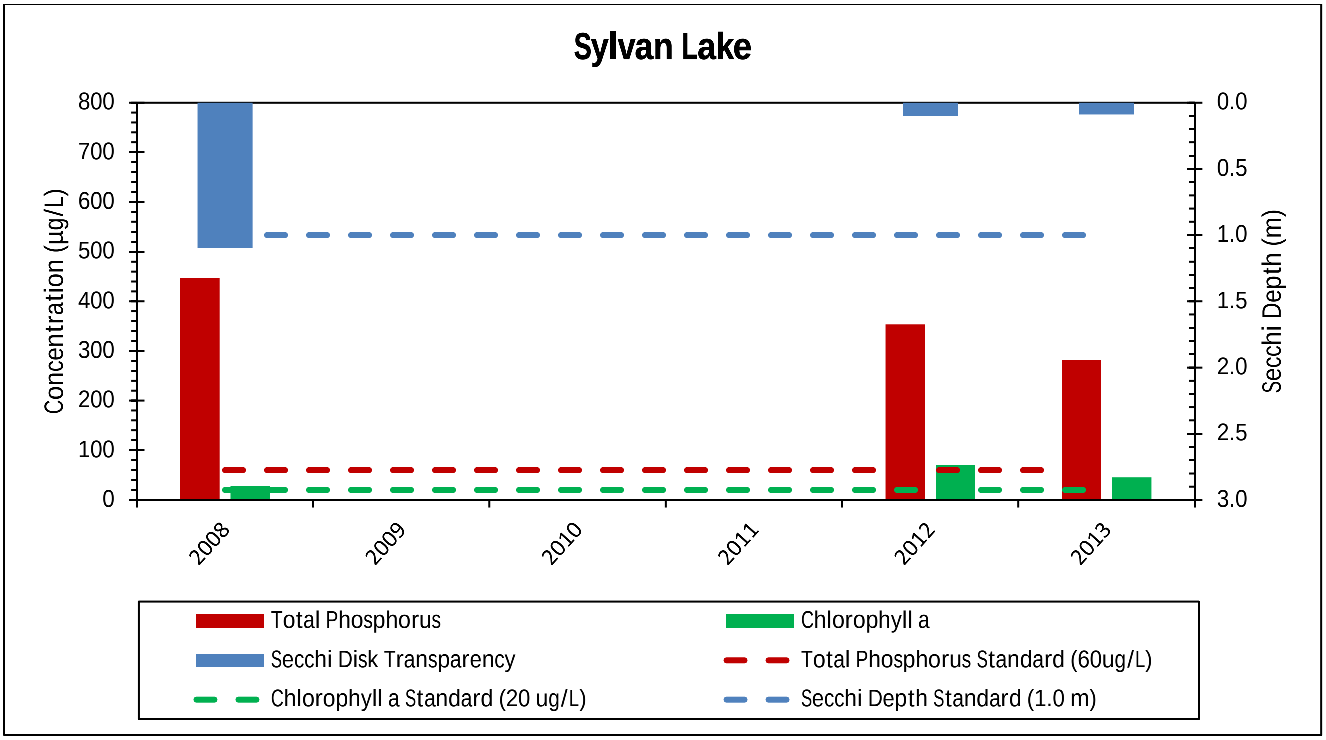
MPCA assessment period for listing determination 2006-2015.

Figure 8. Goose Lake Summer Average (June - September) Water Quality Data



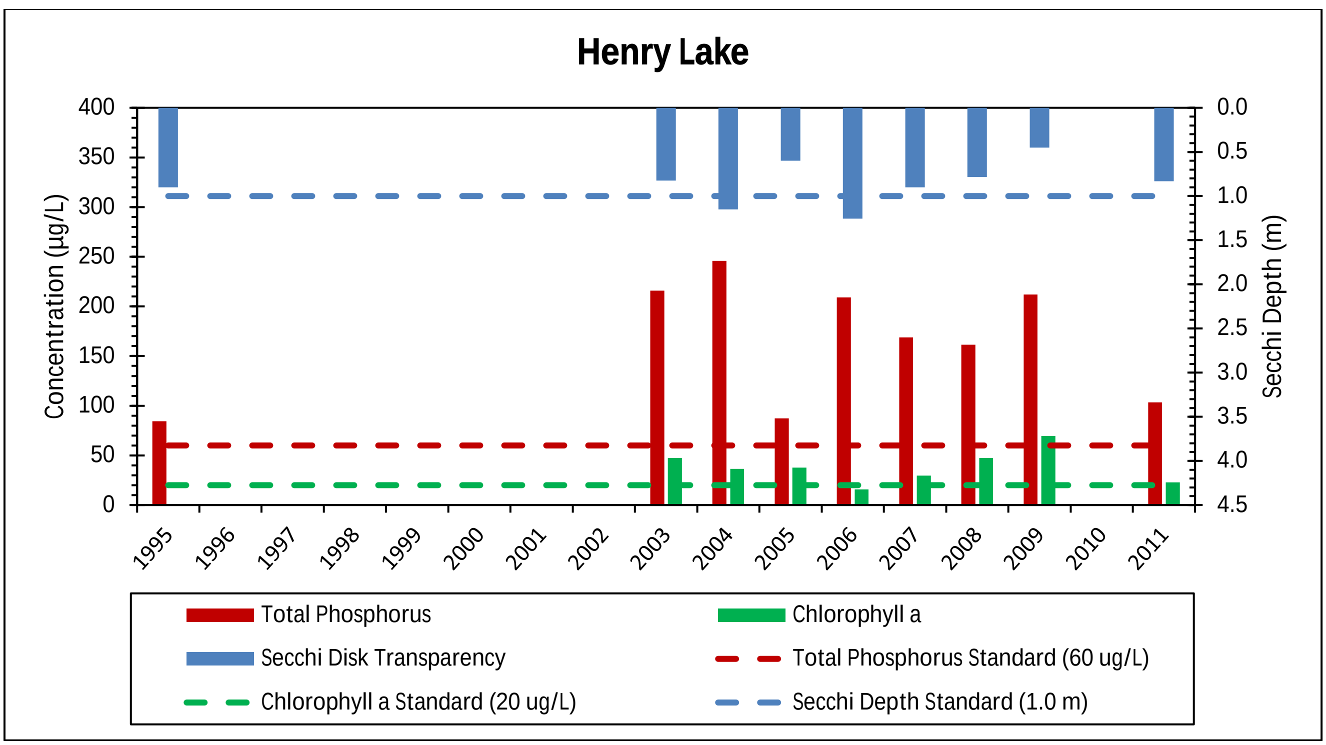
MPCA assessment period for listing determination 2000-2009.

Figure 9. Cowley Lake Summer Average (June - September) Water Quality Data



MPCA assessment period for listing determination 2006-2015.

Figure 10. Sylvan Lake Summer Average (June - September) Water Quality Data



MPCA assessment period for listing determination 1998-2007.

Figure 11. Henry Lake Summer Average (June – September) Water Quality Data

Fish Lake is the only lake that has been consistently close to meeting in-lake water quality standards for all three parameters in the last 10 years, but especially since 2006. Of the remaining lakes, Diamond Lake appears to show a moderate improving trend in water quality, with data for 2011 showing that the lake met standards for the two "response" variables (Chl-*a* and Secchi disk transparency). Henry Lake also met water quality standards for the two response variables in 2006, and has been close in several other years since 2003. The Chl-*a* and Secchi disk transparency data for Rice Lake have been influenced by copper sulfate treatments in 2005, 2006, and 2007 to control nuisance algal blooms. Overall, most of the shallow lakes covered in this TMDL show elevated TP concentrations, while Chl-*a* and Secchi disk transparency are generally closer to meeting their respective standards.

Based on information in MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List (2014), a finding that a lake is no longer impaired for nutrients starts with the following;

- there must be at least 8 paired TP, corrected chlorophyll a, and Secchi disk transparency measurement (June through September) over a minimum of 2 years for the most recent 10 years and;
- the data must show that TP and either corrected Chl-*a* or Secchi transparency meet their respective standards or;
- that TP exceeds the standard but both corrected chlorophyll a and Secchi disk transparency meet the standards. An improving trend in TP must also be in evidence or there must be documentation of management activities that are in place to maintain improved chlorophyll a or transparency conditions.

3.4.3 Low DO

Based on their classification as 2B waters, a concentration of 5 mg/l of DO as a daily minimum is the applicable standard for the three stream reaches in the Elm Creek Watershed that are listed as being impaired for low DO. Based on the MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List (2014), a stream is considered impaired if:

1. more than 10% of the "suitable" readings (defined as being taken before 9 a.m. each day) between May and September, or more than 10% of the total data points taken between May and September, or;
2. more than 10% of the October through April measurements violate the standard and;
3. there are at least three violations and at least 20 independent observations

Table 7 and Table 8 summarize the information on the DO monitoring data collected at each monitoring site within each of the three stream reaches listed as impaired for low DO. Table 7 summarizes data generated by periodic instantaneous readings of DO during routine site visits, while Table 8 summarizes data taken by instruments (sondes) deployed in the field that generate a continuous record of DO at the site over weeks or months. Where multiple monitoring sites lie within a single impaired reach, the data is presented for those monitoring sites in upstream to downstream order. The information presented includes the site, the period of record for the data presented, the number of data points, and the number of data points with values less than 5 mg/l. Numbers in red indicate those sites where more than 10% of the recorded data was below the 5 mg/l standard. The location of the monitoring stations is shown in Figure 3.

Table 7. Summary of DO Data for Impaired Stream Reaches (Grab Samples)

AUID 07010206 (Elm Creek)				
Site	**Storet ID**	**Years**	**Total Number of Samples**	**N (under 5.00 mg/L)**
Hamel	S004-545	2011 , 2012	46	17
ECER	S004-544	2011 , 2012	45	17
EC77	S004-543	2011 , 2012	50	9
ECW	S003-441	2011 , 2012	29	1
EC81	S005-338	2011 , 2012	50	4
USGS	S004-222	2011 , 2012	64	5
ECHO	S004-221	2011 , 2012	47	21
MPO	S005-818	2010-2013	61	16
AUID 07010206 (Rush Creek)				
Site	**Storet ID**	**Years**	**Total Number of Samples**	**N (under 5.00 mg/L)**
RCTH	S004-541	2011 , 2012	33	22
RC116	S004-540	2011 , 2012	33	20
RT	S004-539	2011 , 2012	38	21
AUID 07010206 (Diamond Creek)				
Site	**Storet ID**	**Years**	**Total Number of Samples**	**N (under 5.00 mg/L)**
DCZ	S004-536	2011 , 2012	34	19
SD	S004-537	2012	13	7
DC	S004-538	2007 , 2008 , 2011 , 2012	65	8

Notes: Values in red indicate violation of standard

Table 8. Summary of DO Data for Impaired Stream Reaches (Continuous Sondes)

AUID 07010206-508 (Elm Creek)					
Site	**Storet ID**	**Years**	**Total Number of Samples**	**Min D.O. N (under 5.00 mg/L)**	**Max D.O. N (under 5.00 mg/L)**
EC77	S004-543	2010 , 2011	317	161	75
EC81	S005-338	2010 , 2011	254	164	45
USGS	S004-222	2010 , 2011	142	35	8
ECHO	S004-221	2010 , 2011	253	244	142
AUID 07010206-528 (Rush Creek)					
Site	**Storet ID**	**Years**	**Total Number of Samples**	**Min D.O. N (under 5.00 mg/L)**	**Max D.O. N (under 5.00 mg/L)**
RT	S004-539	2010 , 2011	330	265	198
AUID 07010206-525 (Diamond Creek)					
Site	**Storet ID**	**Years**	**Total Number of Samples**	**Min D.O. N (under 5.00 mg/L)**	**Max D.O. N (under 5.00 mg/L)**
DC	S004-538	2010 , 2011	271	173	92

Notes: Values in red indicate violation of standard

The data suggest moderate to severe DO impairments throughout all three listed reaches, with the most severe impairments in Rush Creek where more than half of the data points collected showed a DO concentration lower than the 5 mg/l standard.

3.4.4 Biotic Integrity

Assessment of the aquatic community was done through the use of an IBI. An IBI integrates multiple features of the aquatic community to evaluate the overall health of the biological community. This approach functions on the theory that biological assemblages are a direct reflection of pollutants, habitat alteration, and hydrologic modification over time. For further information regarding the development of stream IBIs, refer to the MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List (2014).

Table 9 shows the IBI scores used to evaluate multiple stream reaches within the Elm Creek Watershed for biotic impairment.

Table 9. Index of Biotic Integrity (IBI) Standards and Relevant Elm Creek Watershed Data by Stream Reach

Year	AUID Steam Reach[1]	Station ID	Location	Fish IBI		Macroinvertebrate IBI	
Rush Creek, South Fork				*Threshold*	*Score*	*Threshold*	*Score*
2010	-760	10UM014	Corcoran	40	0	46.8	37.9
2010	-760	10UM013	Corcoran	40	0	46.8	31.4
2010	-732	10UM011	Maple Grove	40	20	46.8	31.3
Rush Creek Mainstem							
2010	-528	99UM081	Maple Grove	40	26	46.8	42.6
Diamond Creek							
2010	-525	10UM008	Dayton	40	19	46.8	46.8
Elm Creek Mainstem							
2010	-508	10UM034	Hamel/Medina	50	0	46.8	32.9
2010	-508	10UM035	Maple Grove	50	3	46.8	45.6
2010	-508	10UM009	Maple Grove	50	19	46.8	29.0
2010	-508	10UM167	Dayton	50	24	46.8	45.1

[1] All AUIDs are in Hydrologic Unit Code (HUC) 07010206

These data suggest that all of the monitored stream reaches are impaired to some degree for both macroinvertebrate and fish communities, but that the degree of impairment of the fish community is high. The severity of the fish community impairment generally decreases in the Rush Creek and Elm Creek Subwatersheds as one moves from the upstream to downstream. The data indicate that the macroinvertebrate communities in the system are generally moderately to slightly impaired depending on location, and the degree of impairment doesn't show a pronounced trend from upstream to downstream.

3.5 Pollutant Source Summary

3.5.1 *E. coli* Bacteria

As outlined in Table 5, four stream reaches totaling over 48 stream miles, are listed as impaired for *E. coli* bacteria. Discharge from each of the streams eventually reaches the Mississippi River at Champlin, which is itself listed as impaired for *E. coli*. Bacteria loading can occur from both permitted and non-permitted sources.

3.5.1.1 Permitted Sources

Permitted sources of bacteria can include industrial stormwater effluent, municipal and industrial wastewater treatment facility (WWTF) effluent, Concentrated Animal Feeding Operations (CAFOs), and municipal stormwater runoff. A review of the MPCA permit information for the watersheds draining to each of the impaired reaches indicate there are no CAFOs currently, nor are there any permitted industrial dischargers with direct discharges to surface water operating in the watersheds. There is one permitted domestic wastewater discharger—Maple Hill Estates-located in Corcoran and discharging to the South Fork-Rush Creek. This facility (Permit MN0031127) serves a 189-unit mobile home park and has a continuous discharge averaging 0.03 million gallons per day (mgd) to a 1.08-acre impoundment, which in turn discharges to a wetland that is tributary to the South Fork of Rush Creek.

Municipal stormwater runoff can also contain *E. coli* bacteria, primarily as a result of improperly disposed of fecal matter from domestic animals (i.e. dogs and cats) that is carried in runoff to the storm water conveyance system. Urban wildlife can also contribute *E. coli* to the stormwater system, either via overland runoff from areas where they concentrate or via direct deposit in the storm sewer pipes (generally small mammals) or receiving water (usually waterfowl). There are nine jurisdictions within the Elm Creek Watershed project area that are permitted municipal separate storm sewer systems (MS4s) in the watershed. Table 10 shows these jurisdictions and their MS4 Permit numbers.

Table 10. Permitted MS4s in the Elm Creek Watershed Project Area

Permitted MS4	Permit ID Number
City of Champlin	MS400008
City of Corcoran	MS400081
City of Dayton	MS400083
Hennepin County	MS400138
City of Maple Grove	MS400102
City of Medina	MS400105
MnDOT Metro District	MS400170
City of Plymouth	MS400112
City of Rogers	Future MS4[1]

[1] Coverage under current MS4 permit expected by December 2016

3.5.1.2 Non-Permitted Sources

Non-permitted sources include livestock, wildlife, and failing septic systems. Loadings from livestock can occur from feedlots and/or land areas where manure has been applied for disposal and crop nutrient management purposes. Delivery of the associated bacteria load is usually a result of precipitation runoff events that provide the transport mechanism to move the bacteria to a conveyance system or receiving water. In addition, livestock with direct access to receiving waters or the conveyance systems that feed them can deliver bacteria loads in the absence of runoff-driven processes. Failing or non-conforming Individual Sewage Treatment Systems (ISTSs) can also be a source of *E. coli* to streams, especially during dry periods when these sources continue to discharge and runoff-driven processes are not occurring. The most recent information available for subsurface sewage treatment systems failure rates in Hennepin County is from 2009 and suggests that about 29% of the systems then in operation were failing (MPCA 2011).

3.5.1.3 Estimate of *E. coli* Produced

Figure 12 through Figure 15 show the estimated number of *E. coli* bacteria produced by major source category within the subwatersheds of the four *E. coli*-impaired stream reaches. The livestock component of this analysis is based on a livestock inventory of the watershed for 2011 that involved a detailed examination of high resolution pictometry from Hennepin County. The results of the inventory are summarized in Appendix A. The pictometry facilitated an estimate of livestock numbers, type, and location. Human population and household information was derived from the 2010 census, while estimates of wildlife numbers and type were based on the professional judgment of Minnesota Department of Natural Resources (DNR) and Three Rivers Park District wildlife managers.

Based on the results of the various surveys and the production estimate, it appears that fecal matter from livestock is the primary potential source of bacteria loading. Livestock were by far the largest producers of bacteria in the Diamond Creek, Rush Creek, and South Fork-Rush Creek Subwatersheds. They were still the dominant producer in the Elm Creek Subwatershed as well, though urban sources were estimated to constitute about one third of the bacteria generated. The worksheets showing how the bacteria production estimates were calculated are in Appendix B and graphical summaries of the results are presented in the following figures.

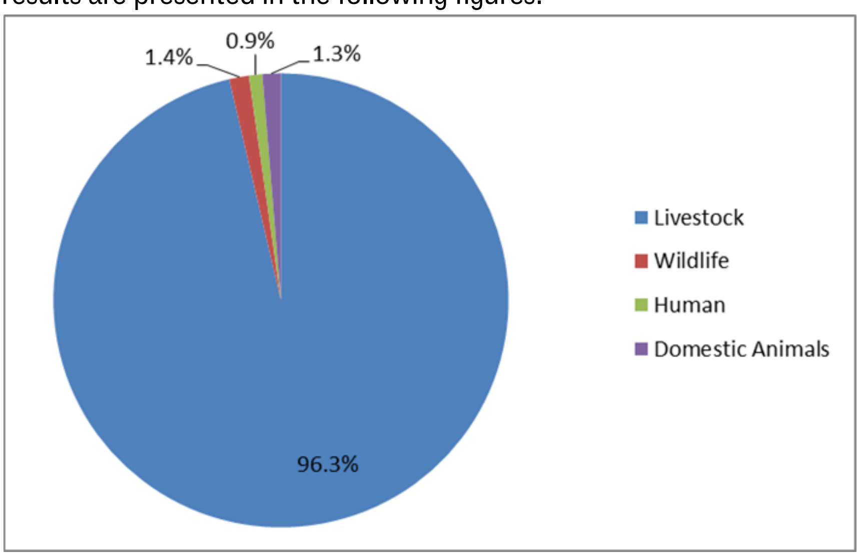


Figure 12. *E. coli* Bacteria produced and available within the South Fork, Rush Creek Subwatershed

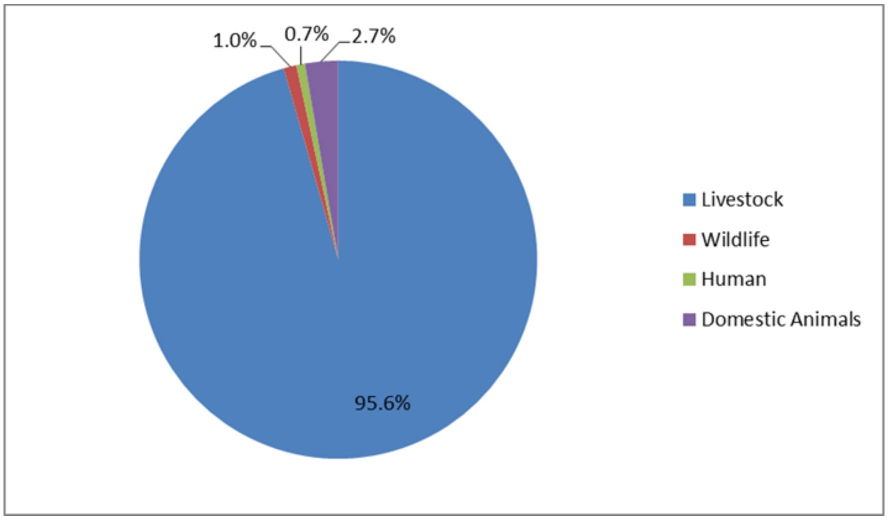


Figure 13. ***E. coli*** **bacteria produced and available within the Rush Creek Subwatershed**

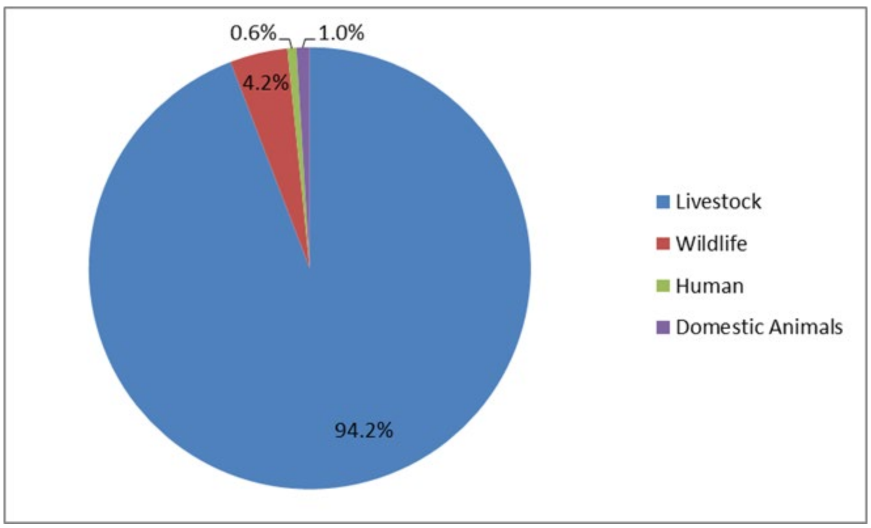


Figure 14. ***E. coli*** **bacteria produced and available within the Diamond Creek Subwatershed**

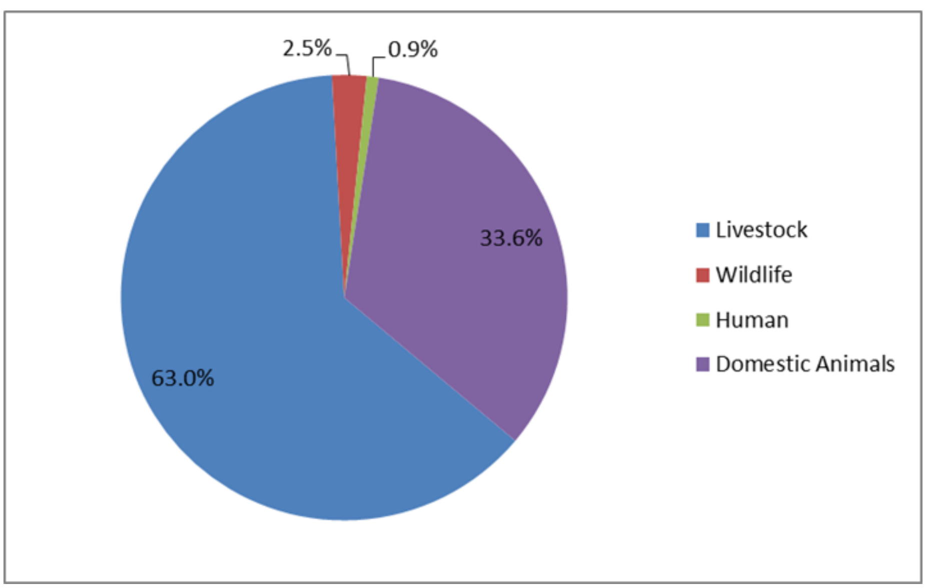


Figure 15. ***E. coli*** **bacteria produced and available within the Elm Creek Subwatershed**

3.5.2 Lake Nutrients

There are seven lakes impaired for nutrients that are addressed in this TMDL report. Excess plant nutrients, mainly nitrogen and phosphorus, from human-driven activities contribute to excess productivity in lakes. Excess productivity manifests itself as an increase in algal blooms and a consequent decrease in water clarity, both of which may significantly impair or prohibit the use of lakes for aquatic recreation. In Minnesota, the primary focus in managing nutrient enrichment of lakes has been to emphasize the control of phosphorus because of its role as a limiting nutrient in lake productivity.

There are three primary sources of phosphorus loading to lakes; watershed (external) loading, internal loading, and atmospheric deposition. Each is described in more detail below to address both permitted and non-permitted sources.

3.5.2.1 Watershed Loading

Watershed loading refers to phosphorus carried from the land draining to receiving water and transported by runoff processes. Both permitted and non-permitted sources of watershed loading are present within the Elm Creek Watershed. Permitted sources for the impaired lakes in this watershed include primarily discharges from storm water runoff. There are no municipal wastewater treatments plants, combined sewer overflows, sanitary sewer overflows, or confined animal feeding operations CAFOs present in the lake watersheds of the TMDL study area.

Regulated MS4s and Wastewater Treatment Facilities

All of the communities within the TMDL project area are (or, in the case of the city of Rogers, soon will be) permitted MS4s, and the area of each community served by a regulated MS4 conveyance systems varies widely.

identifies the current and pending permitted MS4 entities in the watershed. The MS4 conveyance system provides the mechanism to transport vegetative material (such as grass clippings, leaves, and seeds), dust and dirt, car wash wastewater, improperly disposed of pet waste, and other phosphorus-containing material to receiving water.

The only WWTF in the project area watershed is the Maple Hills Estates facility in Corcoran. The facility is described in Section 3.5.1.1. The effluent discharged from the facility does not affect any of the seven impaired lakes in this report.

Construction Stormwater

Construction stormwater permits are required for any construction activities that disturb:

1. One acre or more of soil
2. Less than one acre of soil if that activity is part of a “larger common plan of development or sale”, or
3. Less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources

Phosphorus loading from construction sites is mostly associated with movement of soil off the site due to erosion.

Industrial Stormwater

Industrial stormwater discharge permits are required for facilities with Standard Industrial Classification codes in 10 categories of industrial activity with significant materials and activities exposed to stormwater. These include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and are carried off-site.

Non-permitted

Finally, there are watershed loads that are non-permitted. These loads generally include runoff-driven loads from land – in most cases rural – that does not pass through a regulated MS4 conveyance system. Examples include nutrients from manure, eroded soil, and other material that may be deposited in, or conveyed to, receiving water without entering a regulated MS4 conveyance system.

3.5.2.2 Internal Loading

Internal nutrient loading in a lake is usually the result of enriched bottom sediments releasing phosphorus into the water column. In most cases, lakes retain a large percentage of the pollutant load that is discharged to them. Much of the incoming phosphorus to a lake can end up in its bottom sediments, and a percentage of this accumulated phosphorus can be available for release. The actual amount released depends on a number of factors, including the magnitude of past phosphorus loading to the lake, the type and degree of enrichment of the sediments, the lake's bathymetric (depth) profile, and the area of and length of time a lake's bottom sediments are exposed to low or no oxygen conditions. In areas where human disturbance of the contributing watershed has been on-going for decades or longer due and/or there have been historic wastewater discharges, internal release of phosphorus can be a major component of the overall phosphorus load affecting the quality of a lake. It should be noted that the overabundance of carp or other roughfish as well as some invasive aquatic plants (notably curly leaf pond weed) can also contribute to the internal phosphorus. Internal loading is typically designated as a non-permitted source in any lake TMDL.

3.5.2.3 Atmospheric Deposition

Precipitation and dry fall (i.e. dust particles suspended by wind) that fall directly on a lake surface contribute phosphorus to the lake's overall load. Like internal loading, phosphorus loading associated with atmospheric deposition is also considered a non-permitted source.

3.5.3 Low DO

Oxygen depletion in streams commonly occurs from the presence and subsequent breakdown of organic matter within the system. The breakdown process, facilitated by bacteria and other micro-organisms, consumes oxygen. Loading of biochemical oxygen demanding (BOD) substances can be from both "natural" and human-caused sources. Natural sources of BOD include plant decay, leaf fall and decomposition, and, at times, wetlands. Algal growth is commonly identified as a significant source of BOD in watersheds with elevated nutrient levels. The most common human-related inputs are those associated with effluent from WWTFs. The MS4s can also discharge oxygen-depleting organic matter in the form of grass clippings, leaves, and pet waste. Organic matter from livestock and other agricultural operations is also another potential source. Generally, discharges from WWTFs and designated municipal separate stormwater systems are permitted sources, while those associated with natural sources and most agricultural operations are non-permitted sources. It is important to note that while there are numerous agricultural feedlot operations in the Elm Creek Watershed project area, there are no CAFOs. Permitted WWTFs and permitted MS4 systems in the project area are described in Section 3.5.1.

A more detailed summary of conditions that can also cause low DO levels is presented below.

3.5.3.1 Nutrients, Eutrophication, and Plants

High in-stream nutrient concentrations often lead to eutrophication, characterized by accelerated primary production in the form of plants. The plants affected can be rooted aquatic plants, free-floating algae suspended in the water column (especially in low gradient, slow-moving streams), periphyton (which are plants attached to substrate that does not wash away, such as rocks, logs, etc.), or some combination of the three. The plants cause high oxygen levels during sunlit daylight hours when they are photosynthesizing and producing oxygen. During the night, when there is no sunlight to support photosynthesis, oxygen levels are driven down since plants respire and consume oxygen. Often the lowest levels of oxygen in this type of system occur early in the morning. In addition, when plants die, microorganisms that facilitate the decomposition process consume DO while at the same time releasing nutrients back into the water column.

3.5.3.2 Shallow Impoundments

Shallow impoundments, including wetlands, on streams or rivers can have a great influence on downstream DO. Often, impoundments raise the temperature of the water during the warm months of the year, and warmer water cannot hold as much oxygen as cooler water. In addition, shallow impoundments slow flows resulting in deposition and accumulation of organic and finer sediment particles which often exert an elevated demand for oxygen. Finally, shallow impoundments/wetlands on nutrient-rich streams can support extensive submergent and emergent aquatic plant communities as well as periphyton, and/or planktonic algal communities. The same eutrophication-driven processes described in the preceding section can be exacerbated and exert an even more profound effect on downstream DO levels.

3.5.3.3 Other Conditions Causing Low DO

Other conditions which can cause low DO include:

- Water Column Biochemical Oxygen Depletion. The oxygen-demanding substances referred to earlier in this section are usually comprised of two primary components; nitrogenous biochemical oxygen demand (NBOD) and carbonaceous biochemical oxygen demand (CBOD). The NBOD is the biologic oxidation of ammonia to nitrate. The CBOD is the oxidation through decomposition of organic carbon to carbon dioxide through the metabolic action of micro-organisms. Carbonaceous demand is usually exerted first, normally as a result of a lag in the growth of the nitrifying bacteria necessary for oxidation of the nitrogen forms.
- Sediment Oxygen Demand. Another factor influencing oxygen concentrations in streams is sediment oxygen demand (SOD). The SOD is the aerobic decomposition of organic materials (including animal waste and decaying plant material) that settle to the bottom of the stream and become incorporated into the streams sediments. In natural, free-flowing streams, the SOD is usually negligible because frequent scouring as a result of runoff events prevents long-term accumulation of organic materials.
- Water Temperature/Groundwater Inflow. All other factors being equal, streams with cooler temperatures have higher DO content than streams with warmer water temperatures. This is because oxygen is more soluble in cooler water than warmer water. Streams with a strong baseflow driven by cool groundwater (GW) inputs can support higher DO levels during the summer because GW temperatures are generally significantly lower than normal surface water

temperatures. However, GW itself often has low DO (sometimes close to zero), and therefore can exert a negative impact on stream DO concentrations unless opportunities exist re-aerate the cool water discharge from the GW system.

- Canopy Cover and Water Temperature. Canopy coverage may also have an effect on stream DO content. Decreased shading leads to more sunlight exposure which often warms the water and in turn decreases the amount of oxygen the water can hold. Shading plays a bigger role in governing the temperature of small streams like those in the Elm Creek Watershed than it does in larger rivers, where even robust shoreline vegetation can only shade a very small percentage of the river's surface.
- Stream Geomorphology. The ability of streams to take in oxygen from the atmosphere is often highest in rocky bottomed streams with swift moving, agitated waters. Thus, changes to stream morphology such as smoothing of the stream bottom, deepening/widening of the channel, impoundments and flow-through wetlands, etc. can greatly affect re-aeration and DO concentrations. During periods of very low flow, there is often limited low-flow channel meandering across the streambed. If this occurs in summer when water temperatures may be high already, exposed sediments, shallow stagnant pools, and excessive aquatic plant/algae growth can all exacerbate oxygen depletion.

3.5.4 Biotic Impairments

Potential sources causing biotic impairments are numerous and varied. The EPA has produced guidance documents that provide a methodology for identifying and evaluating those factors (known as stressors) (EPA 2000). Stressors generally fall into two broad categories; pollutant stressors and non-pollutant stressors. This project involved carrying out a stream-lined process based on the MPCA SID Framework and the EPA's Causal Analysis/ Diagnoses Decision Information System (CADDIS) to identify the main stressors causing impairment of the fish and macroinvertebrate communities in five stream reaches of the Elm Creek Watershed. CADDIS, 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. The methodology and findings of that effort, including the sources of the stressors evaluated, are presented in the Elm Creek Stressor Identification Report (Lehr 2015).

Potential candidate causes of the biological impairments that were either ruled out or inconclusive based on review of available data include: nitrates; pH; temperature; un-ionized ammonia; and chloride. Water quality sampling for each of these parameters showed respective measurements either within Minnesota standards or a lack of biological response. The TP, excess sediment (TSS), altered hydrology, altered habitat, and low DO were all found to be stressors to aquatic life to varying degrees. A summary of evidence for each of these is provided in Table 23 and Table 24. As a result of the SI process, the TP was found to be a primary stressor in all five listed stream reaches and the TSS was found to be a primary stressor in two of the five reaches. More detailed information can be found in the Elm Creek Stressor Identification Report and section 4.3 of this report. Please refer to The Elm Creek Stressor Identification Report for locations of biological monitoring stations.

4 TMDL Development

A TMDL is defined as the total amount of a given pollutant that can enter a waterbody while still achieving water quality standards. The total allowable load, or TMDL, is allocated to the various sources contributing the pollutant as well as a margin of safety (MOS) and, in general, a RC. The TMDL equation can be written as:

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

Where:

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

Wasteload Allocation(WLA): the pollutant load that is allocated to point sources, including WWTFs and regulated stormwater; all covered under National Pollutant Discharge Elimination System (NPDES) permits for a current or future permitted pollutant source;

Load Allocation (LA): the pollutant load that is allocated to source not requiring NPDES permit coverage, including non-regulated stormwater runoff;

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

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

This section presents TMDLs for *E. coli*, Lake Nutrients, and stressors identified as primary stressors (including low DO) for biotic impairments in the ECWMC.

4.1 *Escherichia Coli*

The following sections describe the approach used to develop the various components of the TMDL for the *E. coli* impairments in the five listed stream reaches of the Elm Creek Watershed.

4.1.1 Loading Capacity

Flow and LDCs were used to define the loading capacity for *E. coli* for each of the four listed reaches and to help characterize the pattern of exceedances. For each reach, a flow duration curve was developed using daily flow data collected between 2003 and 2012 during the April through October period at the most downstream location in the listed reach. Figure 16 shows the location of each impaired reach and the stream monitoring stations along those reaches. The flow stations used for generating the curves were as follows:

- Station RCSL for Rush Creek, South Fork (AUID 07010206-732)
- Station RT for Rush Creek mainstem (AUID 07010206-528)
- Station DC for Diamond Creek (AUID 07010206-525)
- Station USGS for Elm Creek (AUID 07010206-508)

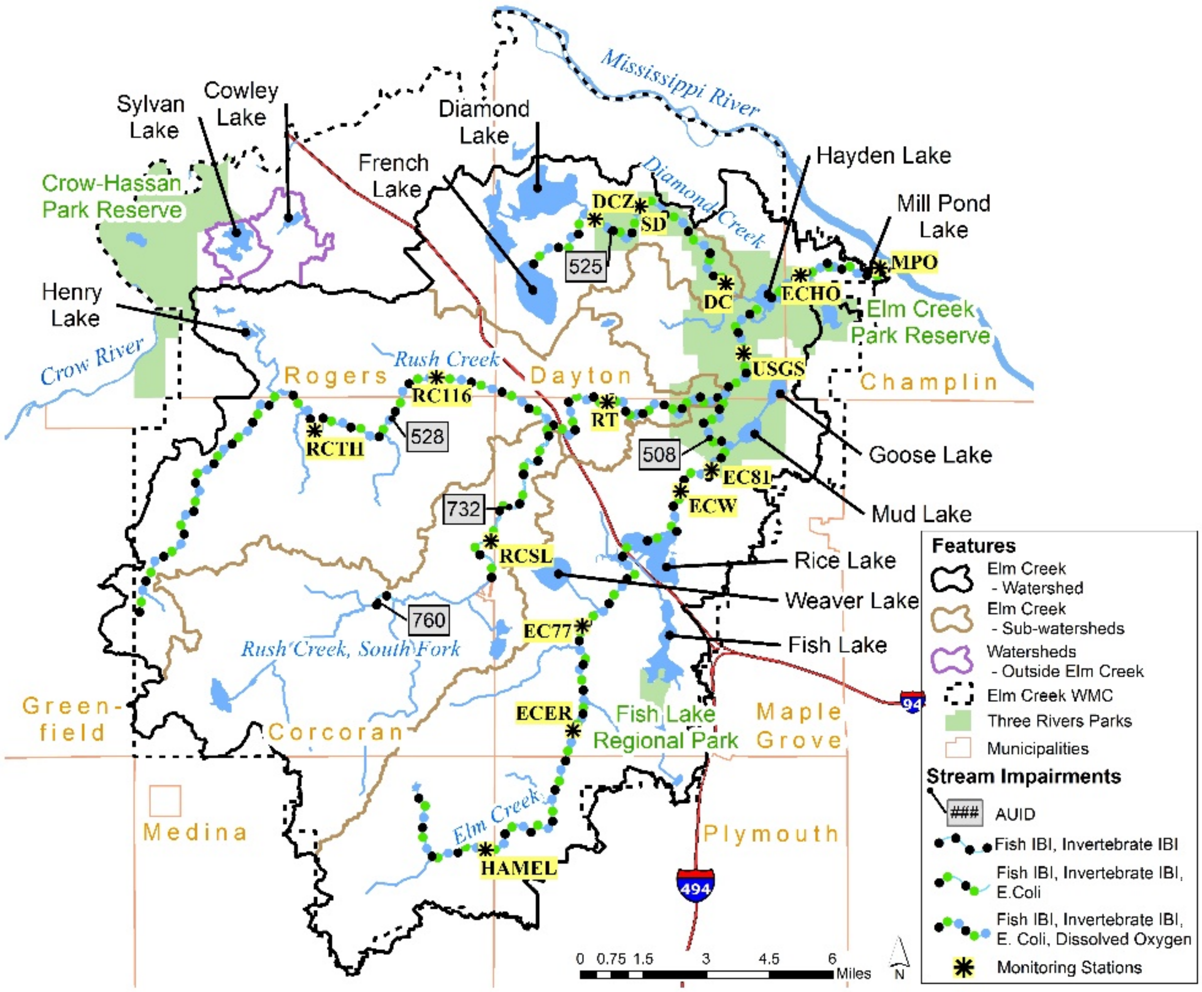


Figure 16. Stream Monitoring Sites and Impaired Reaches

Since not all of the flow data at the selected monitoring stations covered a full 10-year period of record, a simulated daily flow record was developed to cover the missing period of record. This involved developing a regression equation based on the overlapping period of record between the U.S. Geological Survey's (USGS) monitoring station on lower Elm Creek and the period of record for daily flows at the monitoring site on each reach. This relationship was used to simulate the daily flows for the missing period of record during 2003 through 2012. The daily flows at each station in the impaired reach were then adjusted again to account for the increased contributing watershed area between the location of the monitoring site and the bottom of the impaired reach. The resulting flow duration curves for each reach of the four impaired reaches are presented in Figure 17. The curved line relates mean daily flow to the percent of time those values are exceeded. For example, at the 20% exceedance value for the Diamond Creek reach, the average daily streamflow of 10 cfs was exceeded 80% of the time for the 10- year period of record. The 50% exceedance is also the mid-point or median flow value for the bottom of each reach. The flow duration curve is then divided into flow zones including very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%), and dry (90% to 100%) exceedance flow conditions. Subdividing all flow data over the 10-year period of record into these five categories ensures the full range of potentially critical conditions are accounted for in this TMDL study.

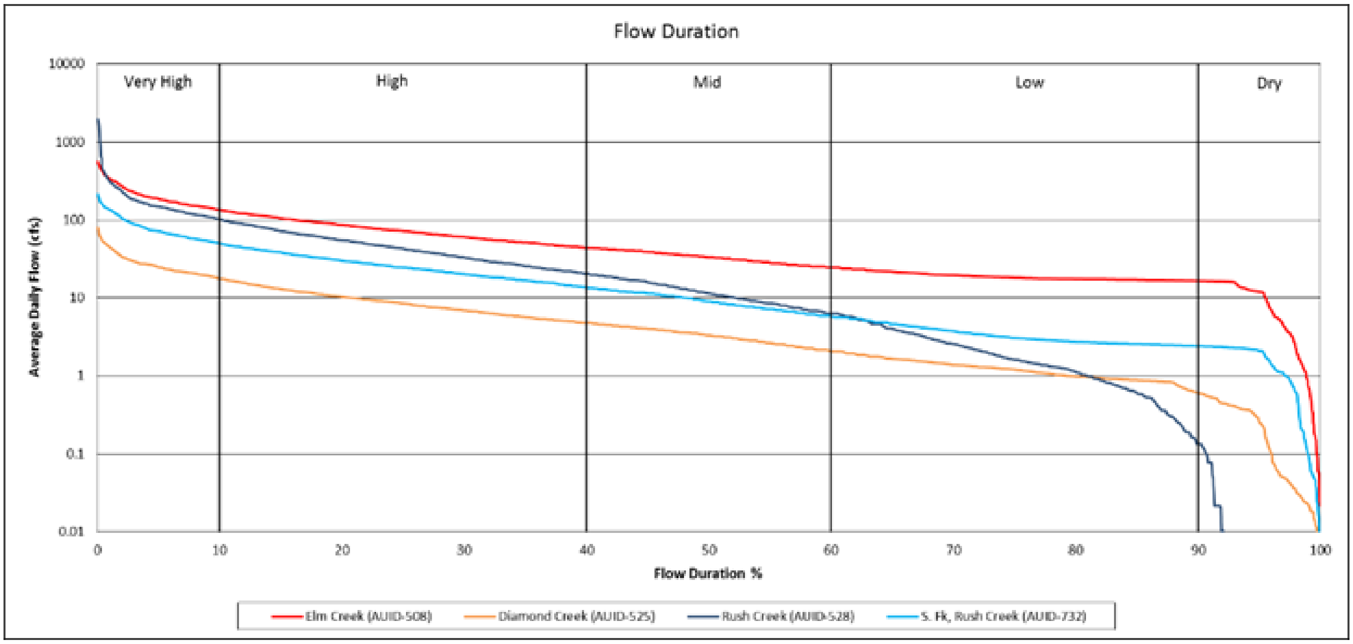


Figure 17. Flow Duration Curves by Impaired Reach

To develop the LDC for each reach, all daily average flows were multiplied by the *E. coli* standard of 126 cfu/100 ml and converted to a daily load to create a continuous LDC representing the loading capacity of the stream. The loading capacity can then be compared with current conditions by plotting the measured load for each water quality sampling event. The values above the curve are those which exceed the standard, while those below the LDC line are below the standard.

The LDCs and measured load data for the listed reaches are presented in Figure 21. Note that at the top of each graph the percent reductions needed to meet the standard in that flow regime is shown. It should also be noted that only concentration data from stations showing exceedances of the chronic standard for one or more months during the period 2003 through 2012 were used in calculating the actual loads. This means that *E. coli* data for monitoring stations ECW, USGS, ECHO, and MPO at the lower end of Elm Creek are not included in the Elm Creek (AUID – 508) LDC.

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

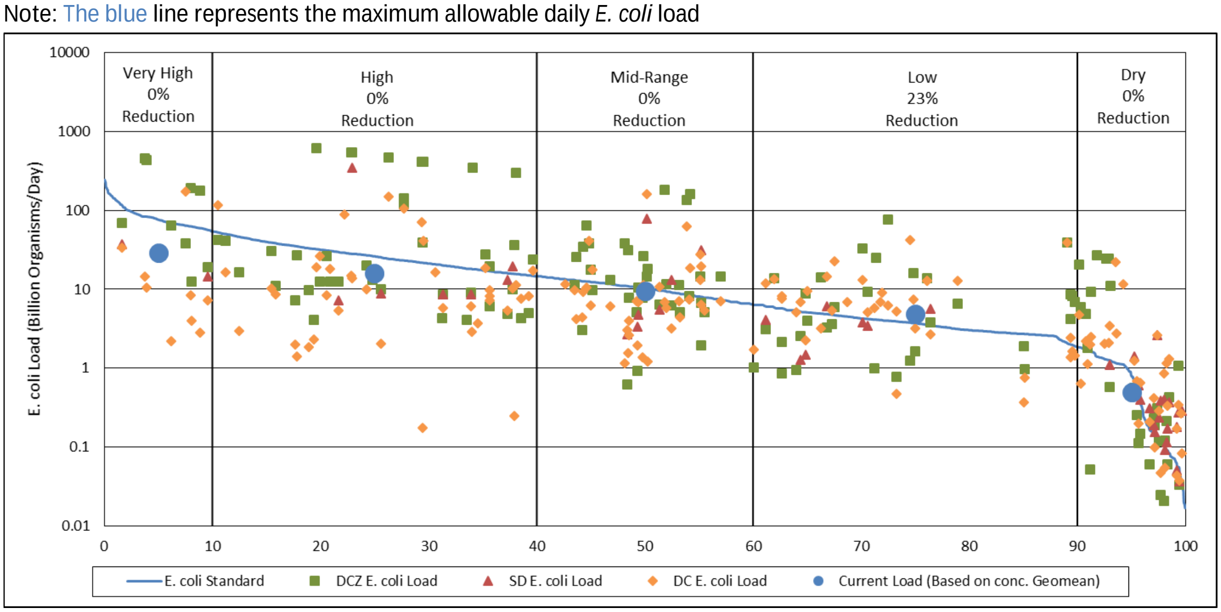


Figure 18. Diamond Creek (AUID - 525) *E. coli* LDC and Required Load Reductions by Flow Regime

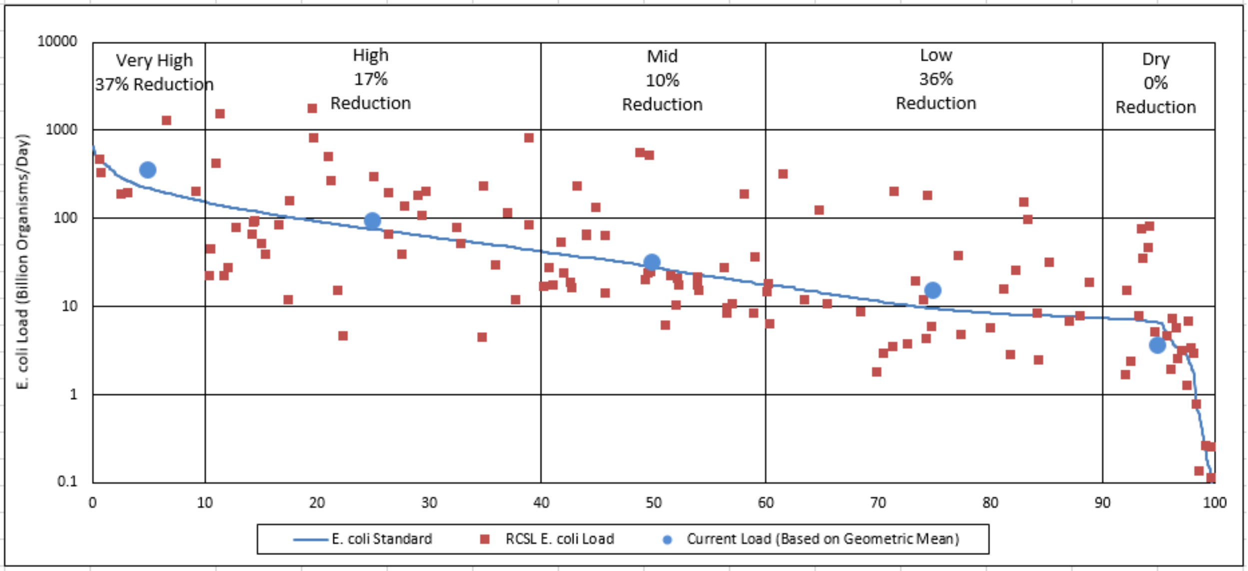


Figure 19. Rush Creek-South Fork (AUID - 732) *E. coli* LDC and Required Load Reductions by Flow Regime

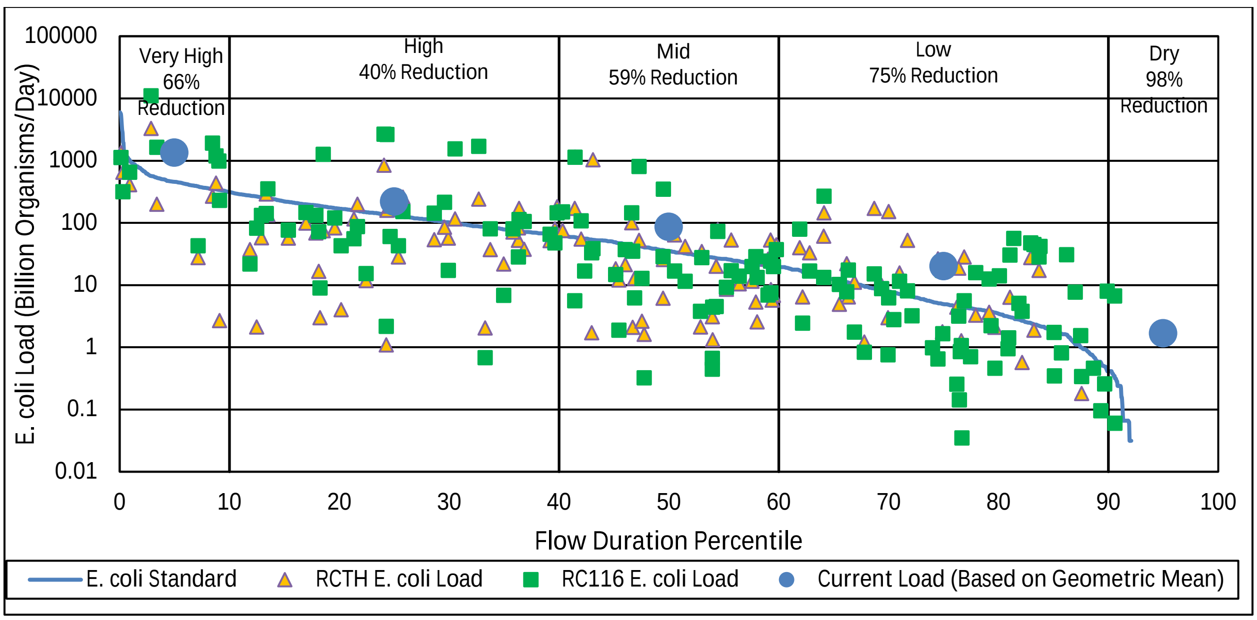


Figure 20. Rush Creek Mainstem (AUID - 528) *E. coli* LDC and Required Load Reductions by Flow Regime

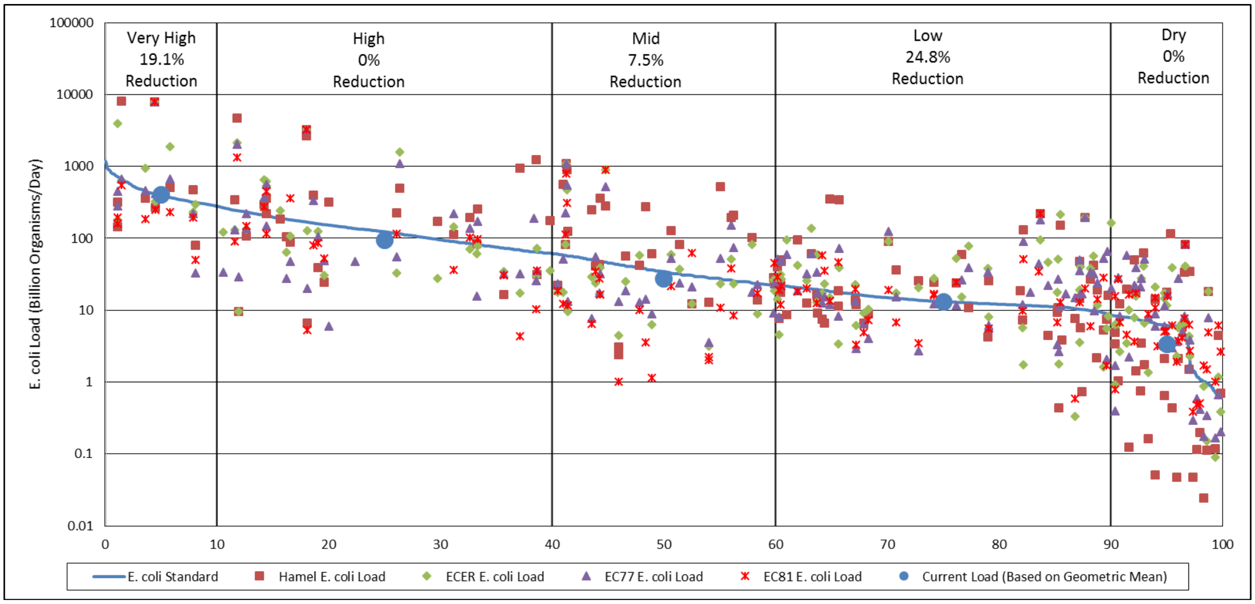


Figure 21. Elm Creek (AUID - 508) *E. coli* LDC and Required Load Reductions by Flow Regime

The LDC method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables that are presented later in this report (Section 4.1.7), only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA.

4.1.2 Wasteload Allocation Methodology

The WLAs for these bacteria TMDLs have been allocated between the permitted sources. There is currently one active permitted NPDES wastewater discharger in the watershed, Maple Hills Estate in the city of Corcoran, which discharges wastewater that reaches the South Fork of Rush Creek. In addition, six local communities within the Elm Creek Watershed are permitted to discharge stormwater from their regulated conveyance systems under the Phase II MS4 Permit. The seventh, the city of Rogers, has been notified that it will be permitted as a regulated MS4, likely by late 2016. Finally, there are two road authorities – the Minnesota Department of Transportation (MnDOT) and Hennepin County, which are also permitted to discharge stormwater from their stormwater conveyance systems to the subwatersheds of impaired reaches.

Figure 22 summarizes the methodology used in this TMDL for determining which areas within a community or road authority jurisdiction were included in the WLA. Using the screening process outlined in Figure 22 and consistent with direction from the Technical Advisory Committee for the project, each WLA assigned was proportionate to the acreage of that jurisdiction within the subwatershed of the affected impaired reach.

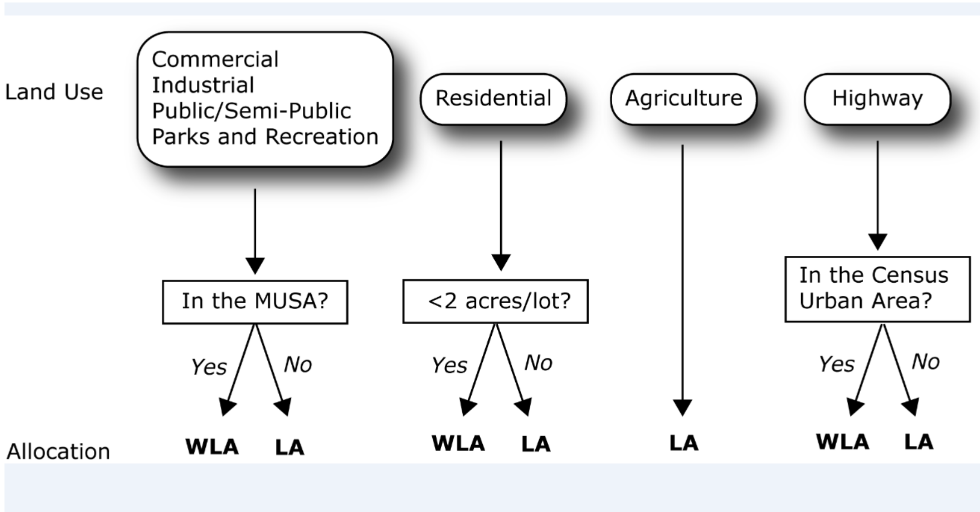


Figure 22. Schematic Representation of Allocation Methodology

4.1.3 Load Allocation Methodology

The non-point source (NPS) allocation also referred to as the watershed LA, is the remaining load after the MOS (see Section 4.1.4) and WLAs are subtracted from the total load capacity for each flow zone. The watershed LA 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.

4.1.4 Margin of Safety

The MOS accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload, monitored flow, and in-stream conditions. 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% of the load capacity was applied, meaning that 5% of the loading capacity was subtracted from the loading capacity for each flow regime before allocations were made among wasteload and NPSs. Five percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty associated with development of the TMDLs, given that 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 reach. For this TMDL, extensive continuous flow data was collected over a four to six-year period in at least one location within each impaired reach. Overlapping periods of record with the a long-term USGS gaging station on lower Elm Creek (35+ year period of record) were used to simulate a 10-year flow record at the bottom of each reach to provide the basis for development of the LDCs. Thus, this component of uncertainty was fairly well controlled.

4.1.5 Seasonal Variation

Seasonal variability was addressed through collection and analysis of data across the entire April through October recreation period to which the standard applies. Further, the data collection period for each impaired reach ranged from four to six years, providing the opportunity to characterize exceedances under a variety of weather and flow patterns. The data analysis approach used (calculation of geomeans for each month as well as plotting of data using flow duration curves customized for each reach) allowed an evaluation of variability in exceedances across individual months as well as across flow regimes.

4.1.6 Future Growth Consideration/Reserve Capacity

4.1.6.1 New or Expanding Permitted MS4 WLA Transfer Process

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

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

4.1.6.2 New or Expanding Wastewater

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

4.1.7 TMDL Summary

Table 11 to Table 16 presents the total loading capacity, MOS, WLAs, and remaining watershed LAs for the four *E. coli*-impaired reaches.

Table 11. Diamond Creek (AUID - 525) *E. coli* TMDL and Allocations by Flow Zone

Diamond Creek: AUID 07010206-525		Flow Zones				
		Very High	High	Mid	Low	Dry
		E. coli Load (Billions of Organisms/Day)				
WLAs	Total WLA	36.09	12.38	4.81	1.75	0.37
	MS4-Dayton	36.09	12.38	4.81	1.75	0.37
LAs	Total Load Allocations	36.67	12.58	4.88	1.78	0.38
	Non-MS4 runoff	36.67	12.58	4.88	1.78	0.38
5% Explicit Margin of Safety (MOS)		3.83	1.31	0.51	0.19	0.04
Total Load (TMDL)		76.59	26.28	10.20	3.71	0.80
Existing Load		29.23	16.14	9.46	4.81	0.5
Estimated Reduction (%)		0	0	0	23	0

Table 12. Rush Creek - South Fork (AUID - 732) *E. coli* TMDL and Allocations by Flow Zone

Rush Creek - South Fork: AUID 07010206-732		Flow Zones				
		Very High	High	Mid	Low	Dry
		E. coli Load (Billions of Organisms/Day)				
WLAs	Total WLA	109.96	37.68	13.98	4.82	3.28
	Maple Hills Estates WWTF	0.14	0.14	0.14	0.14	0.14
	MS4 - Corcoran	72.43	24.76	9.13	3.09	2.08
	MS4 - Maple Grove	23.63	8.08	2.98	1.01	0.68
	MS4 - Medina	13.41	4.58	1.69	0.57	0.38
	MS4 - Hennepin County	0.36	0.12	0.04	0.01	.005
LAs	Total Load Allocations	98.50	33.67	12.42	4.20	2.83
	Non MS4 runoff	98.50	33.67	12.42	4.20	2.83
5% Explicit Margin of Safety (MOS)		10.97	3.76	1.39	0.47	0.32
Total Load (TMDL)		219.44	75.11	27.80	9.49	6.44
Existing Load		348.96	90.43	30.73	14.83	3.47
Estimated Reduction (%)		37	17	10	36	0

Table 13. Rush Creek Mainstem (AUID - 528) E. coli TMDL and Allocations by Flow Zone

Rush Creek Mainstem: AUID 07010206-528		Flow Zones				
		Very High	High	Mid	Low	Dry
		E. coli Load (Billions of Organisms/Day)				
WLAs	Total WLA	164.88	47.67	12.72	1.88	0.03
	Maple Hills Estates WWTF	0.14	0.14	0.14	0.14	**
	MS4 - Corcoran	43.33	12.50	3.31	0.46	**
	MS4 - Dayton	42.93	12.38	3.28	0.45	**
	MS4 - Maple Grove	29.29	8.45	2.24	0.31	**
	MS4 - Rogers	47.66	13.75	3.64	0.50	**
	MS4 - Hennepin County	0.42	0.12	0.03	0.00	**
	MS4 - MnDOT	1.11	0.32	0.08	0.01	**
LAs	Total Load Allocations	269.25	77.68	20.56	2.84	**
	Non MS4 runoff					
5% Explicit Margin of Safety (MOS)		22.85	6.60	1.75	0.25	0.00

Total Load (TMDL)	456.98	131.94	35.03	4.96	0.03
Existing Load	1335.54	219.97	85.96	19.98	1.68
Estimated Reduction (%)	66	40	59	75	98

** Allocation = flow contribution from a given source x 126 cfu *E. coli*/100 ml

Table 14. Elm Creek (AUID - 508) E. coli TMDL and Allocations by Flow Zone

Elm Creek: AUID 07010206-508		Flow Zones				
		Very High	High	Mid	Low	Dry
		E. coli Load (Billions of Organisms/Day)				
WLAs	Total WLA	305.29	95.46	26.24	10.20	4.75
	Maple Hills Estates WWTF	0.14	0.14	0.14	0.14	0.14
	MS4 - Champlin	18.23	5.70	1.56	0.60	0.28
	MS4 - Corcoran	15.32	4.78	1.31	0.51	0.23
	MS4 - Dayton	54.54	17.04	4.67	1.80	0.82
	MS4 - Maple Grove	141.94	44.34	12.14	4.68	2.14
	MS4 - Medina	32.97	10.30	2.82	1.09	0.50
	MS4 - Plymouth	32.17	10.05	2.75	1.06	0.49
	MS4 - Hennepin County	3.52	1.10	0.30	0.12	0.05
	MS4 - MnDOT	6.46	2.02	0.55	0.21	0.10
LAs	Total Load Allocations	71.47	22.33	6.11	2.36	1.08
	Non MS4 runoff	71.47	22.33	6.11	2.36	1.08
5% Explicit Margin of Safety (MOS)		19.83	6.20	1.70	0.66	0.31
Total Load (TMDL)		396.59	123.99	34.06	13.22	6.13
Existing Load		490.11	120.79	36.82	17.57	3.74
Estimated Reduction (%)		19	0	8	25	0

The total daily loading capacity (TDLC) in the "dry" flow zone for the Rush Creek mainstem (Table 13 above) is very low due to the occurrence of very low flows in the flow record. Consequently, the permitted wastewater treatment design flows will exceed the stream flow in this flow zone. This means that the WWTF discharge would exceed the available loading capacity, based on the method described here to calculate the TMDL components. To account for this unique situation, the WLAs and LAs for this flow regime are expressed as an equation. The equation is:

Allocation = flow contribution from a given source x 126 cfu *E. coli*/100 ml

This approach effectively assigns a concentration-based limit to all discharges for the "dry" flow zone. Since there will be essentially no runoff in this flow zone anyway, permitted and non-permitted stormwater discharges should be essentially unaffected. The impact will be on any WWTF discharges from the Maple Hills Estates Facility.

To provide additional guidance for the magnitude of reductions required to meet the bacteria standard in each of the reaches, another analysis was prepared and is presented below. Table 15 shows the percent reduction in the monthly geomean *E. coli* concentration values needed to reach the standard for each month by monitoring station within each impaired reach. The location of the monitoring stations is show in Figure 3, and the monitoring station information in Table 15 is presented in upstream to downstream order for each stream reach. The table cells are color-coded to help identify the magnitude of reductions required (red for large reductions to yellow for small reductions and white for no reductions). For Elm Creek, it is important to note that MS4 communities discharging to Elm Creek below monitoring station EC81 (i.e. the cities of Champlin and Dayton) have no reduction obligation, since monitoring data at the USGS, ECHO, and MPO sites in the lower end of the listed reach show no violation of water quality standards for *E. coli*. Similarly, the MS4's discharging below the confluence of the South Fork, Rush Creek (AUID -732) and mainstem of Rush Creek (i.e. portions of the cities of Maple Grove and Dayton as well as MnDOT right-of-way associated with Interstate 94) have no reduction obligations, since monitoring data at Site RT at the lower end of the Rush Creek mainstem reach (AUID -528) shows no violation of water quality standards for *E. coli*. As shown in the tables, the exceedances of the *E. coli* standard are most frequent and severe in the upper reaches of the watershed, which are currently dominated by rural and agricultural uses.

Table 15. Percent Reduction of *E. coli* Monthly Geomeans to Achieve Standard by Impaired Reach

***E. coli* Monthly Geomeans (cfu/100mL) - % Reductions to Meet Chronic Standard**							
	April	**May**	**June**	**July**	**August**	**September**	**October**
Diamond Creek: Headwaters/French Lake to Un-named Lake (AUID 07010206-525)							
DCZ	0	0	0	44%	66%	7%	15%
SD		0	31%	6%	28%	42%	0
DC	0	0	0	0	41%	37%	24%
Rush Creek, South Fork: Un-named lake to Rush Creek (AUID 07010206-732)							
RCSL	0	0	2%	16%	11%	59%	63%
Rush Creek: Headwaters to Elm Creek (AUID 07010206-528)							
RCTH	0	0	0	32%	57%	0	0
RC116	0	0	17%	47%	38%	0	0
RT	0	0	0	0	0	0	0
Elm Creek: Headwaters/Lake Medina to Miss. R. (AUID 07010206-508)							
Hamel	0%	11%	52%	24%	30%	0%	2%
ECER	0%	0%	32%	7%	43%	28%	24%
EC77	0%	0%	20%	49%	39%	46%	0%
ECW	0%	0%	0%	0%	0%	0%	0%
EC81	0%	0%	5%	12%	31%	36%	0%
USGS	0%	0%	0%	0%	0%	0%	0%
ECHO	0%	0%	0%	0%	0%	0%	0%
MP	0%	0%	0%	0%	0%	0%	0%

4.2 Lake Nutrients

4.2.1 Loading Capacity Methodology

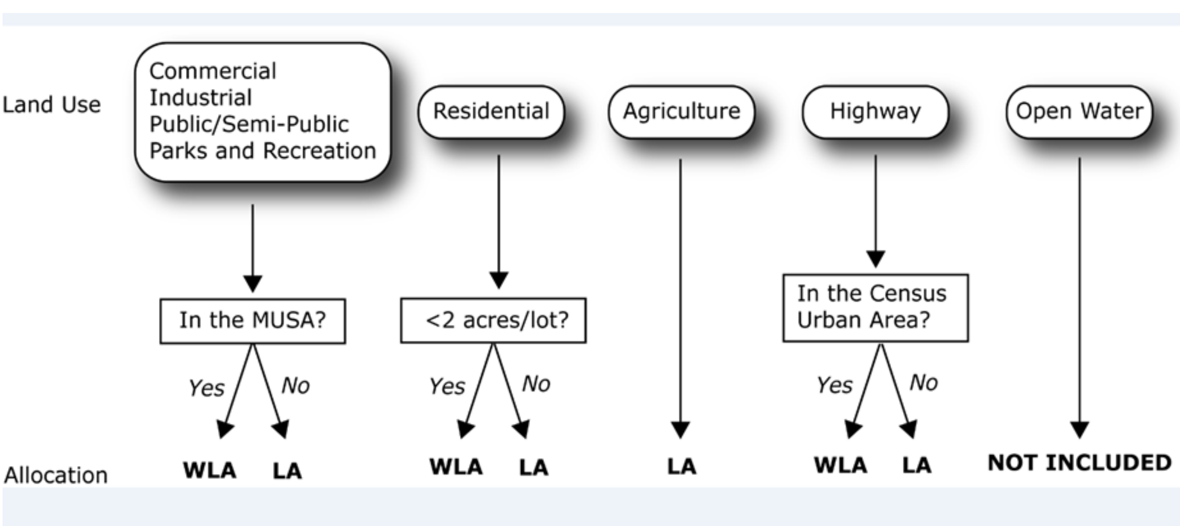
The initial step in developing an excess nutrient TMDL for lakes is to determine the total nutrient loading capacity for the lake, defined as the maximum nutrient load it can receive and still meet water quality standards. To determine the loading capacity for a lake, the average annual nutrient and water budgets were coupled with a lake response model to calibrate to a monitored in-lake condition for a specified time period (generally a one to three-year time period and always within the 10-year period between 2003 and 2012). Where monitored watershed loads were available, that data was either used directly in the estimation of total watershed loads or a watershed model was calibrated to the monitored loads. Once a lake-specific calibrated model was developed, it was used to define a load response curve that reflected the relationship between total nutrient loading (regardless of source) and in-lake water quality. The curve was used to determine the total load required to meet the June-September in-lake phosphorus standard for that lake (60 ug/l for a shallow lake and 40 ug/l for a deep lake). The total load required to achieve the in-lake water quality goal was established as the loading capacity for that lake.

Appendix C- Modeling Methods, Input, and Output for Lakes (including Lake Bathymetry), Appendix D – Elm Creek Watershed SWAT Technical Memo, Appendix E-Bathymetric and Vegetation Surveys for Lakes, and Appendix F – Internal Phosphorus Loading and Sediment Phosphorus Fractionation all provide detailed information on the technical methods and information used to develop TMDLs for the lakes addressed in this report.

4.2.2 Wasteload Allocation Methodology

The WLAs for lakes are typically divided into three categories: NPDES surface wastewater discharges, construction and industrial stormwater, and Municipal Storm Sewer Systems (MS4). The only NPDES surface wastewater discharge in the entire project area is from the Maple Hill Estates mobile home park in Corcoran, which discharges to the South Fork of Rush Creek. The discharge does not reach any of the impaired lakes addressed in this report, however, and therefore is not included in any of the allocation tables for lake TMDLs. To account for construction activity and possible industrial stormwater in the watersheds of the impaired lakes as well as future growth in the watersheds, WLAs equal to 1.0% of the loading capacity for each lake were assigned to cover both these categories, based on guidance from the MPCA staff. All of the municipalities in the watershed are, or soon will be, permitted MS4s, as are two road authorities (the MnDOT and Hennepin County).

Figure 23 summarizes the methodology used in the lakes TMDLs for determining the areas within a community or road authority were included in the wasteload allocation. Using the screening process outlined in Figure 23, each wasteload allocation assigned was proportionate to the acreage of that jurisdiction within the subwatershed of a give impaired lake.



[1] "Open water" refers to the area of the lake for which the allocations are prepared

Figure 23. Schematic Representation of Allocation Methodology[1]

4.2.3 Load Allocation Methodology

The LAs for the lake TMDLs includes atmospheric and internal loading from release of phosphorus by lake bottom sediments, curly leaf pondweed (CLPW) senescence, etc. Also included are watershed loads from areas identified in the comprehensive land use plans for each community that are expected to develop after 2030 or are not expected to be within the MUSA. Existing and future residential development where lots are two acres or greater (generally considered rural residential) are not expected to be served by a regulated conveyance system, and thus are included under the LA. Finally, all the areas owned by the two road authorities -Hennepin County and MnDOT- that are outside the 2010 urban service are included under the LA.

4.2.4 Margin of Safety

The MOS is intended to ensure achievement of the water quality goals despite scientific uncertainty. Most lakes addressed in this TMDL have a robust data set including in-lake monitoring over multiple years and at a frequency of bi-weekly to monthly. In addition, there are over a dozen tributary monitoring sites that were used to estimate loads from particular land use types, and several lakes (notably Fish, Rice, and Diamond) have lab measured internal phosphorus release rates (RRs). An explicit margin of 5% of the loading capacity has been set aside in each lake TMDL. The 5% MOS was considered adequate given each lake's reasonably robust data set and the lake response model performance.

4.2.5 Seasonal Variation and Critical Conditions

Seasonal variation was taken into account in the TMDL by using the eutrophication standards, which are based on growing season averages as the TMDL goals. The eutrophication standards were set with seasonal variability in mind. The load reductions are established so that the receiving water will meet the water quality standard over the course of the growing season (June through September).

Critical conditions in the impaired lakes occur during the growing season when the lakes are used most intensively for direct and indirect contact aquatic recreation. Since the TMDL is based on growing season averages, the critical period is covered by the TMDL.

4.2.6 Future Growth/Reserve Capacity

See Section 4.1.6

4.2.7 TMDL Summary

Numerical TMDL's for each lake were calculated as the sum of the WLA, the LA, and the MOS expressed as a phosphorus mass per unit time. Table 16 to Table 22 present the TMDL equations for each lake. Annual LAs were rounded to the nearest tenth of a pound, while daily LAs were rounded to the nearest thousandth of a pound. The sections below summarize the primary findings applicable to the existing conditions and management of each lake as it pertains to achieving the applicable in-lake water quality standard. The TMDL for each lake is them presented in tabular form, including the loading capacity of the lake and the reductions in nutrient loading needed by permitted or non-permitted source to reach the in-lake standard.

4.2.7.1 Fish Lake

Key findings pertaining to Fish Lake are as follows:

- Fish Lake is approximately 238 acres in surface area and has a maximum depth of 60 feet. About 39% of the lake is less than 15 feet deep. Fish Lake is the only lake classified as a **deep lake** in this TMDL. Recent water quality data indicate it is very close to meeting the eutrophication standard for deep lakes.
- The lake's watershed is fully urbanized, primarily with single family residential and park land uses, and has virtually no vacant land available to support new development. Further, soils in the watershed are generally not conducive to infiltration practices.
- Based in part on incubation of sediment cores and estimation of phosphorus RRs under both anoxic and oxic conditions, about 70% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while about 27% comes from watershed sources.
- Both CLPW and common carp are present in the lake but at non-nuisance levels. Only 39% of the lake's area is littoral (i.e. less than 15 feet deep), which limits somewhat the potential negative impact these invasive species are likely to have on water quality in this system.

To meet the TMDL, a net reduction in TP load affecting Fish Lake of 206.7 lbs/yr. will be needed, equal to a 9.1% reduction of the current total load of 2,262.2 lbs/yr. However, the gross reduction from all sources must include the MOS as well, and therefore is 206.7 lbs/yr. + 102.8 = 309.5 lbs/yr. This load reduction can be achieved through internal load reductions of 19.6%.

Table 16 presents the phosphorus TMDL and allocations for Fish Lake.

Table 16. Fish Lake Phosphorus TMDL and Allocations

Fish Lake TMDL Summary (AUID 27-0118)		**Existing TP Load[1]**	**TP Allocations**		**Load Reduction**	
		lbs./yr.	lbs./yr.	lbs./day	lbs./yr.	%
TOTAL LOAD/LOADING CAPACITY		2262.2	2055.5	5.632	206.7	9.1%
5% EXPLICIT MOS		0.0	102.8	0.282	102.8	4.5%
TOTAL REDUCTION					***309.5***	***13.7%***
WLAs	Construction/Industrial Stormwater	20.6	20.6	0.056	0.0	0.0%
	Maple Grove MS4	551.7	551.7	1.511	0.0	0.0%
	Plymouth MS4	37.6	37.6	0.103	0.0	0.0%
	Hennepin County MS4	8.2	8.2	0.022	0.0	0.0%
	MnDOT MS4	3.7	3.7	0.010	0.0	0.0%
LAs	Atmospheric Deposition	63.5	63.5	0.174	0.0	0.0%
	Internal Load	1577.0	1267.5	3.473	309.5	19.6%

[1] Existing TP load is the average for the years 2010 - 2012.

4.2.7.2 Rice Lake

Key findings pertaining to Rice Lake are as follows:

- Rice Lake is approximately 330 acres in surface area. It has a maximum depth of 11 feet and is classified as a **shallow lake**. The lake is a shallow reservoir/impoundment on the mainstem of Elm Creek and has a contributing watershed area of over 17,460 acres.
- Recent water quality data indicates the lake is severely degraded.
- Both CLPW and common carp are present in the lake at nuisance levels.
- About 25% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while about 74% comes from watershed sources. Release of phosphorus by bottom sediments is the largest source of internal loading, followed by growth and senescence of CLPW.

To meet the TMDL, a net reduction in TP load affecting Rice Lake of 10,325.6lbs/yr will be needed, equal to an 81.7% reduction of the current total load of 12,632.7 lbs/year. However, the gross reduction from all sources must include the MOS as well, and therefore is 10,325.6 lbs/yr + 115.4 = 10,441.0 lbs/yr It is not possible to meet the TMDL through watershed load reductions alone (i.e. the sum of the existing loads from atmospheric deposition and internal loading exceed the total loading capacity for Rice Lake). Therefore, a combination of watershed load reduction and internal load reduction will be necessary to meet the TMDL. The total load reduction needed can be achieved through:

- Watershed load reductions of 84.1%, and
- Internal load reductions of 84.3%, aimed at reducing CLPW to non-nuisance conditions and reducing releases from bottom sediments.

Table 17 presents the phosphorus TMDL and allocations for Rice Lake.

Table 17. Rice Lake Phosphorus TMDL and Allocations

Rice Lake-Main Basin TMDL Summary (AUID 27-0116-01)		**Existing TP Load[1]**	**TP Allocations**		**Load Reduction**	
		lbs/yr	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD/LOADING CAPACITY		12632.7	2307.1	6.321	10325.6	81.7%
5% EXPLICIT MOS		0.0	115.4	0.316	115.4	0.9%
TOTAL REDUCTION					**10441.0**	**82.7%**
WLAs	Construction/Industrial Stormwater	23.1	23.1	0.063	0.0	0.0%
	Maple Grove MS4	4104.1	654.5	1.793	3449.5	84.1%
	Plymouth MS4	1216.0	193.9	0.531	1022.1	84.1%
	Medina MS4	1271.0	202.7	0.555	1068.3	84.1%
	Corcoran MS4	370.2	59.0	0.162	311.2	84.1%
	Hennepin County MS4	79.1	12.6	0.035	66.5	84.1%
	MnDOT MS4	151.3	24.1	0.066	127.2	84.1%
LAs	Non-MS4 Runoff	1952.3	311.3	0.853	1640.9	84.1%
	Upstream Lake (Fish Lake)	107.0	107.0	0.293	0.0	0.0%
	Atmospheric Deposition	88.4	88.4	0.242	0.0	0.0%
	Internal Load	3270.3	515	1.411	2755.3	84.3%

[1] Existing TP load is the average for the years 2010 - 2012.

4.2.7.3 Diamond Lake

Key findings pertaining to Diamond Lake are as follows:

- Diamond Lake is approximately 389 acres in surface area. Diamond Lake is classified as a **shallow lake**, with a maximum depth of 7.4 feet. The lake is at the headwaters of Diamond Creek and has a contributing watershed area of about 2,580 acres.
- Recent water quality data indicates the lake has shown an improving trend in water clarity and that June through September seasonal mean water clarity values have been as good as or better than shallow lake standards for this parameter in three of the four years prior to 2012 (inclusive). Phosphorus and Chl-*a* remain above the shallow lake standards.
- CLPW is present throughout the lake, often at nuisance levels.
- About 28% of the phosphorus load affecting surface water quality in the lake comes from internal sources, while about 69% comes from watershed sources. Growth and senescence of CLPW is the largest source of internal loading, followed by release of phosphorus by bottom sediments.

To meet the TMDL, a net reduction in TP load affecting Diamond Lake of 2,062.2 lbs/yr will be needed, equal to a 71.2% reduction of the current total load of 2,898.0 lbs/year. However, the gross reduction from all sources must include the MOS as well, and therefore is 2,062.2 lbs/yr + 41.8 = 2,104.0 lbs/yr. It is not possible to meet the TMDL through watershed load reductions alone (i.e, the sum of the existing loads from atmospheric deposition and internal loading exceed the total loading capacity for Diamond Lake). Therefore, a combination of watershed load reduction and internal load reduction will be necessary to meet the TMDL. The total load reduction needed can be achieved through:

- Watershed load reductions of 73.5%, and
- Internal load reductions of 80.5%, aimed at reducing CLPW to non-nuisance conditions.

Table 18 presents the phosphorus TMDL and allocations for Diamond Lake.

Table 18. Diamond Lake Phosphorus TMDL and Allocations

Diamond Lake TMDL Summary (AUID 27-0125)		**Existing TP Load[1]**	**TP Allocations**		**Load Reduction**	
		lbs/yr	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD/LOADING CAPACITY		2898.0	835.8	2.290	2062.2	71.2%
5% EXPLICIT MOS		0.0	41.8	0.114	41.8	1.4%
TOTAL REDUCTION					**2104.0**	**72.6%**
WLAs	Construction/Industrial Stormwater	8.4	8.4	0.023	0.0	0.0%
	Dayton MS4	258.4	68.4	0.187	190.0	73.5%
	Rogers MS4	1209.5	320.3	0.877	889.2	73.5%
	Hennepin County MS4	16.2	4.3	0.012	11.9	73.5%
	MnDOT MS4	15.4	4.1	0.011	11.3	73.5%
LAs	Non-MS4 Runoff	489.8	129.7	0.355	360.1	73.5%
	Atmospheric Deposition	103.8	103.8	0.284	0.0	0.0%
	Internal Load	796.5	155.1	0.425	641.4	80.5%

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

4.2.7.4 Goose Lake

Key findings pertaining to Goose Lake are as follows:

- Goose Lake is approximately 64.4 acres in area and has a maximum depth of 6.6 feet and is a **shallow lake**. The watershed area draining to the lake is approximately 240 acres. A major portion of the watershed acreage resides within the Elm Creek Park Reserve. A small residential development also drains to the lake.
- Water quality data indicates the lake is hyper-eutrophic, with conditions that exceed the shallow lake standards for phosphorus, Chl-*a*, and secchi depth transparency. The lake is proposed for listing as impaired for nutrients in 2016.
- An aquatic vegetation survey conducted in 2012 indicated the lake does not have a diverse native plant community. The lake also does not appear to have nuisance growth of CLPW. The lake appears to be in a persistent algal-dominated condition.
- Watershed loading accounts for approximately 33.6% of the TP load; and internal loading accounts for approximately 53.4% of the TP load. Sediment release of phosphorus is the primary source of internal loading.

To meet the TMDL, a net reduction in TP load affecting Goose Lake of 106.5 lbs/yr will be needed, equal to an 80.0% reduction of the current total load of 133.2 lbs/year. However, the gross reduction from all sources must include the MOS as well, and therefore is 106.5 lbs/yr + 1.3 lbs/yr = 107.8 lbs/yr. It is not possible to meet the TMDL through watershed load reductions alone (i.e. the sum of the existing loads from atmospheric deposition and internal loading exceed the loading capacity for Goose Lake). Therefore, a combination of watershed load reduction and internal load reduction will be necessary to meet the TMDL. The total load reduction needed can be achieved through:

- Watershed load reductions of 82.2%, and
- Internal load reductions of 100%.

Table 19 presents the phosphorus TMDL and allocations for Goose Lake.

Table 19. Goose Lake Phosphorus TMDL and Allocations

Goose Lake TMDL Summary (AUID 27-0122)		Existing TP Load[1]	TP Allocations		Load Reduction	
		lbs/yr	lbs/yr	lbs/day	lbs/yr	%
LOADING CAPACITY/TOTAL LOAD		133.2	26.7	0.073	106.5	80.0%
5% EXPLICIT MOS		0.0	1.335	0.004	1.3	1.0%
TOTAL REDUCTION					**107.8**	**81.0%**
WLAs	Construction/Industrial SW	0.3	0.3	0.001	0.0	0.0%
	Champlin MS4	20.8	3.7	0.010	17.1	82.2%
	Dayton MS4	19.9	3.5	0.010	16.3	82.2%
	Hennepin County MS4	0.9	0.2	0.0004	0.8	82.2%
LAs	Non-MS4 Runoff	3.0	0.5	0.001	2.4	82.2%
	Atmospheric Deposition	17.2	17.2	0.047	0.0	0.0%
	Internal Load	71.2	0	0.000	71.2	100.0%

[1] Existing TP load is the average for the years 2011 and 2012.

4.2.7.5 Cowley Lake

Key findings pertaining to Cowley Lake are as follows:

- Cowley Lake is approximately 32.9 acres in area with a maximum depth of 8.0 feet. It is classified as a **shallow lake**. The watershed area draining to the lake is approximately 827 acres. The primary land use within the watershed is agricultural.
- Water quality data indicates the lake is considered hyper-eutrophic with June through September seasonal mean TP, Chl-*a*, and secchi depth values exceeding the shallow lake standards.
- Aquatic vegetation surveys indicated nuisance levels of CLPW present within the lake.
- Approximately 49.5% of the TP load to the lake is from watershed sources. Internal loading accounts for 49.4% of the TP loading. Sediment release of phosphorus is the primary source of internal loading followed by growth and senescence of CLPW.

To meet the TMDL, a net reduction in TP load affecting Cowley Lake of 751.1 lbs/yr will be needed, equal to an 88.8% reduction of the current total load of 846.1 lbs/year. However, the gross reduction from all sources must include the MOS as well, and therefore is 751.1 lbs/yr + 4.8 lbs/yr = 755.9 lbs/yr. It is not possible to meet the TMDL through watershed load reductions alone (i.e, the sum of the existing loads from atmospheric deposition and internal loading exceed the loading capacity for Cowley Lake). Therefore, a combination of watershed load reduction and internal load reduction will be necessary to meet the TMDL. The total load reduction needed can be achieved through:

- Watershed load reductions of 80.7%, and;
- Internal load reductions of 100%, aimed at reducing sediment phosphorus release to the background levels embedded in the lake response models used to analyze Cowley Lake and reducing CLPW to non-nuisance conditions.

Table 20 presents the phosphorus TMDL and allocations for Cowley Lake.

Table 20. Cowley Lake Phosphorus TMDL and Allocations

Cowley Lake TMDL Summary (AUID 27-0169)		**Existing TP Load[1]**	**TP Allocations**		**Load Reduction**	
		lbs/yr	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD/LOADING CAPACITY		846.1	95	0.260	751.1	88.8%
5% EXPLICIT MOS		0.0	4.75	0.013	4.8	0.6%
TOTAL REDUCTION					**755.9**	**89.3%**
WLAs	Construction/Industrial Stormwater	1.0	1.0	0.003	0.0	0.0%
	Rogers MS4	292.9	56.5	0.155	236.5	80.7%
	Hennepin County MS4	1.0	0.2	0.001	0.8	80.7%
LAs	Non-MS4 Runoff	123.7	23.8	0.065	99.9	80.7%
	Atmospheric Deposition	8.8	8.8	0.024	0.0	0.0%
	Internal Load	418.7	0	0.000	418.7	100.0%

[1] Existing TP load is the average for the year 2006

4.2.7.6 Sylvan Lake

Key findings pertaining to Sylvan Lake are as follows:

- Sylvan Lake is approximately 148.1 acres in area with a maximum depth of 10.0 feet. It is therefore classified as a **shallow lake**. The watershed area draining to the lake is approximately 320 acres. The dominant land use within the watershed is agricultural.
- Water quality data indicates the lake exhibits hyper-eutrophic conditions and exceed the shallow lake standards for phosphorus, Chl-*a*, and Secchi depth transparency.
- Aquatic vegetation surveys conducted in 2012 indicated the lake has nuisance levels of CLPW. After senescence of CLPW, the lake has severe algal blooms that persist throughout the remaining portion of the summer.
- Watershed loading accounts for approximately 24% of the TP load; internal loading accounts for approximately 73% of the TP load. Sediment release of phosphorus is the primary source of internal loading followed by the senescence of CLPW.

To meet the TMDL, a net reduction in TP load affecting Sylvan Lake of 999.1 lbs/yr will be needed, equal to an 83.0% reduction of the current total load of 1203.1 lbs/year. However, the gross reduction from all sources must include the MOS as well, and therefore is 999.1 lbs/yr + 10.2 lbs/yr = 1009.3 lbs/yr It is not possible to meet the TMDL through watershed load reductions alone (i.e, the sum of the existing loads from atmospheric deposition and internal loading exceed the loading capacity for Sylvan Lake). Therefore, a combination of watershed load reduction and internal load reduction will be necessary to meet the TMDL. The total load reduction needed can be achieved through:

- Watershed load reductions of 76.7%, and
- Internal load reductions of 90.2%, aimed at reducing sediment phosphorus release to near the background levels embedded in the lake response models used to analyze Sylvan Lake and reducing CLPW to non-nuisance conditions.

Table 21 presents the phosphorus TMDL and allocations for Sylvan Lake.

Table 21. Sylvan Lake Phosphorus TMDL and Allocations

Sylvan Lake TMDL Summary (AUID 27-0171)		**Existing TP Load[1]**	**TP Allocations**		**Load Reduction**	
		lbs/yr	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD/LOADING CAPACITY		1203.1	204	0.559	999.1	83.0%
5% EXPLICIT MOS		0.0	10.2	0.028	10.2	0.8%
TOTAL REDUCTION					**1009.3**	**83.9%**
WLAs	Construction/Industrial Stormwater	1.9	1.9	0.005	0.0	0.0%
	Rogers MS4	47.1	11.0	0.030	36.1	76.7%
LAs	Non-MS4 Runoff	237.2	55.2	0.151	182.0	76.7%
	Atmospheric Deposition	39.7	39.7	0.109	0.0	0.0%
	Internal Load	877.2	86	0.236	791.2	90.2%

[1] Existing TP load is the average for the year 2012.

4.2.7.7 Henry Lake

Key findings pertaining to Henry Lake are as follows:

- Henry Lake is approximately 47 acres in area with a maximum depth of 8.2 feet. It is therefore classified as a **shallow lake**. The watershed area draining to the lake is approximately 812 acres. The primary land use within the watershed is agricultural.
- The seasonal average phosphorus concentrations (June through September) indicate the lake has hyper-eutrophic conditions exceeding the shallow lake standard. The Chl-*a* and water clarity response variables also exceed the shallow lake standards for majority of the years, but have occasionally met the shallow lake standards during periods in which the lake is in a rooted-plant dominated condition. The shallow lake seems to alternate between the algal and plant dominated conditions.
- Aquatic vegetation surveys indicated the lake has nuisance levels of CLPW. The lake also has a diverse native plant community in some years. The lake was in the rooted aquatic plant-dominated condition at the time of the macrophyte survey in 2011.
- Watershed loading accounts for approximately 71% of the TP load to the lake; internal loading accounts for approximately 27.6% of the TP load. Both sediment release of phosphorus and senescence of CLPW are considered significant sources of internal loading.

To meet the TMDL, a net reduction in TP load affecting Henry Lake of 778.9 lbs/yr will be needed, equal to an 80.1% reduction of the current total load of 972.5 lbs/year. However, the gross reduction from all sources must include the MOS as well, and therefore is 778.9 lbs/yr + 9.7 lbs/yr = 788.6 lbs/yr. It is not possible to meet the TMDL through watershed load reductions alone (i.e. the sum of the existing loads from atmospheric deposition and internal loading exceed the loading capacity for Henry Lake). Therefore, a combination of watershed load reduction and internal load reduction will be necessary to meet the TMDL. The load reduction needed can be achieved through:

- Watershed load reductions of 82.4%, and
- Internal load reductions of 82.1%, aimed at reducing curlyleaf pondweed growth to non-nuisance conditions and reducing sediment phosphorus release.

Table 22 presents the phosphorus TMDL and allocations for Henry Lake.

Table 22. Henry Lake Phosphorus TMDL and Allocations

Henry Lake TMDL Summary (AUID 27-0175)		Existing TP Load[1]	TP Allocations		Load Reduction	
		lbs/yr	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD/LOADING CAPACITY		972.5	193.6	0.530	778.9	80.1%
5% EXPLICIT MOS		0.0	9.7	0.027	9.7	1.0%
TOTAL REDUCTION					**788.6**	**81.1%**
WLAs	Construction/Industrial Stormwater	1.8	1.8	0.005	0.0	0.0%
LAs	Non-MS4 Runoff	689.4	121.5	0.333	567.9	82.4%
	Atmospheric Deposition	12.6	12.6	0.035	0.0	0.0%
	Internal Load	268.7	48	0.132	220.7	82.1%

[1] Existing TP load is the average for the years 2009 and 2011.

4.3 Biotic Impairments/Stressors (including DO)

A SID analysis based on the CADDIS methodology (EPA 2000) was conducted to apply a "strength of evidence" approach to evaluate candidate causes affecting biotic integrity. The Elm Creek Watershed SID Report (Lehr 2015) evaluated the following candidate stressors:

- Water temperature
- ph
- un-ionized ammonia
- excess nitrate
- organic contaminants
- inorganic contaminants (heavy metals)
- altered hydrology
- altered physical habitat
- excess sediment
- excess phosphorus
- low DO
- excess chloride

Six probable stressors were identified within the Elm Creek Watershed; however, the relative impact of these stressors varies based on the stream reach. The relative impact of these different stressors is summarized in Table 23.

Table 23. Summary of Stressors to Biotic Assemblages in the Elm Creek Watershed

HUC-8 Subwatershed	AUID (Last 3 digits)	Stream	Reach Description	Biological Impairment	Primary Stressor: Altered Hydrology	Altered Physical Habitat	Excess Sediment	Excess Phosphorus	Low DO	Excess Chloride
7010206 Mississippi River-Twin Cities	508	Elm Creek	Headwaters (Lk Medina 27-0146-00) to Mississippi River	Fish	•	o	•	o	•	/
				Macroinvertebrates	o	o	o	o	o	/
	525	Diamond Creek	Headwaters (French Lk 27-0127-00) to Unnamed Lake	Fish	•	•	•	o	•	/
				Macroinvertebrates	•	o	o	o	•	/
	528	Rush Creek, Main Stem	Headwaters to Elm Creek	Fish	•	o	•	o	•	/
				Macroinvertebrates	•	o	•	o	o	/
	732	Rush Creek, South Fork	Unnamed Lk (27-0439-00) to Rush Creek	Fish	•	•	•	•	•	/
				Macroinvertebrates	o	•	o	•	o	/
	760	Rush Creek, South Fork	Unnamed ditch to County Ditch 16	Fish	•	•	•	•	•	/
				Macroinvertebrates	o	•	o	o	•	/

• = Primary Stressor
o = Secondary Stressor
/ = Inconclusive Stressor

A summary of the recommendations from the SID report pertaining to the pollutant and non-pollutant stressors and how they should be addressed in this TMDL effort is summarized in Table 24.

Table 24. Recommended Prioritization of TMDLs Relative to the Stressors Contributing to the Biological Impairment in the Elm Creek Watershed

Stressor	Priority	Comment
Altered Hydrology	High	TMDL should focus on reestablishing historical hydrologic patterns.
Altered Physical Habitat	High	TMDL should focus on increasing the diversity of sediment types and functionality of large woody debris.
Excess Sediments	High	TMDL should be conducted concurrent to altered habitat to focus on increasing the diversity of bed sediment size.
Excess Phosphorus	Medium	TMDL should focus on addressing the current loads and historical accumulation of phosphorus in wetlands (should potentially be expanded to include nitrogen).
Low DO	Medium	Additional monitoring should be conducted to describe the relative contribution of low DO from wetland complexes and the alignment of biological monitoring stations with different habitat types. TMDL should focus on historical accumulation of phosphorus in wetlands and nitrification (particularly in Rush Creek).

In summary, the non-pollutant stressors of altered hydrology and altered physical habitat will be addressed as part of this TMDL project, as will the pollutant stressors of excess sediments and excess phosphorus.

It is important to note that TP (and the corresponding TMDL) is being used as a surrogate to address low DO based on the spatial correlation between DO impairment, TP concentrations and BOD (Lehr 2015). Low DO conditions can be caused through a variety of mechanisms (see Section 3.5.3); however, excessive oxygen demand resulting from excess nutrient-driven productivity is common throughout urban and agricultural stream systems (Dodds 2006). Given the high TP concentrations observed throughout the Elm Creek system, the potential role of excess TP as a primary cause of low DO was investigated by examining the correlation between DO impairment, carbonaceous BOD (which results from microbial degradation or organic matter) and TP concentrations. A summary of findings from the SID analysis (Lehr 2015) pertaining to this issue is presented below:

- Biological and chemical evidence suggests that the severity of DO impairment decreases from upstream to downstream. This trend is strongly correlated with TP-BOD relationships.
- Rush Creek (AUID 528) has the strongest evidence for DO impairment and similarly, the second highest average BOD concentration—and BOD concentrations are relatively well correlated to TP concentrations. This relationship between DO impairment, BOD and TP concentrations is consistent across sites in South Rush Creek, Diamond Creek and Upper Elm Creek, where sites with the strongest level of DO impairment also have the highest BOD concentrations and/or strongest TP-BOD correlations.
- Lower Elm Creek has consistent chemical data to support DO impairment, but the corresponding biological communities are less consistent with low DO conditions. Given the diurnal variation in DO concentration associated with wetland-influenced sites in lower Elm Creek, low DO conditions are likely driven by BOD that originates from wetland plant decomposition. The BOD-TP relationship from lower Elm Creek corroborates the chemical and biological data. Relatively high BOD concentrations were observed in lower Elm Creek, but the correlation to TP was particularly weak. Taken together, these data suggest that localized areas of low DO likely exist

in lower Elm Creek, but that this is primarily driven by wetland processes and not general water quality conditions.

4.3.1 Altered Hydrology

4.3.1.1 Extent of Impairment and Determination of Loading Capacity

Extent of Impairment. Evidence for biotic impacts from altered hydrology is relatively common across all AUIDs. The SID report (Lehr 2015) presents information that shows land use and precipitation patterns driving stream hydrology have clearly shifted over the last 30 years. Concurrently, discharge patterns in Elm Creek have shifted to a flashier hydrologic regime and the physical and chemical stressors that commonly result from altered hydrology have increased throughout the watershed. Given the lack of historical biological data, biotic assemblages within Elm Creek cannot be analyzed for temporal response. However, the current fish and macroinvertebrate assemblages are generally consistent with those commonly observed in flashy hydrologic systems, in which high-flow events episodically scour stream habitat, but the majority of the hydrograph is dominated by low-flow conditions (Poff and Allan 1995; Roy, et. al. 2005; Dewson, et. al. 2007). Hydrologically-induced shifts in fish assemblage composition are the most pronounced and consistent across AUIDs, while the response of Macroinvertebrate matrices is less pronounced and less consistent across AUIDs, suggesting that flow-regime structure may be a more significant driver of community structure than peak erosive potential and that habitat conditions may vary within Elm Creek. Among AUIDs, the biotic response to altered hydrology is most pronounced in stream AUIDs -508 (Elm Creek), -732 (Lower South Fork, Rush Creek) and -528 (Rush Creek mainstem) and least pronounced in -760 (upper South Fork, Rush Creek) and -525 (Diamond Creek).

Determination of Loading Capacity/Implementation Priorities. No specific criteria for hydrological stability/instability have been developed in the state of Minnesota. As such, it is not possible to calculate a specific loading capacity for this stressor, but there are a range of implementation activities that will complement and enhance the reduction of the stressors for which TMDLs are being developed. The primary cause of hydrologic instability is conversion of lands away from native vegetative cover towards more impervious surfaces, which increases the rate and volume of runoff and minimizes GW recharge and base flow. Management practices that reduce the rate and volume of runoff and maximize infiltration will have the greatest benefit to the Elm Creek system. Secondarily, management efforts should focus on a reconnection of the incised stream channel to its formerly connected floodplain and wetlands systems. Management practices that increase habitat connectivity will benefit the management of both high and low flow periods as well as maximize habitat diversity for aquatic organisms. Implementation of management practices to address altered hydrology should be initially focused in upstream reaches of the watershed to maximize the benefits of hydrologic restoration throughout the watershed.

4.3.2 Altered Physical Habitat

4.3.2.1 Extent of Impairment and Determination of Loading Capacity

Extent of Impairment. Evidence for biotic impacts from physical habitat alteration is mixed across AUIDs and assemblages (Lehr 2015). Altered hydrologic and land use patterns that commonly result in altered physical habitat in streams have clearly shifted throughout the watershed over the last 30 years.

Concurrently, physical habitat in streams throughout the Elm Creek Watershed has shifted to a more homogenous, lower quality condition, although areas of moderate to good habitat continue to persist in lower Elm and Rush Creeks. Given the lack of historical biological data, assemblages within Elm Creek cannot be analyzed for temporal response to physical habitat alteration. Current fish assemblages in all AUIDs except -528 are consistent with homogenous, lower quality stream habitat conditions—richness of fish assemblages is generally reduced over unimpaired sites and dominated by relatively few taxa that utilize a limited number of habitat types (or are generalists across a range of habitat types). However, richness, diversity and proportional dominance of taxa for of Macroinvertebrate assemblages in all AUIDs are relatively consistent with unimpaired sites.

Determination of Loading Capacity/Implementation Priorities. No specific criteria for habitat quality have been developed in the state of Minnesota. As such, it is not possible to calculate a specific loading capacity for this stressor. However, there are a range of implementation activities that will complement and enhance the reduction of the stressors for which TMDLs are being developed. The primary cause of habitat alteration is altered stream hydrology, which has led to channel incision and a homogenization of substrate types throughout the system. Efforts to restore hydrologic stability in the system will likely have the greatest impact on habitat throughout the Elm Creek system. In addition to hydrologically-oriented restoration, localized efforts to enhance large woody debris recruitment, maximize the diversity of flow regimes and minimize streambank sediment erosion will increase the rates of habitat restoration throughout the system. As with hydrology, management/restoration efforts should focus on sites in upstream reaches to maximize benefits throughout the watershed. Additionally, hydrologic restoration should generally precede efforts to restore streambank stability to maximize the longevity and minimize the costs associated with any engineered structures.

4.3.3 Excess Sediment

4.3.3.1 Extent of Impairment and Determination of Loading Capacity

Extent of Impairment. The state stream standards for TSS adopted by MPCA (MPCA 2014) establishes the connection between stream TSS levels and the condition of stream biologic communities. The Elm Creek Watershed project area is located within the Central River region as identified in the technical support document for those standards. A stream within the Central River region is considered impaired for TSS if more than 10% of the April-September samples exceed 30 mg/l. Table 25 summarizes TSS data collected by stream reach and by monitoring station within the Elm Creek Watershed during the period 2003 to 2012. The information presented includes the stream reach within which the data was collected, the monitoring site designation, the period of record for the data presented, the total number of data points during the April through September period, the number of data points with values greater than 30 mg/l, and the percent of those samples exceeding the standard. Where multiple monitoring sites lie within a single impaired reach, the data presented for those monitoring sites is in upstream to downstream order. Finally, the last row under each stream reach is a summary of data for all the monitoring sites in that reach and was used as the main factor in determining which stream reaches required a TMDL to address TSS. Red figures in the far right-hand column indicate exceedance of the TSS standard. Note that the upper reach of the South Fork, Rush Creek (AUID -760) has no TSS monitoring data, therefore the data for the lower reach of the South Fork, Rush Creek (AUID -732) was used as a surrogate.

Table 25. Summary of TSS Data for Biotic Community-Impaired Reaches

Stream Reach (AUID)	Monitoring Site	EQuIS ID	Years	Total Number of TSS Samples (N)	N Greater Than 30 mg/L	% of N greater than 30 mg/L
South, Fk, Rush Cr. (Lower) (AUID - 732)	RCSL	S004-542	2007-2012	56	3	5.4%
	Reach Total			**56**	**3**	**5.4%**
Rush Cr., Main stem (AUID - 528)	RCTH	S004-541	2007-2012	56	7	12.5%
	RC116	S004-540	2009-2012	25	2	8.0%
	RT	S004-539	2007-2012	111	8	7.2%
	Reach Total			**192**	**17**	**8.9%**
Diamond Cr. (AUID 525)	DCZ	S004-536	2007-2012	66	17	25.8%
	SD	S004-537	2007-2012	35	18	51.4%
	DC	S004-538	2007-2012	103	15	14.6%
	Reach Total			**204**	**50**	**24.5%**
Elm Cr. (AUID - 508)	HAMEL	S004-545	2003-2012	163	64	39.3%
	ECER	S004-544	2003-2012	126	28	22.2%
	EC77	S004-543	2007-2012	141	43	30.5%
	ECW	S003-441	2009-2012	46	7	15.2%
	EC81	S005-338	2008-2012	97	17	17.5%
	USGS	S004-222	2003-2012	106	1	0.9%
	ECHO	S004-221	2009-2012	72	0	0.0%
	Reach Total			**751**	**160**	**21.3%**

[1] Includes only data collected during April-September period
[2] Values highlighted in red exceed 100 ug/l standard

Figure 24 overlays the TSS data and information on a map of the watershed. The data indicate that TSS do not exceed the threshold percent exceedance in Rush Creek mainstem when considering the entire monitoring data set for that reach, nor is the impairment threshold exceeded in the South Fork of Rush Creek. Both Diamond Creek (AUID -525) and Elm Creek (AUID -508) show moderate exceedances, especially in their upper reaches. Finally, monitoring data for Elm Creek below its confluence with Rush Creek show that this stream segment meets the TSS standard, even though it is part of the longer AUID reach for Elm Creek that does not. In summary, these data support the preparation of a TMDL to address TSS exceedances in Diamond Creek and Elm Creek (their subwatersheds are shaded in Figure 24).

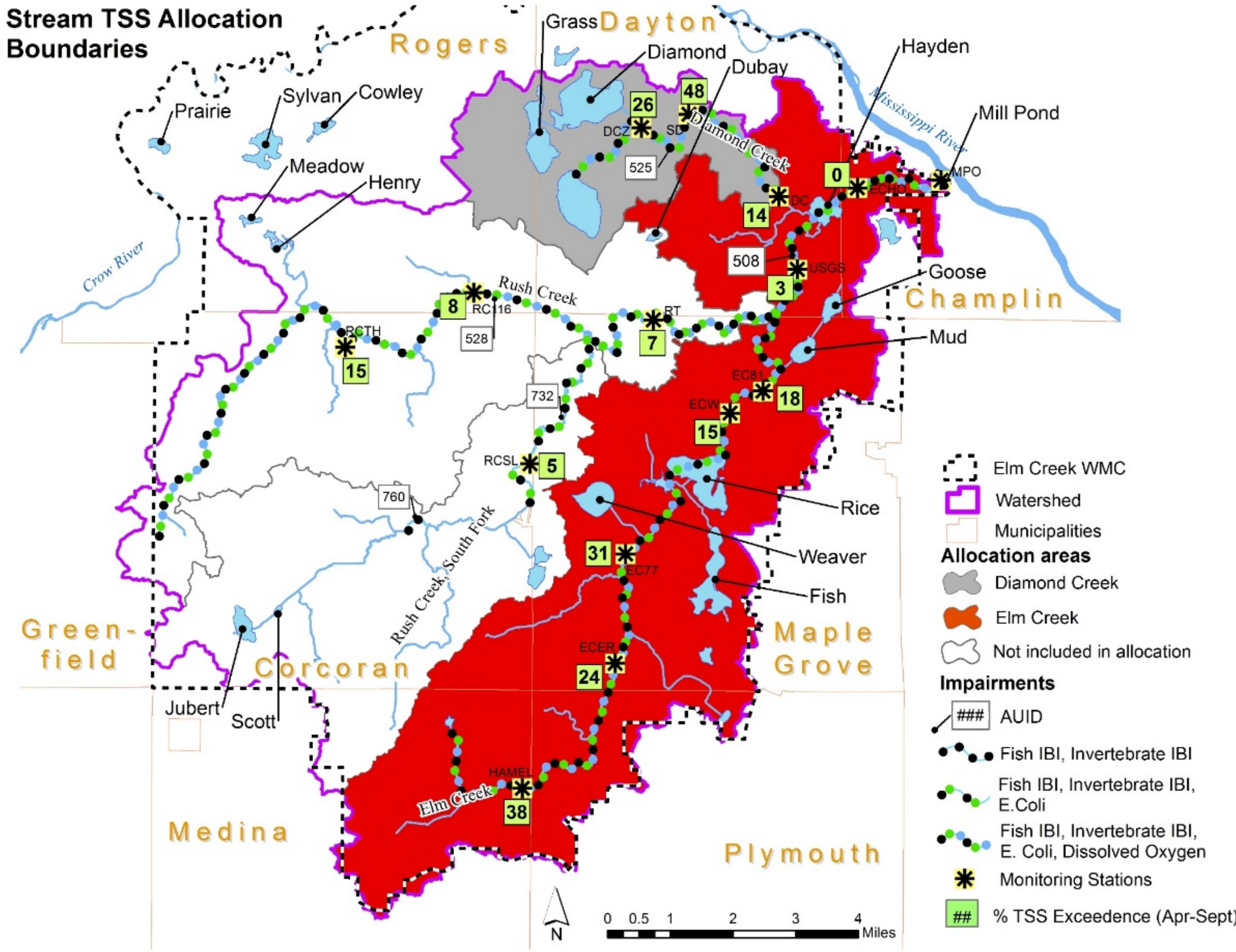


Figure 24. Summary of TSS Data for Biotic Community-Impaired Reaches

Determination of Loading Capacity. Flow and LDCs were used to define the loading capacity for TSS for each of the reaches showing excessive TSS concentrations. The methodology employed for this approach was as described in Section 4.1.1, with flow data from monitoring stations DC and USGS used to generate the flow duration curves for Diamond Creek and Elm Creek, respectively.

To develop the LDC for each reach, all the daily average flows were multiplied by the TSS standard of 30 mg/l and converted to a daily load to create a continuous LDC. The line represents the loading capacity of the stream for each daily flow. The loading capacity can also be compared with current conditions by plotting the measured TSS load for each water quality sampling event. The values above the curve are those which exceed the standard, while those below are better than the standard.

The LDCs and measured load data for the listed reaches are presented in Figure 25 and Figure 26. Note that there are figures at the top of each graph that show the percent reductions needed to meet the standard in that flow regime. It should also be noted that only concentration data from stations showing exceedances of the chronic standard for one or more months during the period 2003 through 2012 were used in calculating the actual loads.

Note: The blue line represents the maximum allowable daily TSS load

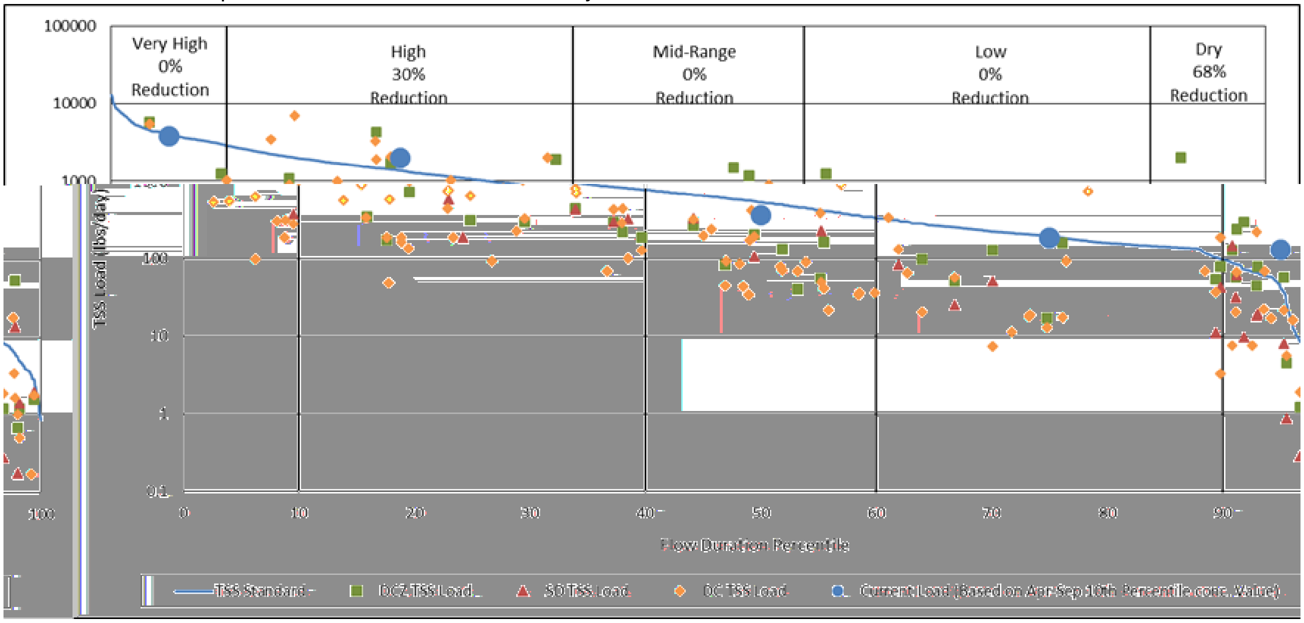


Figure 25. Diamond Creek (AUID - 525) TSS LDC and Required Load Reductions by Flow Regime

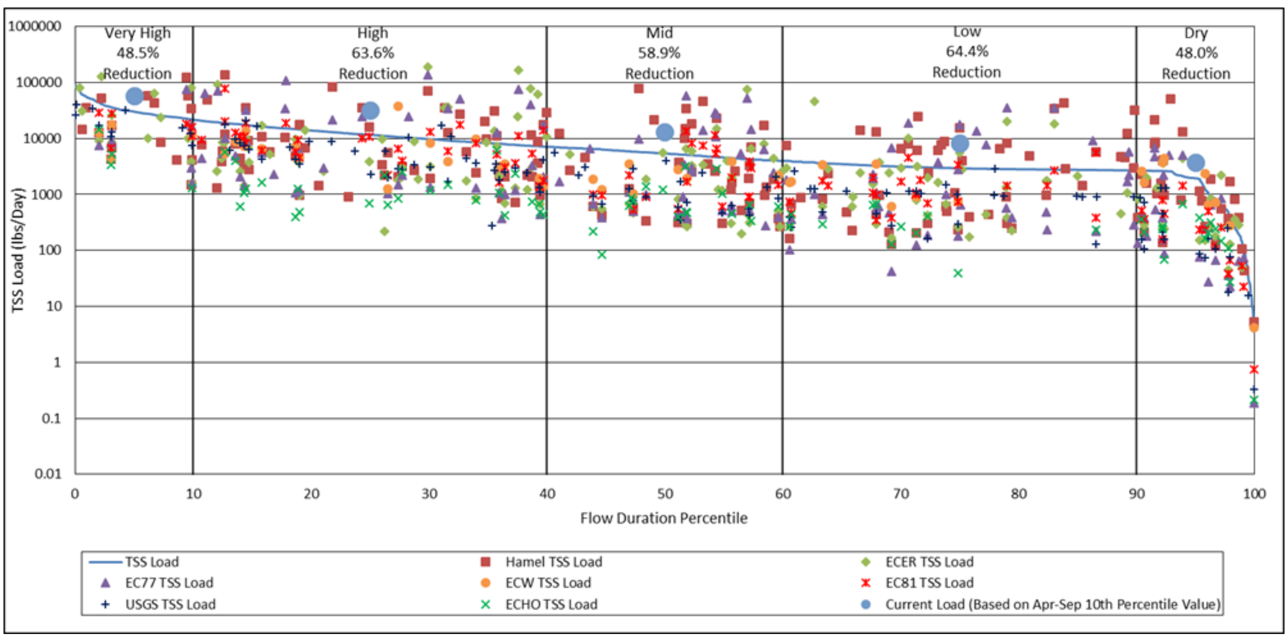


Figure 26. Elm Creek (AUID - 508) TSS LDC and Required Load Reductions by Flow Regime

4.3.3.2 Wasteload and Load Allocation Methodology

The WLA and LA Methodology used to address the TSS stressor for biotic impairments is the same as the methodology described in Section 4.1 for bacteria allocations except for the boundary conditions employed for the Elm Creek TMDL. Here, boundary conditions were established at the bottom of the Rush Creek Subwatershed (AUID -528) based on the fact that this reach meets the stream standard for TSS (and that anti-degradation will sustain this condition) and at the bottom of AUID -525 (Diamond Creek) in anticipation that the TSS TMDL will be fully implemented in that subwatershed. The loads for both reaches were accounted for under the heading "Upstream subwatersheds" in the allocation tables for the Elm Creek mainstem, with the loads for Rush Creek based on monitored current loads and those for Diamond Creek based on loads consistent with meeting the stream standard of 30 mg/l.

4.3.3.3 Margin of Safety

See Section 4.1.4.

4.3.3.4 Seasonal Variation

See Section 4.1.5.

4.3.3.5 Future Growth

See Section 4.1.6.

4.3.3.6 TMDL Summary

Table 26 and Table 27 present the total loading capacity, MOS, WLAs, and remaining watershed LAs for the two stream reaches that violate the MPCA's TSS stream standard.

Table 26. Diamond Creek TSS TMDL by Flow Zone (AUID - 525)

Diamond Creek: AUID 07010206-525		Flow Zones				
		Very High	High	Mid	Low	Dry
		Total Suspended Solids Load (lbs./Day)				
WLAs	Total WLA	2621.37	899.32	349.07	126.94	27.24
	Construction Stormwater	40.21	13.80	5.36	1.95	0.42
	Industrial Stormwater	20.11	6.90	2.68	0.97	0.21
	MS4 - Dayton	1632.77	560.16	217.43	79.07	16.96
	MS4 - Rogers	903.09	309.82	120.26	43.73	9.38
	MS4 - Hennepin County	13.74	4.71	1.83	0.67	0.14
	MS4 - MnDOT	11.45	3.93	1.52	0.55	0.12
LAs	Total Load Allocations	1198.97	411.33	159.66	58.06	12.46
	Non-MS4 runoff	1198.97	411.33	159.66	58.06	12.46
5% Explicit Margin of Safety (MOS)		201.07	68.98	26.78	9.74	2.09
Total Load (TMDL)		4021.41	1379.63	535.51	194.74	41.78
Existing Load		3843.87	1980.6	331.54	181.88	78.79
Estimated Reduction (%)		0	30	0	0	68

Table 27. Elm Creek TSS TMDL by Flow Zone (AUID - 508)

Elm Creek: AUID 07010206-508		Flow Zones				
		Very High	High	Mid	Low	Dry
		Total Suspended Solids Load (lbs./Day)				
WLAs	Total WLA	9740.83	4308.60	1771.44	1391.02	1024.43
	Construction Stormwater	302.22	116.36	53.69	29.39	19.47
	Industrial Stormwater	151.11	58.18	26.85	14.69	9.73
	MS4 - Champlin	353.62	157.40	64.38	51.28	37.89
	MS4 -Corcoran	1600.87	712.58	291.46	232.17	171.55
	MS4 - Dayton	2172.41	966.98	395.51	315.06	232.79
	MS4 - Maple Grove	3413.36	1519.35	621.44	495.03	365.77
	MS4 - Medina	896.93	399.24	163.30	130.08	96.11
	MS4 - Plymouth	625.82	278.56	113.94	90.76	67.06
	MS4 - Hennepin County	78.40	34.90	14.27	11.37	8.40
	MS4 - MnDOT	146.11	65.03	26.60	21.19	15.66
LAs	Total Load Allocations	7279.30	3240.16	1325.29	1055.70	780.03
	Upstream Subwatersheds (Rush/ Diamond Cr.)	11690.30	3505.90	2004.00	345.00	44.90
	Non-MS4 runoff	7279.30	3240.16	1325.29	1055.70	780.03
5% Explicit Margin of Safety (MOS)		1511.08	581.82	268.46	146.93	97.33
Total Load (TMDL)		30221.50	11636.48	5369.19	2938.65	1946.69
Existing Load		58629.77	32011.66	13064.93	8259.63	3744.87
Estimated Reduction (%)		48.5	63.6	58.9	64.4	48.0

4.3.4 Excess Phosphorus

4.3.4.1 Extent of Impairment and Loading Capacity

Extent of Impairment. As with the TSS, the state stream standards for TP adopted by the MPCA (MPCA 2013) provide a credible means of connecting stream TP data to the condition of a stream biologic community. The Elm Creek Watershed project area is located within the Central River region as identified in the technical support document for those standards. A stream within the Central River region is considered impaired for TP if the mean summertime (June through September) values are greater than 100 ug/l.

Table 28 summarizes the TP data collected by stream reach and by monitoring station within the Elm Creek Watershed during the period 2003 to 2012. The information presented includes the stream reach within which the data was collected, the monitoring site designation, the period of record for the data presented, the total number of data points during the June through September period, and the mean values of all data collected during that period. Where multiple monitoring sites lie within a single impaired reach, the data presented for those monitoring sites is in upstream to downstream order. Red figures in the far right-hand column indicate exceedance of the TP standard. Note that the upper reach of the South Fork, Rush Creek (AUID -760) has no TP monitoring data, therefore the data for the lower reach of the South Fork, Rush Creek (AUID -732) was used as a surrogate.

Table 28. Summary of TP Data for Biotic Community-Impaired Reaches

Stream Reach (AUID)	Monitoring Site	EQuIS ID	Years	Total Number of TP Samples (N)	Mean TP (µg/L)
South, Fk, Rush Cr. (Lower) (AUID - 732)	RCSL	S004-542	2007-2012	44	485.4
	Reach Total			**44**	**485.4**
Rush Cr., Mainstem (AUID - 528)	RCTH	S004-541	2007-2012	31	514
	RC116	S004-540	2007-2012	49	561
	RT	S004-539	2007-2012	76	461
	Reach Total			**156**	**502.9**
Diamond Cr. (AUID 525)	DCZ	S004-536	2007-2012	46	429.6
	SD	S004-537	2007-2012	27	447.5
	DC	S004-538	2007-2012	68	266.5
	Reach Total			**141**	**354.4**
Elm Cr. (AUID - 508)	HAMEL	S004-545	2003-2012	115	313.7
	ECER	S004-544	2003-2012	83	325.8
	EC77	S004-543	2007-2012	98	285.8
	ECW	S003-441	2009-2012	31	365.6
	EC81	S005-338	2008-2012	65	276.9
	USGS	S004-222	2003-2012	93	222.8
	ECHO	S004-221	2009-2012	47	397.1
	Reach Total			**532**	**304.9**

[1] Includes only data collected during June-September period
[2] Values highlighted in red exceed 100 µg/l standard

Figure 27 overlays the TP data and surrogate information on a map of the watershed. The data indicate that TP concentrations exceed the stream standard at all monitoring locations, and that the exceedances are generally most severe in the upper reaches of the listed reaches.

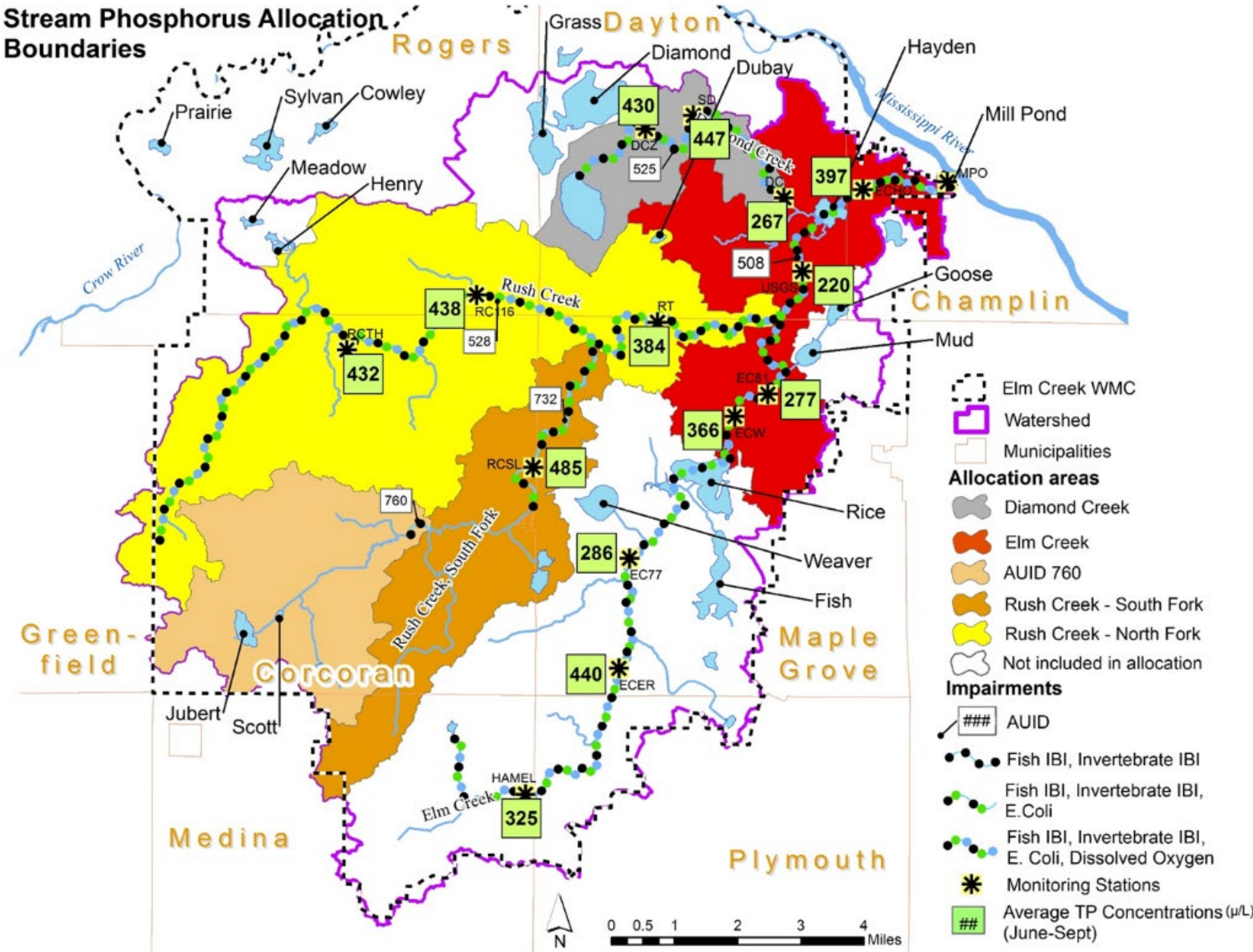


Figure 27. Summary of TP Data for Biotic Community-Impaired Reaches

Determination of Loading Capacity. Flow and LDCs were used to define the loading capacity for TP for each of the stream reaches showing excessive TP concentrations. The methodology employed for this approach was as described in Section 4.1.1.

To develop the LDC for each reach, all the daily average flows were multiplied by the TP standard of 100 ug/l and converted to a daily load to create a continuous LDC. The line represents the loading capacity of the stream for each daily flow. The loading capacity can also be compared with current conditions by plotting the measured TP load for each water quality sampling event. The values above the curve are those which exceed the standard, while those below the LDC line are better than the standard.

The LDCs and measured load data for the listed reaches are presented in the following five Figures. Note that there are figures at the top of each graph that show the percent reductions needed to meet the standard in that flow regime.

Note: The blue line represents the maximum allowable daily TP load

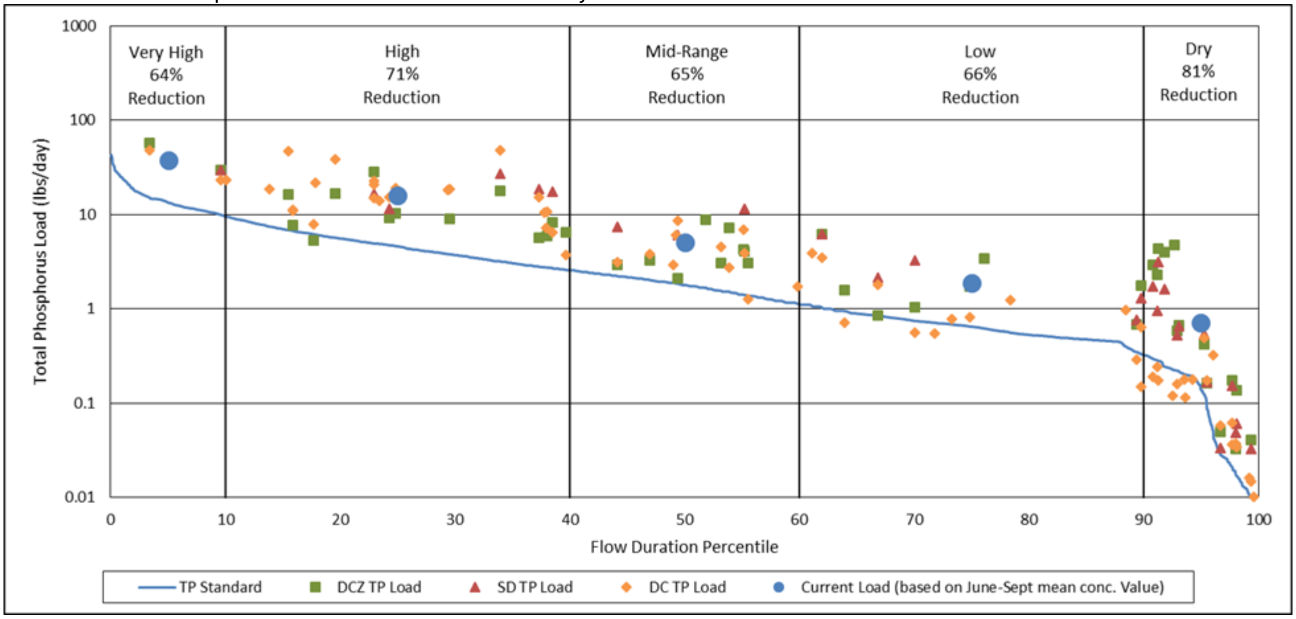


Figure 28. Diamond Creek (AUID - 525) TP LDC and Required Load Reductions by Flow Regime

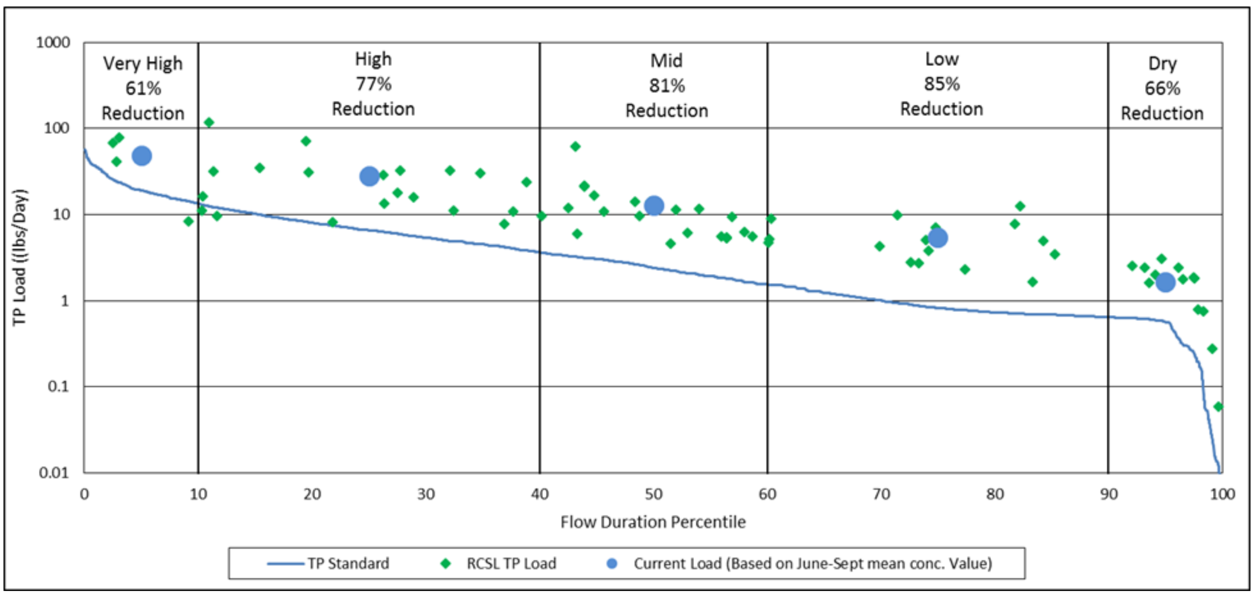


Figure 29. South Fork, Rush Creek (Upper) (AUID - 760) TP LDC and Required Load Reductions by Flow Regime

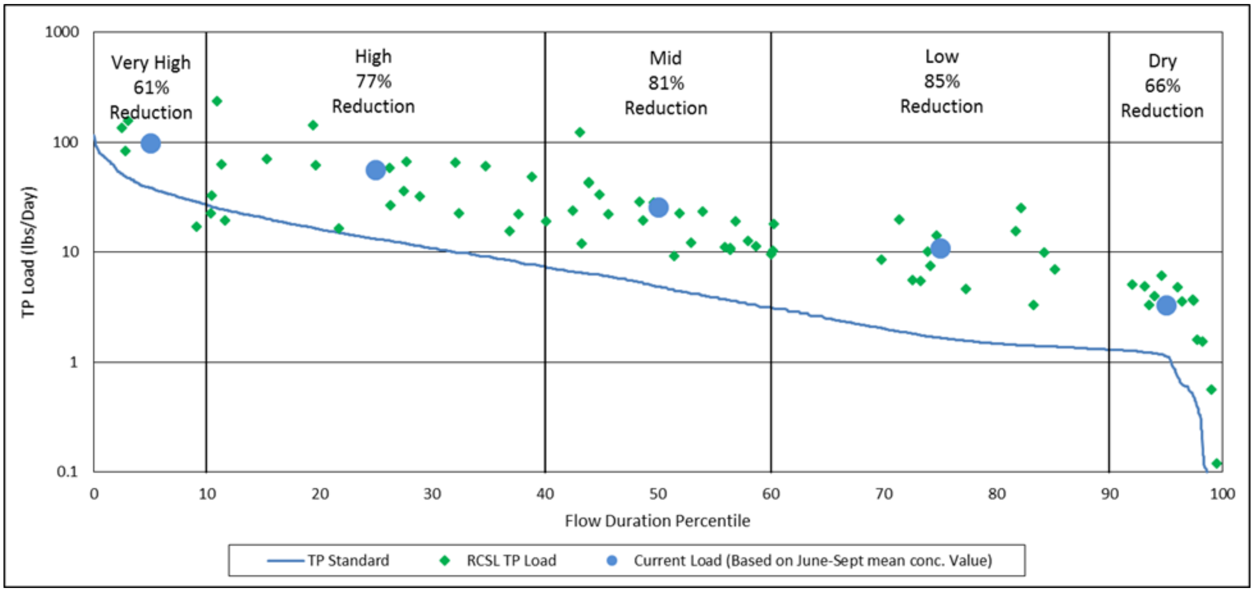


Figure 30. South Fork, Rush Creek (Lower) (AUID - 732) TP LDC and Required Load Reductions by Flow Regime

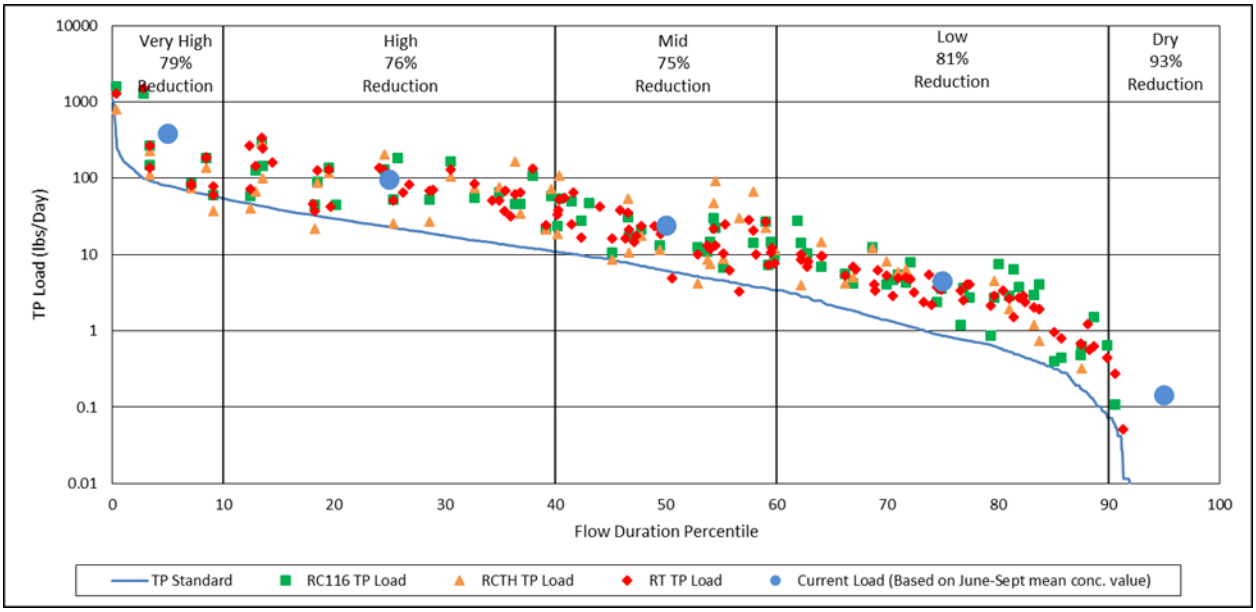


Figure 31. Rush Creek Mainstem (AUID - 528) TP LDC and Required Load Reductions by Flow Regime

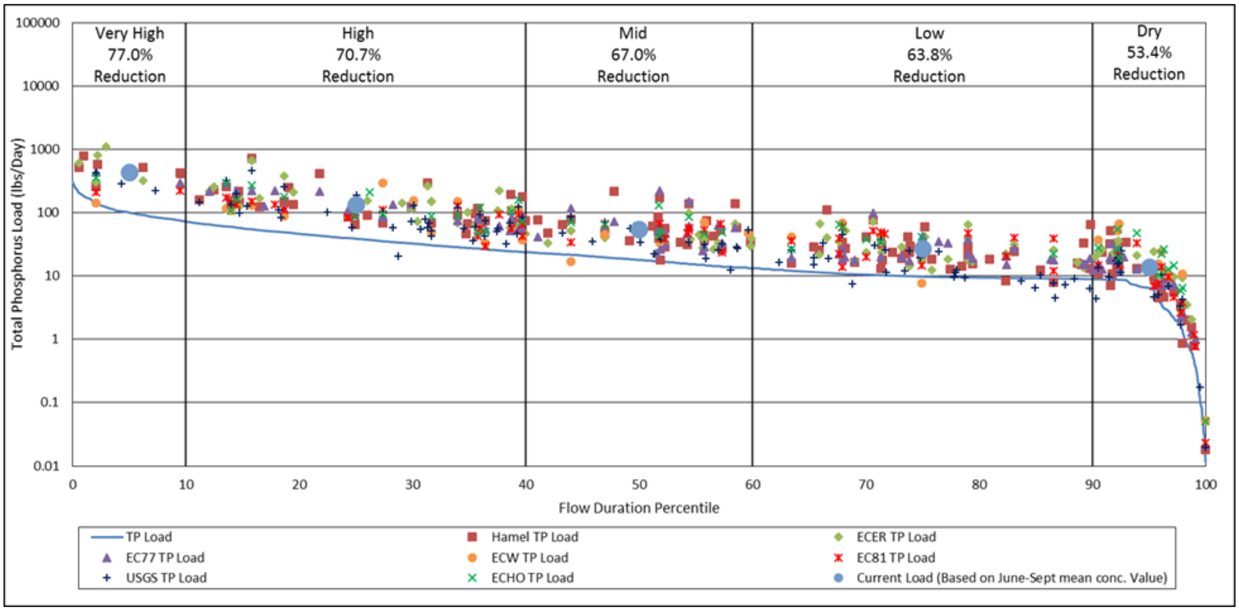


Figure 32. Elm Creek (AUID - 508) TP LDC and Required Load Reductions by Flow Regime

4.3.4.2 Wasteload and Load Allocation Methodology

The WLA and LA Methodology used to address the TP stressor for biotic impairments is the same as the methodology described in Section 4.1 for bacteria allocations except for the boundary conditions employed. The boundary conditions employed are described by reach below:

- Rush Creek mainstem (AUID -528) – Boundary condition established at the outlet of Henry Lake. "Upstream lake" LA assumes Henry Lake will meet an in-lake standard of 60 ug/l TP as per the Henry Lake TMDL.
- Diamond Creek (AUID -525) – Boundary condition established at outlet of Diamond Lake. "Upstream lake" LA assumes Diamond Lake will meet an in-lake standard of 60 ug/l TP as per the Diamond Lake TMDL.
- Elm Creek (AUID – 508) - Boundary conditions established at outlet of Rice Lake and Mud Lake. "Upstream lake" LA assumes Rice Lake will meet an in-lake standard of 60 ug/l TP as per the Rice Lake TMDL and that Mud Lake will continue to meet shallow lake water quality standard of 60 ug/l.

4.3.4.3 Margin of Safety

See Section 4.1.4.

4.3.4.4 Seasonal Variation

See Section 4.1.4

4.3.4.5 Future Growth

See Section 4.1.6.

4.3.4.6 TMDL Summary

Table 29 through Table 33 present the total loading capacity, MOS, WLAs, and remaining watershed LAs for the two stream reaches that violate the MPCA's TP stream standard.

Table 29. Diamond Creek TP TMDL by Flow Zone (AUID - 528)

Diamond Creek: AUID 07010206-525		Flow Zones				
		Very High	High	Mid	Low	Dry
		Total Phosphorus Load (lbs./Day)				
WLAs	Total WLA	6.12	2.10	0.81	0.30	0.06
	Construction Stormwater	0.13	0.05	0.02	0.01	0.00
	Industrial Stormwater	0.07	0.02	0.01	0.00	0.00
	MS4 - Dayton	3.42	1.17	0.46	0.17	0.04
	MS4 - Rogers	2.46	0.84	0.33	0.12	0.03
	MS4 - Hennepin County	0.04	0.01	0.00	0.00	0.00
LAs	Total Load Allocations	6.62	2.27	0.88	0.32	0.07
	Upstream lake (Diamond Lake)	3.35	1.15	0.45	0.16	0.03
	Non-MS4 runoff	3.26	1.12	0.43	0.16	0.03
5% Explicit Margin of Safety (MOS)		0.67	0.23	0.09	0.03	0.01
Total Load (TMDL)		13.40	4.60	1.79	0.65	0.14
Existing Load		37.52	16.08	5.1	1.9	0.72
Estimated Reduction (%)		64	71	65	66	81

Table 30. South Fork, Rush Creek (Upper) TP TMDL by Flow Zone (AUID - 760)

Rush Creek, South Fork (Upper): AUID 07010206-760		Flow Zones				
		Very High	High	Mid	Low	Dry
		Total Phosphorus Load (lbs./Day)				
WLAs	Total WLA	3.70	1.27	0.47	0.16	0.11
	Construction Stormwater	0.19	0.07	0.02	0.01	0.01
	Industrial Stormwater	0.10	0.03	0.01	0.00	0.00
	MS4 - Corcoran	2.90	0.99	0.36	0.13	0.08
	MS4 - Medina	0.51	0.18	0.06	0.02	0.01
LAs	Total Load Allocations	14.50	4.97	1.82	0.63	0.42
	Non-MS4 runoff	14.50	4.97	1.82	0.63	0.42
5% Explicit Margin of Safety (MOS)		0.96	0.33	0.12	0.04	0.03
Total Load (TMDL)		19.16	6.56	2.41	0.83	0.56
Existing Load		48.99	27.92	12.81	5.45	1.65
Estimated Reduction (%)		61	77	81	85	66

Table 31. South Fork, Rush Creek (Lower) TP TMDL by Flow Zone (AUID - 732)

Rush Creek, South Fork: AUID 07010206-732		Flow Zones				
		Very High	High	Mid	Low	Dry
		Total Phosphorus Load (lbs./Day)				
WLAs	Total WLA	17.01	5.75	2.06	0.63	0.39
	Maple Hills Estates WWTF	0.25	0.25	0.25	0.25	0.25
	Construction Stormwater	0.38	0.13	0.05	0.02	0.01
	Industrial Stormwater	0.19	0.07	0.02	0.01	0.01
	MS4 - Corcoran	9.92	3.35	1.20	0.36	0.22
	MS4 - Medina	2.36	0.80	0.28	0.09	0.05
	MS4 - Maple Grove	4.10	1.38	0.49	0.15	0.09
	MS4 - Hennepin County	0.06	0.02	0.01	0.00	0.00
LAs	Total Load Allocations	19.22	6.49	2.32	0.70	0.43
	Non-MS4 runoff	19.22	6.49	2.32	0.70	0.43
5% Explicit Margin of Safety (MOS)		1.92	0.66	0.24	0.08	0.06
Total Load (TMDL)		38.41	13.15	4.87	1.66	1.13
Existing Load		98.56	56.17	25.76	10.97	3.31
Estimated Reduction (%)		61.03	76.60	81.12	84.85	65.94

Table 32. Rush Creek Mainstem TP TMDL by Flow Zone (AUID - 528)

Rush Creek, Mainstem: AUID 07010206-528		Flow Zones				
		Very High	High	Mid	Low	Dry
		Total Phosphorus Load (lbs./Day)				
Wasteload	Total WLA	30.43	8.71	2.24	0.23	**
	Maple Hills Estates WWTF	0.25	0.25	0.25	0.25	**
	Construction Stormwater	0.80	0.23	0.06	0.01	**
	Industrial Stormwater	0.40	0.12	0.03	0.00	**
	MS4 - Corcoran	11.79	3.37	0.87	0.09	**
	MS4 - Medina	2.06	0.59	0.15	0.02	**
	MS4 - Maple Grove	6.44	1.84	0.47	0.05	**
	MS4 - Rogers	4.61	1.32	0.34	0.03	**
	MS4 - Dayton	4.15	1.19	0.30	0.03	**
	MS4 - Hennepin County	0.09	0.03	0.01	0.00	**
	MS4 - MnDOT	0.09	0.03	0.01	0.00	**
Load	Total Load Allocations	44.03	12.61	3.24	0.33	**
	Upstream lake (Henry)	1.27	0.37	0.10	0.01	**
	Non-MS4 runoff	44.03	12.61	3.24	0.33	**
5% Explicit Margin of Safety (MOS)		4.00	1.15	0.31	0.04	0.0005
Total Load (TMDL)		79.98	23.09	6.13	0.86	0.01
Existing Load		386.85	97.27	24.15	4.50	0.14
Estimated Reduction (%)		79	76	75	81	93

** Allocation = flow contribution from a given source x 100 ug/l TP

Table 33. Elm Creek TP TMDL by Flow Zone (AUID - 508)

Elm Creek: AUID 07010206-508		Flow Zones				
		Very High	High	Mid	Low	Dry
		Total Phosphorus Load (lbs./Day)				
WLAs	Total WLA	39.33	15.09	6.91	3.74	2.45
	Maple Hills Estates WWTF	0.25	0.25	0.25	0.25	0.25
	Construction Stormwater	1.01	0.39	0.18	0.10	0.06
	Industrial Stormwater	0.50	0.19	0.09	0.05	0.03
	MS4 - Corcoran	8.76	3.37	1.56	0.85	0.56
	MS4 - Champlin	2.04	0.78	0.36	0.20	0.13
	MS4 - Dayton	13.27	5.08	2.32	1.25	0.81
	MS4 - Maple Grove	8.26	3.16	1.44	0.78	0.51
	MS4 - Medina	1.54	0.59	0.27	0.14	0.09
	MS4 - Rogers	3.38	1.30	0.59	0.32	0.21
	MS4 - Hennepin County	0.19	0.07	0.03	0.02	0.01
	MS4 - MnDOT	0.38	0.14	0.07	0.04	0.02
LAs	Total Load Allocations	35.23	13.49	6.16	3.31	2.16
	Upstream lakes (Rice, Diamond, Mud, Henry)	20.79	8.00	3.69	2.02	1.34
	Non-MS4 runoff	35.23	13.49	6.16	3.31	2.16
5% Explicit Margin of Safety (MOS)		5.04	1.94	0.90	0.49	0.32
Total Load (TMDL)		100.74	38.79	17.90	9.79	6.49
Existing Load		437.51	132.48	54.21	27.08	13.94
Estimated Reduction (%)		77.0	70.7	67.0	63.8	53.4

The WLA's assigned to the Maple Hills Estates WWTF for the phosphorus TMDL's for South Fork, Rush Creek (AUID –732), Rush Creek Mainstem (AUID -528), and Elm Creek (AUID -508) will require a reduction in effluent phosphorus concentration discharged from the facility from approximately 2.5 mg/l (2012 data) to no greater than 1 mg/l if the discharge rate remains the same. See Section 7.2.4 for a more detailed discussion of this issue. The exception to this is the TDLC in the "dry" flow zone for the Rush Creek mainstem (Table 33 above). Here, the loading capacity is very low due to the occurrence of very low flows in the flow record. Consequently, the permitted wastewater treatment design flows will exceed the stream flow in this flow zone. This means that the WWTF discharge would exceed the available loading capacity, based on the method described here to calculate the TMDL components. To account for this unique situation, the WLAs and LAs for this flow regime are expressed as an equation. The equation is:

Allocation = flow contribution from a given source x 1.0 mg/l TP

This approach effectively assigns a concentration-based limit to all discharges for the "dry" flow zone. Since there will be essentially no runoff in this flow zone anyway, permitted and non-permitted stormwater discharges should be essentially unaffected. The impact will be on any WWTF discharges from the Maple Hills Estates Facility.

5 Reasonable Assurance

The following should be considered reasonable assurance that implementation will occur and result in bacteria, nutrient, and sediment load reductions to the listed waters.

5.1 MPCA NPDES Permits

The issuance of an NPDES Permit provides reasonable assurance that the WLA's contained in a TMDL will be achieved. This is because 40 C.F.R. § 122.44(d)(1)(vii)(B), requires that effluent limits in permits be consistent with "the assumptions and requirements of any available WLA" in an approved TMDL. All of the municipalities comprising the Elm Creek Watershed project area are (or in the case of the city of Rogers, will be) covered under updated versions of the MS4 General Permit and the Construction Stormwater Permit, both of which became effective on August 1, 2013. Both permits mandate an increase in the volume of water that must be retained or abstracted on-site as well as require measures to minimize/address soil compaction, control flow rates to protect the stability of downstream open channels, provide buffers adjacent to surface waters, etc. In addition, the next MS4 General Permit (expected to be issued in 2018) will trigger a regulatory requirement for all MS4s receiving WLAs under this TMDL to demonstrate annual progress meeting the required load reductions. The MS4 Permit therefore provides an important regulatory link between a permittee's authorization to legally discharge stormwater to waters of the state and its progress in meeting its load reduction obligations under the TMDLs affecting it. The wastewater treatment system operated by Maple Hills Estate in Corcoran (NPDES/SDS Permit MN0031127) is the only permitted wastewater source discharger affected by this TMDL. The TMDL for TP will require an effluent limit to be determined and assigned through the NPDES Permit. More details regarding the permits in the Elm Creek Watershed can be found in section 7.

5.2 Elm Creek Watershed Management Commission

The ECWMC adopted its third generation watershed management plan on October 14, 2015. The updated plan supports the implementation elements of this TMDL through regulatory requirements for new and re-development, a public education and outreach program, a capital projects selection and funding process, and a monitoring program. The application of updated stormwater mitigation requirements to new urban/suburban developments in the watershed provides a cost-effective opportunity to significantly decrease pollutant loads relative to current conditions. As part of the third generation plan process, the Commission revised their development requirements for stormwater management to reflect the MIDs standards recommended by the MPCA. An analysis conducted to quantify the potential impact of implementing the revised standards indicated that very significant landscape load reduction of phosphorus, TSS and other pollutants could be achieved, especially where non-urban land uses with high pollutant export potential (such as pasture and cropland) were replaced with urban uses that fully incorporate the stormwater mitigation measures in the Commissions new standards. Despite the fact that the complete third generation plan was not finally approved for full implementation until October 2015, the Commission proceeded with an amendment of their second generation plan to adopt and implement the revised development standards effective January 1, 2015. This action helps demonstrate the commitment of the Commission to execute implementation elements in the TMDL.

For all TMDLs completed as part of this study, the resources are located within the ECWMC. The ECWMC was formed on February 1, 1973, through a joint powers agreement by Champlain, Corcoran, Dayton, Maple Grove, Medina, Plymouth, and the Hennepin Conservation District (now Hennepin County Environmental Services) under the authority conferred to the member parties through Minn. Stat. § 471.59 and 103B.211. The ECWMC has a comprehensive approach to managing water resources within their jurisdictional limits which includes the following:

- All significant development, redevelopment, industrial, and construction projects need to be designed to maintain or improve existing developed hydrology and pollutant loadings to fully comply with the local watershed and government authorities, NPDES, and anti-degradation requirements. The ECWMC currently implements rules that require construction site erosion and sediment controls, post-construction stormwater management, and permits for any wetland alterations.
- Although there have been several versions of the ECWMC's Watershed Management Plan, the most current version was adopted in 2015 and the ECWMC is expected to have another 10-year overall plan adopted in 2025.
- The current ECWMC rules and standards were adopted in 2015 and, among other items, include the stormwater management performance standards developed through the MPCA's Minimal Impact Design Standards (MIDS) project. The ECWMC plans to continue to implement initial abstraction requirements for development, redevelopment, and linear projects as they happen.
- The ECWMC implements a water quality monitoring program and intends to perform water quality trend analyses that will allow the Commission to track progress and guide adjustments in the implementation approach. In addition, the ECWMC contracts for routine aquatic plant surveys and will consider the management of aquatic plants based on this information.
- The ECWMC has recently started partnering with member communities on water quality improvement projects. An example of this partnering effort is the ECWMC capital improvements cost-share program, which provides funding to cover up to 25% of project capital costs to public entities for water quality improvement projects.

Additionally, all local units of government within the ECWMC are required to prepare a local watershed management plan, capital improvement program, and official controls as necessary to bring local water management into conformance with the ECWMC Watershed Management Plan. These local plans are reviewed and approved by the ECWMC.

5.3 Funding

Historically, a variety of funding sources have been used for water resource projects within the TMDL study area and these sources are expected to continue into the foreseeable future.

The ECWMC funds its operations mostly through assessments to member cities, which in turn raise those funds through either a tax levy imposed on residents or a special purpose stormwater utility fee. Revenue raised from these sources fund such ECWMC activities as public education and outreach, monitoring, and preparation of annual activity reports.

Capital improvement projects undertaken by the (ECWMC) can be funded through an ad valorem tax levy imposed through Hennepin County at the ECWMC's request on residents anywhere within the ECWMC jurisdictional limits. This annual tax levy is one of the main funding mechanisms available to support for capital-related implementation activities within the impaired subwatersheds of this study. Funds generated through the ad valorem process are used to fund projects outright, sponsor cost-share projects with municipal partners, as well as provide cash matches to secure grants.

A third funding source available to the ECWMC was made possible by Minnesota voters approving the Clean Water, Land, and Legacy (CWLA) amendment in 2008. This amendment increased the state sales and use tax rate by three-eighths of 1% on all taxable sales, starting July 1, 2009, and continuing through 2034. Of the funds generated, approximately one third have been dedicated to a Clean Water Fund to, *"protect, enhance, and restore water quality is lakes, rivers, streams, and groundwater, with at least 5% of the fund targeted to protect drinking water sources."* (MPCA, 2014).

A fourth funding avenue available to support implementation of this TMDL study is the Clean Water Partnership (CWP) Program established by the Minnesota Legislature in 1987. The CWP program focuses on the control of non-point pollution sources and provides financial assistance through matching grant opportunities and loans, as well as technical assistance to local government units (LGUs).

The Federal Section 319 NPS Management Program was established through amendment to the Clean Water Act in 1987 and is recognizes as a fourth source of potential funding. Section 319 NPS funds support a wide variety of activities including technical and financial assistance, education, training, technology transfers, demonstration projects, and monitoring, to assess the success of specific NPS implementation projects. Section 319 projects are typically implementation-oriented and must offer a means of moving towards a resolution of a NPS pollution problem identified as part of a project. This can involve the implementation of a TMDL study to address impaired waters.

5.4 Schedule and Tracking

The ECWMC will work with its member communities to track the number, type, location, load reduction benefits, and costs of best management practices (BMPs) (with an emphasis on structural BMPs) that are implemented in the watershed to address this TMDL. The Commission expects to summarize this information annually and have it available for agencies and interested members of the public.

5.5 Other Considerations

The BMPs and other actions outlined in section 7 have all been demonstrated to be effective in reducing the generation and/or transport of pollutants to surface waters (MPCA 2014). Many of these actions are being promoted by state and local resource managers and have shown significant levels of adoption in both regulatory and non-regulatory environments.

Roughly 20% of the Elm Creek Watershed is expected to change from current land uses to rural residential land uses between 2010 and 2013, and hobby farms with livestock could be a significant component of that change. Good siting and management of new hobby livestock operations will be important to minimize the export of pollutants from these operations to surface waters. More discussion of BMPs recommended to address bacteria can be found in Section 7.

In addition, the technical advisory committee (TAC) formed to provide feedback and input for the project had broad representation from LGUs and agencies that are directly affected by the implementation recommendations. Citizens who have a direct stake in the success of the implementation strategy were also informed about the process and provided input. Their interest and knowledge will help assure accountability in the implementation process. Finally, state and regional government representatives who will play a pivotal role in regulating and/or financially supporting many of the implementation elements were also involved in developing those elements.

Finally, a WRAPS has also been developed for the Elm Creek Watershed project area as a complementary effort to this TMDL. That document presents a detailed, locally-supported, MPCA-approved strategy for restoring the water bodies identified in this TMDL document as well as for protecting water bodies in the watershed that now meet state standards.

In summary, the regulatory efforts, non-regulatory planning efforts, and multiple funding sources detailed above collectively provide reasonable assurance that WLAs prescribed as part of this study will be implemented.

6 Monitoring Plan

Progress on TMDL implementation will be measured through regular periodic monitoring of water quality and tracking of the BMP's completed. This will be accomplished through the combined efforts of the organizations receiving allocations as well as the cooperating agencies (notably the ECWMC and MPCA). The Intensive Watershed Monitoring program conducted by the MPCA is expected to provide a large-scale, longer term picture of the degree to which conditions are changing in the Elm Creek Watershed. Monitoring by the MPCA under this program was last conducted in 2010 and is expected to be undertaken again in 2020 as part of the 10-year monitoring cycle. As part of its third Generation Watershed Management Plan, the Commission will adopt and fund a rotating sampling program for streams and lakes designed in part to monitor progress in implementing the TMDL.

A summary of the monitoring program to assess implementation progress is presented below.

6.1 Lake Monitoring

Fish Lake, Diamond Lake, Rice Lake will continue to be monitored at least every two years because of their visibility and priority as a public resource. The other lakes (Henry, Goose, Cowley, and Sylvan) will be monitored at least once every three years as access is made available and resources – either through volunteers or under contract with professional staff- are allocated. Lakes are generally monitored for chlorophyll a, TP, and Secchi disk transparency. Aquatic plant surveys should also be conducted on each lake at approximately five year intervals.

In-lake monitoring will continue as implementation activities are undertaken across the respective watersheds. These monitoring activities will continue until water quality goals are met. Some inflow monitoring has been completed on the inlets to some of the lakes (notably on Elm Creek above Rice Lake) and may be important to continue as implementation activities take place in those subwatersheds.

The DNR will continue to conduct fish surveys on lakes with developed public access (currently Fish Lake and Diamond Lake) as allowed by their regular schedule. Currently, fish surveys are conducted every five years.

6.2 Stream Monitoring

Stream monitoring in the Elm Creek Watershed, which includes Elm Creek, Rush Creek, and Diamond Creek, has been coordinated by the ECWMC. The Commission currently partners with the USGS to operate a flow and water quality monitoring station on Elm Creek. The station has a long-term period of record (35+ years) and gauges discharge from about 70% of Elm Creek Watershed. Other efforts have included those funded by the MPCA through a Surface Water Assessment Grant (SWAG) and the TMDL itself to carry out flow and/or water quality monitoring at the sites shown in Figure 3 in Section 3.2 of this report.

The Commission will continue to partner with the USGS to obtain routine flow and water quality data at the site on Elm Creek. As funding allows, monitoring will be carried out further upstream on Elm Creek as well as at some or all of the sites used to generate data for the TMDL. As BMP practices are implemented in the watershed, it is also suggested that monitoring will take place in those subwatersheds to track progress toward meeting the TMDLs for the stream reaches of interest.

6.3 Stream Biologic Monitoring

Continuing to monitor water quality and biotic communities so that composite metrics can be developed will help determine the need for/effectiveness of stream habitat restoration measures in bringing the watershed into compliance with standards for biota. At a minimum, fish and macroinvertebrate sampling should be conducted by the MPCA, DNR, or other qualified agencies every 5 to 10 years during the summer season at each established location until compliance is observed for two consecutive assessments.

7 Implementation Strategy Summary

7.1 Implementation Framework

The strategies described in this section include potential actions to reduce nutrient, bacteria, and sediment loads in the subject watersheds. The NPDES Permit compliance includes being consistent with the assumptions and requirements of an approved TMDL and associated WLA as they apply to the permittee. For the purposes of this TMDL, the baseline period will be approximately the mid-point in the data years used for lake response modeling (Table 34) and the development of the LDCs for bacteria, stream TP, and stream TSS (generally 2010). Any load-reducing BMP implemented since the baseline year (inclusive) will be able to count toward an MS4's load reductions. If a BMP was implemented during or just prior to the baseline year, the MPCA is open to presentation of evidence by the MS4 Permit holder to demonstrate that it should be considered as a credit.

Table 34. Implementation Baseline Years

Water Body	Baseline Year
Fish Lake	2010
Rice Lake	2010
Diamond Lake	2009
Goose Lake	2010
Cowley Lake	2006
Sylvan Lake	2012
Henry Lake	2010
Stream Bacteria TMDLs	2010
Stream Total Suspended Solids TMDLs	2010
Stream Phosphorus TMDLs	2010

7.2 Permitted Sources

7.2.1 MS4

There are nine jurisdictions within the Elm Creek Watershed project area that are permitted MS4s in the watershed.

Table 10 in Section 3.5 of this report identifies these jurisdictions and their MS4 Permit numbers.

Many of the watersheds of the impaired waters identified in this report are expected to undergo significant land use changes between now and 2030. Table 35 and Table 36 shows the approximate total area of the watersheds draining to the impaired stream reaches and lakes addressed in this report and the percentage of the area expected to change land uses by 2030. Further, in the stream systems, much of the development is likely to occur in the upper reaches of those systems which experience the most severe exceedances of bacteria, phosphorus, and (to a lesser extent) TSS. An improvement in the quality of waters at the upstream end of these systems should contribute significantly to reducing the more moderate exceedances in the downstream reaches.

Table 35. Expected Land Use Change by Stream Reach Subwatershed

Subwatershed Name (AUID)	***Approximate Drainage Area***	***% of Drainage Area Expected to Change Land Use by 2030[1]***
S. Fork Rush Creek, Upper (AUID - 760)	6,700	68%
S. Fork Rush Creek, Lower (AUID - 732)	13,700	58%
Rush Creek Mainstem (AUID -528)	32,600	62%
Diamond Creek (AUID-525)[2]	3,600	30%
Lower Elm Creek (AUID -508)[3] below Rice Lake outlet	43,600	51%
Upper Elm Creek (AUID -508)[4] above Rice Lake outlet	13,000	30%

[1] From baseline year of 2010
[2] Excludes drainage area to Diamond Lake (~2,400 acres)
[3] Excludes drainage area to Rice (~16,100 ac.), Henry (~820 ac.), and Diamond lakes (~2,400 ac.)
[4] Excludes drainage to Rice Lake-West Basin and Rice Lake-Main Basin other than through Elm Creek (~3,100 ac.)

Table 36. Expected Land Use Change by Lake Subwatershed

Lake Subwatershed	***Approximate Drainage Area***	***% of Drainage Area Expected to Change Land Use by 2030[1]***
Cowley	830	60%
Sylvan	320	79%
Henry	820	61%
Diamond	2,400	32%
Rice	16.100	30%
Fish	1,600	<1%
Goose	240	5%

[1] From baseline year of 2010

To take advantage of the opportunity afforded by land use transition, aggressive stormwater management measures must be applied to new development everywhere in the watershed. Effective January 1, 2015, the ECWMC adopted updated standards that govern stormwater management standards for quality, runoff volume and rate control for new development projects. Key provisions of those updated standards are the following:

- A decrease in the threshold for application of stormwater quality and quantity standards to one acre of disturbed surface, regardless of land use. This will result in more new developments subject to the updated stormwater management requirements of the Commission.

- Require infiltration of 1.1 inches of runoff volume off new impervious surfaces within 48 hours, based on the MPCA's MIDs. Where infiltration is not feasible, the new rules require that runoff be filtered before discharge from the site. The rules include several credits toward meeting the abstraction requirement, including dis-connection of impervious surface, conservation of existing native vegetation, and the use of de-compacted and amended soil as a BMP.
- A performance standard for stormwater quality to achieve a loading reduction as good as or better than that which would be achieved by abstracting 1.1 inch of runoff depth from new impervious surfaces, or no-net increase in TP or TSS, whichever is lower. Application of the 1.1inch abstraction requirement equates to approximately a 76% reduction in TP compared to the post-development but non-mitigated phosphorus load from urban development (Wenck 2013), well above the 50% to 60% reduction typical of a wet detention pond based on NURP design standards. Compliance with this updated provision will require a calculation of the loading from the pre-development condition, then the load from the post-development condition assuming a 1.1-inch abstraction of impervious runoff from the post-development condition. The development must incorporate water quality BMPs to limit post-construction loading to the lesser of the two figures.

As regulated MS4 systems are expanded to serve new development, those MS4s may be able to take credit for working toward meeting their TMDL allocations based on net decreases in landscape loads associated with replacing high pollutant export non-urban uses with suburban/urban land uses that incorporate the stormwater controls identified. Commission should work with MPCA and the member communities to determine under what conditions this would be appropriate.

Other measures that should be considered by MS4s to meet their pollutant load reduction obligations under this TMDL include the following:

- Pursue stormwater treatment retro-fit projects as opportunities arise (for example as part of road/street re-construction, residential/commercial/industrial re-development, etc.), with an emphasis on runoff infiltration/filtration as site conditions allow
- Undertake intensified street cleaning activities in high priority areas, especially where opportunities for cost-effective implementation of structural BMP's is limited (Baker, et. al. 2014)
- Enhance existing stormwater treatment features, such as by adding iron enhanced sand filters to existing stormwater ponds.

7.2.2 Construction Stormwater

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

7.2.3 Industrial Stormwater

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

7.2.4 Wastewater

The wastewater treatment system operated by Maple Hills Estate in Corcoran (NPDES/SDS Permit MN0031127) is the only permitted wastewater source discharger affected by this TMDL. The TMDL for stream TP will require a significant reduction in phosphorus loading from the facility. The WLA for TP assigned this facility will, at a minimum; require approximately a 60% load reduction from 2012 conditions. If the discharge volume for the facility to the Rush Creek-South Fork remains the same as currently (approximately .03 mgd), effluent concentrations for TP from the facility will need to decrease from approximately 2.5 mg/l (2012 data) to 1 mg/l. Another option is for the area served by the facility to hook up to a regional sanitary interceptor. The city of Corcoran has installed a trunk sewer that borders the south side of the mobile home park but it is not yet in use or connected to the Met Council's regional interceptor sewer. Construction of a force main and lift station to make the connection is planned for 2015 and may be available as early as 2016, however this plan may be delayed until the city of Corcoran needs to start using the pipe or until development picks up in the area served by the trunk sewer.

7.3 Non-Permitted Sources

7.3.1 Agriculture

Based on the livestock inventory completed for this project (Appendix A), there were an estimated 2,800 head of livestock in the Elm Creek Watershed in 2011, including beef and dairy cattle and horses. It was estimated that almost 70,000 lbs of manure-derived phosphorus was generated by livestock in the watershed in 2011, equal to over one pound per acre of watershed area. The amount of manure applied in the Elm Creek Watershed is likely substantial. Routine soil testing would help determine where manure can be applied to satisfy nutrient needs for crops while minimizing potential nutrient loss to runoff. Manure spreading on frozen ground during the winter is a common practice, with many operations having no manure storage facilities. Much of the nutrient content and organic matter is likely lost to runoff when snowmelt events occur. Finally, livestock appear to have un-restricted access to streams in some reaches, which is likely to result in direct loading of bacteria and nutrients, and lead to bare or sparsely vegetated banks and riparian areas that foster streambank failures.

7.3.2 Rural Residential with Livestock

About 20% of the Elm Creek Watershed is expected to change from current land uses to rural residential land uses between 2010 and 2013, and hobby farms with livestock could be a significant component of that change. Good siting and management of new hobby livestock operations will be important to minimize the export of pollutants from these operations to surface waters. Where applicable, the MS4 communities within the watershed (especially those with high hobby farm development potential such as Corcoran, Dayton, and Rogers) should adopt standards modeled after those already adopted by the city of Medina. Those standards include the following components:

- Allowable locations of feedlots, pens, etc. relative to wetland edges as well as stream and lake shorelines.
- Requirements for the design and siting of manure storage, containment, and composting areas, and schedules for the removal of manure or compost from the affected sites.
- Clean water diversions to divert up gradient runoff around feedlot and manure containment areas.
- Site runoff retention and vegetative filtration systems downslope from the feedlot and manure containments areas.
- Pasture management requirements, including allowable livestock densities in pasture areas.

7.3.3 On-Site Septic Systems (ISTSs)

According to MPCA (2004), there is a 25% failure rate for septic systems in Hennepin County. The cities in the watershed are responsible for inspection of on-site septic systems and enforcement of standards, though some contract with the Hennepin County Department of Health to provide those services for them. In any case, the cities should continue to assure that systematic inspections are carried and that septic system upgrades are ordered as necessary, with priority given to systems that are imminent threats to public health and safety, and failing systems near-or whose discharge can reach- streams, waterways, and lakes.

7.3.4 Internal Nutrient Loads (Lakes)

Internal nutrient loads will need to be reduced to meet the TMDL allocations for all of the lakes addressed in this document. One source of internal loading is CLPW. The CLPW is present in most of the lakes addressed in this report, and in some cases at extremely high densities. Senescence of CLPW in summer can be a significant source of internal phosphorus load that often results in mid- to late-summer water quality degradation. Vegetation management, such as successive years of chemical treatments that selectively targets CLPW but does not negatively impact native aquatic plants, may be required to reduce CLPW growths to non-nuisance levels. Another source of internal load is release of accumulated phosphorus from enriched bottom sediments. While there are numerous options for internal load reduction, chemical inactivation of sediment phosphorus using an alum-based compound or another precipitant is likely to be most cost-effective. Ideally, most, if not all, of the watershed load reductions called for in the TMDL for a given lake should be achieved before sediment treatments occur.

However, in lakes that are close to meeting water quality standards, it may be appropriate to implement an initial sediment treatment as part of a two to three phase sediment treatment sequence once progress has been made in reducing watershed loads and/or curly-leaf pondweed generated loads. This approach can help generate a clear-water response that will improve the conditions for development of a robust rooted aquatic plant community and help stabilize the system in a clear water condition. This approach should only be taken with the understanding that fully achieving the targeted watershed load reductions will be important in extending the effective life of the internal load controls, and that the final internal load treatment in the sequence should be carried out only after substantial completion of the watershed load reduction effort.

7.4 Other Measures

The following measures will also be important elements of the implementation effort for this TMDL:

1. **Education**. Educational and outreach opportunities in the watershed should be pursued on such topics as fertilizer use, manure management, grazing management, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to lakes and streams. A high priority of these efforts should be to encourage the adoption of good individual property management practices across all land uses. Also included should be efforts to educate the public on the benefits of a healthy rooted aquatic plant community and the role it plays in a healthy lake or stream system, along with appropriate management expectations, objectives and tools to manage the aquatic plant community without destroying the benefits it offers.
2. **Installation and enhancement of buffers/shoreline restoration.** One of the larger potential sources of *E. coli* and nutrient loading in the upper watershed is associated with pasture use. Installation of new or enhancement of existing buffers to maintain native vegetation along stream banks will help stabilize the streambanks themselves as well as filter runoff from pastures near streams and waterways. Many riparian property owners in all parts of the watershed maintain turf to the shoreline. Property owners should be encouraged/incentivized to restore a portion of their shoreline with native plants to reduce erosion, capture/filter direct runoff, and improve the near-shore riparian habitat that is so important to most of the desirable fish species found in lakes and streams.
3. **Roughfish management**. Where appropriate, monitoring and management of the fish community should be undertaken to restore or maintain quality fish communities. Opportunities to assess roughfish populations (particularly common carp) should be undertaken where there is reason to believe those populations are above the metrics conducive for clear water, native rooted aquatic plant-dominated in-lake condition and a healthy fish community. Control measures appropriate to the magnitude of the problem and the site-specific features of the situation should be undertaken to limit reproductive and recruitment success and roughfish migration.
4. **Biotic Integrity improvement strategies**. Physical habitat improvements in stream reaches with impaired biota will likely be necessary, based on the results of the SID. These improvements are likely to be diverse, including stabilizing eroding stream banks using bio-engineering techniques, improving stream re-aeration capabilities, re-establishing floodplain connectivity, and providing deep water higher oxygen refuges for desirable fish species in stream reaches where low DO episodes present a risk to the survival of those species.

5. **Subwatershed assessments**. The level of detail of the analysis conducted for this TMDL is not generally sufficient to identify specific parcels of neither land nor specific projects that are the most cost-effective for achieving load reductions to the water bodies identified. Additional effort to identify and evaluate potential projects will often be needed as a follow-up activity to this plan, especially for agricultural areas. These efforts should include on-the-ground field investigations to identify the highest priority areas for improvement, development of site-specific remedies, and development of project costs and load reduction benefits. The upper reaches of the Rush Creek Subwatershed appear to be a prime area to conduct such an effort because of the elevated concentrations of bacteria and phosphorus monitored the high concentration of livestock, and close proximity to conveyance features of some of those operations. An excellent example of a subwatershed assessment approach is an assessment completed by Hennepin County (2014) for the Dance Hall Creek Subwatershed of Lake Sarah in western Hennepin County. The outcome of the assessment effort can then be used as the basis to solicit cooperation from affected land owners, inform capital improvement project planning and implementation, and compile effective grant applications.
6. **High infiltration potential assessment**. Poor baseflow conditions and high streamflow volumes are issues throughout much of the Elm Creek Watershed, especially in some of the lower reaches of the major streams. Thus, taking advantage of areas that have a high infiltration capacity will be important in reducing runoff volumes and enhancing baseflows as the watershed develops. Consideration should be given to carrying out an assessment to identify these areas early so that the Commission and/or cities can work with the land owners to take advantage of these features as opportunities arise. Special attention should be given to stream corridors and the uplands within or immediately adjacent to them, as infiltrated water in these areas may be more likely to result in increased baseflows.
7. **Additional monitoring**. The magnitude of the reductions necessary to meet some of the TMDLs will be challenging, and continued periodic water quality monitoring will be necessary for evaluating progress in guiding the process. As per the SID report, additional monitoring should be conducted to describe the role of wetland complexes in low DO episodes in various stream reaches. Wetland-driven low DO conditions appear to be especially prevalent in the lower reaches of Elm Creek, and synoptic surveys are likely to be helpful in better defining the relationship between the two conditions. Finer scale monitoring efforts are also likely to have a role to play in identifying locations in specific watersheds that may be contributing a disproportionately high amount of loading to particular stream reaches. Again, synoptic approaches may be appropriate here as well, especially during or immediately after runoff events and perhaps as part of an overall subwatershed assessment.

7.5 Cost

All TMDLs are now required to include a cost estimate for implementing the necessary actions to restore the impaired waters identified in the TMDL. The level of detail of the information provided in a large-scale, watershed-wide TMDL like this one is not sufficient to provide a good basis for accurately identifying these costs. This TMDL provides explicit guidance on the magnitude of pollutant reductions to meet the requisite standard. However, the implementation strategy for this TMDL recognizes as well that specific projects will be identified -and credible estimates of the costs and benefits of those projects developed - through the subwatershed assessments, feasibility studies, etc. as a follow-up to the TMDL. However, based on a review of the impairments and the scale at which restoration will be necessary in the watershed, it is estimated that a dollar range of $12,300,000 to $25,100,000 might be necessary. An identification of the types of projects and assumptions as well as whether each type of project applies to permitted, non-permitted, or both sources is included in Appendix H. Note that the cost range project is an estimate and many aspects can cause the costs to rise or fall as implementation takes place across the watershed.

7.6 Adaptive Management

The implementation strategies and elements focus will be carried out in the context of adaptive management (Figure 33). Continued monitoring and "course corrections" in response to technically sound monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water bodies.

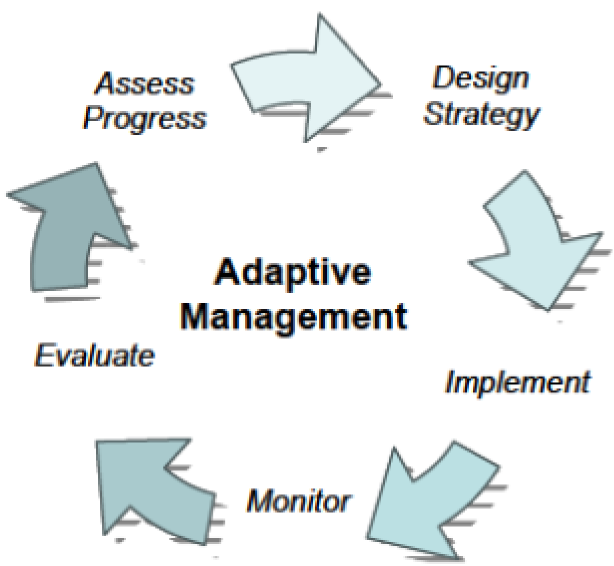


Figure 33. Adaptive Management Framework

8 Public Participation/Stakeholder Involvement

A stakeholder participation process was undertaken for this TMDL to obtain input from, review results with, and take comments from the public and interested/affected agencies and local jurisdictions regarding the development and conclusions of the TMDL. The following cities/agencies/interested parties were invited to project meetings and/or received communications regarding the project:

City of Champlin	Hennepin County
City of Corcoran	BWSR
City of Dayton	Met Council Environmental Services
City of Medina	DNR
City of Maple Grove	MnDOT
City of Plymouth	Rice Lake Area Association
City of Rogers	Fish Lake Area Residents Association
Maple Hills Estates	Diamond Lake Association

A TAC comprised of representatives from the cities and agencies listed above was at the core of the public participation process. This group has met 14 times since 2011 to review and provide feedback on the technical aspects of the project, including the modeling and technical analysis results, allocation methodologies, and implementation elements. Summaries of each meeting were prepared and distributed to the ECWMC and all participants, as well as posted on the Commission's web site. All Power Point presentations given at the meetings were posted on the Commission's web site as well.

Project staff also met separately with a number of organizations to explain the purpose of the project, as well as project findings, recommendation, and implications. These groups included:

City of Maple Grove Lakes Commission
Rice Lake Area Associations (annual meetings)
Fish Lake Area Residents Associations (annual meetings)
City officials from Dayton and residents around Diamond Lake
City of Champlin Environmental Resources Commission
City of Plymouth Environmental Quality Committee

Finally, as part of an amendment to the project scope in 2012, a Knowledge, Attitudes, and Practices (KAP) survey was conducted, which focused on three agricultural audiences (crop farmers, livestock operators, and horse owners), since the Commission knew relatively little about these stakeholder groups. The methods and results are summarized in Eckman (2013) (Appendix G).

The official TMDL public comment period was held from July 5, 2016 through August 4, 2016.

9 Literature Cited

Baker, L., P. Kalinosky, S. Hobble, R. Bintner, and C. Buyarski. 2014. Quantifying Nutrient Removal by Enhanced Street Sweeping.

Dewson, Z.S., A. James, and R. Death. 2007. A review of the consequences of decreased flow for instream habitat and Macro invertebrates. Journal of the North American Benthological Society, Vol. 26, No. 3. pp. 401-415.

Dodds, W.K. 2006. Eutrophication and Trophic State in Rivers and Streams. Limnology and Oceanography, Vol. 51, No. 1, Part 2: Eutrophication of Freshwater and Marine Ecosystems. pp. 671-680.

Eckman, K. 2013. Elm Creek Management Commission KAP Study Report

Hennepin County. 2014. Dance Hall Creek Subwatershed Stormwater Retrofit Assessment. October 2014. Prepared for City of Greenfield, MN

Lehr, R. 2015. Elm Creek Watershed Stressor Identification Report.

MPCA. 2004. 10-Year Plan to Upgrade and Maintain Minnesota's On-site (ISTS) Treatment Systems. Report to the 2004 Minnesota Legislature.

*MPCA. 2005. Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, 3rd Edition. September 2005.**)***

MPCA. 2011. Recommendations and Planning for Statewide Inventories, Inspections of Subsurface Sewage Treatment Systems. Report to the Minnesota Legislature.

MPCA. 2011. Aquatic Life Water Quality Standards Draft Technical Support Document for Total Suspended Solids (Turbidity)

MPCA. 2012. Zumbro Watershed Turbidity TMDL, Section 3.7.1 New and Expanding Discharges.

MPCA. 2013. Minnesota Nutrient Criteria Development for Rivers.

MPCA. 2014. Guidance Manual for Assessing the Quality of Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List-2014 Assessment and Listing Cycle.

MPCA. 2014. Minnesota Stormwater Manual.

MPCA. 2015. Twin Cities Metro Area Chloride Management Plan (draft) March 2015.

Poff, L., and J.D. Allan. 1995. Functional Organization of Stream Fish Assemblages in Relation to Hydrological Variability. Ecology, Vol. 76, No. 2. pp. 606-627.

Roy, A.H., M.C. Freeman, B.J. Freeman, S.J. Wenger, W.E. Ensign, and J.L. Meyer. 2005. Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams. Journal of the North American Benthological Society, Vol. 24, No. 3, pp. 656-678.

U.S. Environmental Protection Agency. 2000. Stressor Identification Guidance Document. EPA document # 822-B-00-025.

Wenck. 2013. Change in Phosphorus Loading From Site Development. Technical Memorandum from R. Kluchhohn and E. Megow – Wenck Associates, Inc. to Elm Creek Watershed Management Commission- November 4, 2013

Appendices

Appendix A – Livestock Inventory for Elm Creek Watershed

Appendix B - Source Assessment Spreadsheets for Bacteria Impairments

Appendix C – Modeling Methods, Input, and Output for Lakes (including Lake Bathymetry)

Appendix D - Elm Creek SWAT Model Technical Memo

Appendix E – Vegetation Surveys for Lakes

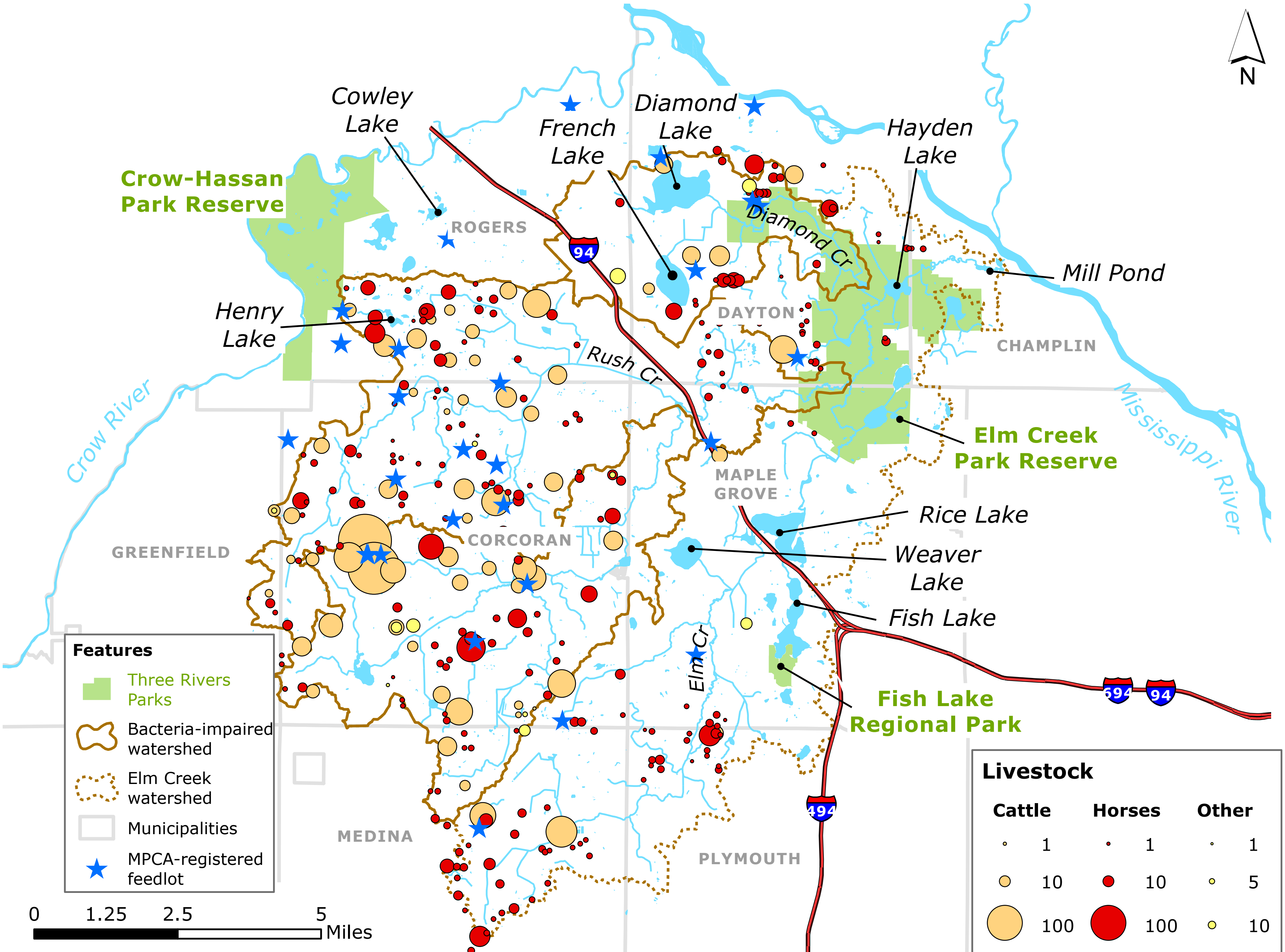
Appendix F – Internal Phosphorus Loading and Sediment Phosphorus Fractionation reports

Appendix G - KAP Study Report

Appendix H – Implementation Cost Estimate

Appendix I – Affected MS4s by Impaired Water

Appendix A – Livestock Inventory for Elm Creek Watershed



Category	Source	Animal Units or Individuals in Subwatershed	E. coli Organisms Produced Per Unit Per Month (Billions of Org.)	Total E.coliProduced Per Month (Billions of Org.)	Total E. coli Produced Per Month by Category (Billions of Org.)	Total E. coli Available Per Month by Category (Billions of Org.)	Percent by Category
Livestock (Surface Applied Manure)	Horses (Animal Units)	60-80	8	480 - 640	49,000 - 68,000	49,000 - 68,000	94.2%
	Cattle (Animal Units)	25-35	1,900	48,000 - 67,000			
	Other (Elk, Sheep, Hogs)	25-35	10	250 - 350			
Wildlife	Deer	120-140	10	1,200 - 1,400	2,400 - 2,800	2,400 - 2,800	4.2%
	Waterfowl	80-100	0.2	20 - 25			
	Other Wildlife	120-140	10	1,200 -1,400			
Human	Failing Septic Systems	10	40	400	400	400	0.6%
Domestic Animals	Improperly Managed Pet Waste	50-70	100	5,000 - 7,000	5,000 - 7,000	500 - 700	1.0%
					Total	52,000 - 72,000	100%

Pie Chart

94% Livestock

4% Wildlife

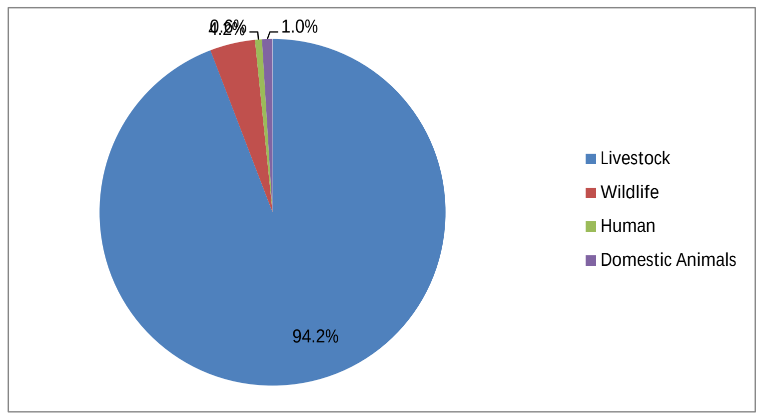
1% Human

1% Domestic Animals

Watershed	Total Area, Acres	Urban Area, acres	Number Residential	Households	Population	Individual Septic Pa	Group Septic	Notables/ F	Cattle, 2011	Horses, 201	Other, 2011
DC	2,783.8		48	48	126	46	2	There is a c	30	70	26

	Subwatershed	Urban Area	Non-urbanized Area
Acres	2783.8	0	2783.8
Square Miles	4.3496875	0	4.3496875
Dogs	28.032		
Cats	30.624		
Septic	0.5		

Acre	Square Mile
1	0.0015625



Category	Source	Animal Units or Individuals in Subwatershed	E. coli Organisms Produced Per Unit Per Month (Billions of Org.)	Total E.coliProduced Per Month (Billions of Org.)	Total E. coli Produced Per Month by Category (Billions of Org.)	Total E. coli Available Per Month by Category (Billions of Org.)	Percent by Category
Livestock (Surface Applied Manure)	Horses (Animal Units)	290 - 350	8	2,300 - 2,800	1,060,000 - 1,300,000	1,060,000 - 1,300,000	96.3%
	Cattle (Animal Units)	560 - 680	1,900	1,060,000 - 1,300,000			
	Other (Elk, Sheep, Hogs)	0 - 10	10	0 - 100			
Wildlife	Deer	760 - 920	10	7,600 - 9,200	16,000 - 19,000	16,000 - 19,000	1.4%
	Waterfowl	520 - 640	0.2	100 - 130			
	Other Wildlife	780 - 960	10	7,800 - 9,600			
Human	Failing Septic Systems	290	40	11,600	11,600	11,600	0.9%
Domestic Animals	Improperly Managed Pet Waste	1,400-1,800	100	140,000 - 180,000	140,000 - 180,000	14,000 - 18,000	1.3%
					Total	1,100,000 - 1,400,000	100%

Pie Chart

96% Livestock

1% Wildlife

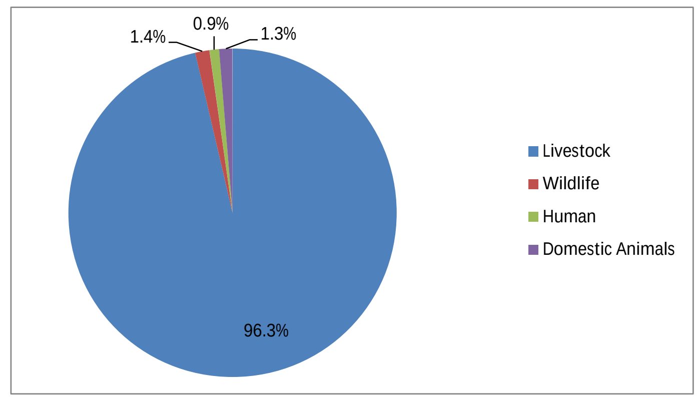
1% Human

1% Domestic Animals

Watershed	Total Area, Acres	Urban Area, acres	Number Residential	Households	Population	Individual Septic Parcels	Group Septic	Notables/ I	Cattle, 2011	Horses, 201	Other, 2011
Rush Mainstem	18,470.7	470.8	1,363	1,321	3,712	1,164			619	321	4

	Subwatershed	Urban Area	Non-urbanized Area
Acres	18470.7	470.8	17999.9
Square Miles	28.86046875	0.735625	28.12484375
Dogs	771.464		
Cats	842.798		
Failing Septic	291		

Acre	Square Mile
1	0.0015625



Category	**Source**	**Animal Units or Individuals in Subwatershed**	**E. coli Organisms Produced Per Unit Per Month (Billions of Org.)**	**Total E.coliProduced Per Month (Billions of Org.)**	**Total E. coli Produced Per Month by Category (Billions of Org.)**	**Total E. coli Available Per Month by Category (Billions of Org.)**	**Percent by Category**
Livestock (Surface Applied Manure)	Horses (Animal Units)	260 - 320	8	2,100 - 2,600	1,000,000 - 1,300,000	1,000,000 - 1,300,000	95.6%
	Cattle (Animal Units)	540 - 660	1,900	1,000,000 - 1,300,000			
	Other (Elk, Sheep, Hogs)	45 - 55	10	450 - 550			
Wildlife	Deer	530 - 650	10	5,900	12,000 - 13,000	12,000 - 13,000	1.0%
	Waterfowl	380 - 460	0.2	80 - 90			
	Other Wildlife	580 - 700	10	5,800 - 7,000			
Human	Failing Septic Systems	200	40	8,000	8,000	8,000	0.7%
	NPDES Permit	1	0.2	0			
Domestic Animals	Improperly Managed Pet Waste	2,800 - 3,400	100	280,000 - 340,000	280,000 - 340,000	28,000 - 34,000	2.7%
					Total	1,050,000 - 1,400,000	100%

Pie Chart

96% Livestock

1% Wildlife

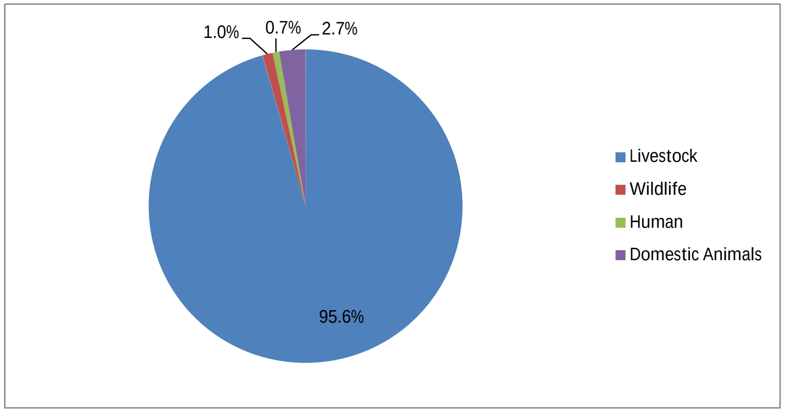
1% Human

3% Domestic Animals

Watershed	Total Area, Acres	Urban Area, acres	Number Residentia	Households	Population	Individual Septic Parcels	Group Septic	Notables/ I	Cattle, 2011	Horses, 201	Other, 2011
Rush South Fork	13,571.4	980.3	2,394	2,500	6,872	798	~186	Maple Hills	596	288	52

	Subwatershed	Urban Area	Non-urbanized Area
Acres	13571.4	980.3	12591.1
Square Miles	21.2053125	1.53171875	19.67359375
Dogs	1460		
Cats	1595		
Septic	199.5		

Acre	Square Mile
1	0.0015625



Category	Source	Animal Units or Individuals in Subwatershed	E. coli Organisms Produced Per Unit Per Month (Billions of Org.)	Total E.coliProduced Per Month (Billions of Org.)	Total E. coli Produced Per Month by Category (Billions of Org.)	Total E. coli Available Per Month by Category (Billions of Org.)	Percent by Category
Livestock (Surface Applied Manure)	Horses (Animal Units)	200 - 240	8	1,600 - 1,900	420,000 - 490,000	420,000 - 490,000	63.0%
	Cattle (Animal Units)	220 - 260	1,900	420,000 - 490,000			
	Other (Elk, Sheep, Hogs)	30 - 50	10	300 - 500			
Wildlife	Deer	450 - 550	10	4,500 - 5,500	17,000 - 20,000	17,000 - 20,000	2.5%
	Waterfowl	780 - 960	0.2	160 - 190			
	Other Wildlife	1,200 - 1,400	10	12,000 - 14,000			
Human	Failing Septic Systems	160	40	6,400	6,400	6,400	0.9%
Domestic Animals	Improperly Managed Pet Waste	22,000 - 27,000	100	2,200,000 - 2,700,000	2,200,000 - 2,700,000	220,000 - 270,000	33.6%
					Total	670,000 - 790,000	100%

Pie Chart

63% Livestock

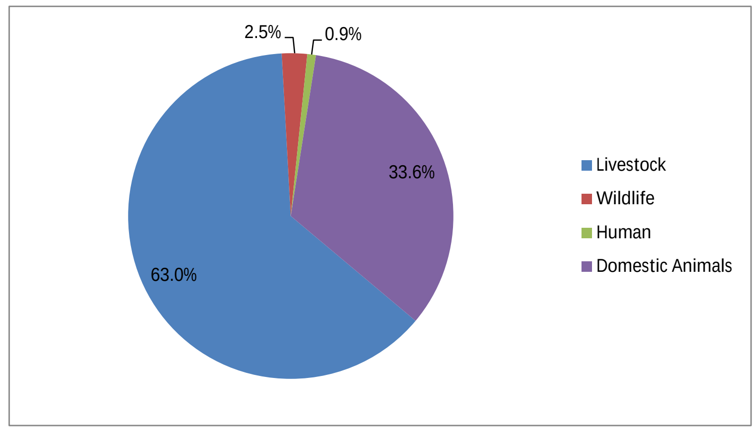
3% Wildlife

1% Human
34% Domestic Animals

Watershed	Total Area, Acres	Urban Area, acres	Number Residential	Households	Population	Individual Septic Pai	Group Septic/	Notables/ I	Cattle, 2011	Horses, 201	Other, 2011
EC	27,680.5	16,824.4	18,842	20,017	53,880	618			240	226	40

	Subwatershed	Urban Area	Non-urbanized Area
Acres	27680.5	16824.4	10856.1
Square Miles	43.25078125	26.288125	16.96265625
Dogs	11689.928		
Cats	12770.846		
Septic	154.5		

Acre	Square Mile
1	0.0015625



Category	Source	Animal Units or Individuals in Subwatershed	E. coli Organisms Produced Per Unit Per Month (Billions of Org.)	Total E.coliProduced Per Month (Billions of Org.)	Total E. coli Produced Per Month by Category (Billions of Org.)	Total E. coli Available Per Month by Category (Billions of Org.)	Percent by Category
Livestock (Surface Applied Manure)	Horses (Animal Units)	150 - 190	8	1,200 - 1,500	330,000 - 410,000	330,000 - 410,000	62.4%
	Cattle (Animal Units)	175 - 215	1,900	330,000 - 410,000			
	Other (Elk, Sheep, Hogs)	30 - 50	10	300 - 500			
Wildlife	Deer	250 - 310	10	2,500 - 3,100	11,000 - 14,000	11,000 - 14,000	2.1%
	Waterfowl	570 - 690	0.2	110 - 140			
	Other Wildlife	850 - 1050	10	8,500 - 10,500			
Human	Failing Septic Systems	25 - 35	40	1,000 - 1,400	1,000 - 1,400	1,000 - 1,400	0.2%
Domestic Animals	Improperly Managed Pet Waste	19,000 - 23,000	100	1,900,000 - 2,300,000	1,900,000 - 2,300,000	190,000 - 230,000	35.3%
					Total	530,000 - 650,000	100%

Pie Chart

62.4% Livestock

2.1% Wildlife

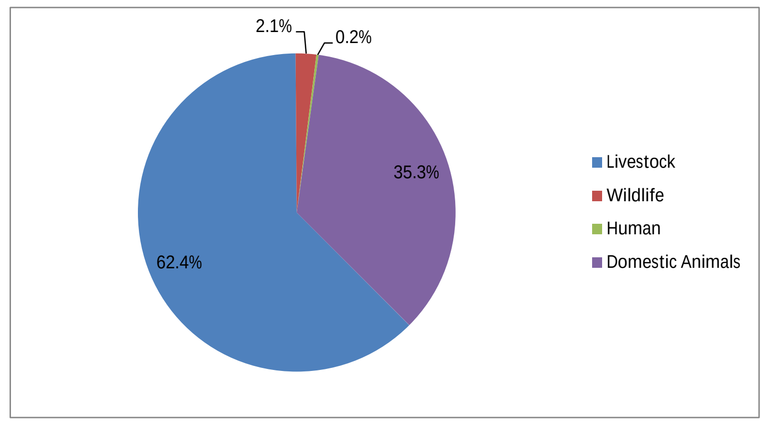
0.2% Human

35.3% Domestic Animals

Watershed	Total Area, Acres	Urban Area, acres	Number Residential Households		Population	Individual Septic Parce	Group Septic/	Notables/ F	Cattle, 2011	Horses, 201	Other, 2011
EC81	20,268.2	14,200.5	16,259	17,147	46,437	530			194	170	40

	Subwatershed	Urban Area	Non-urbanized Area
Acres	20268.2	14200.5	6067.7
Square Miles	31.6690625	22.18828125	9.48078125
Dogs	10013.848		
Cats	10939.786		
Septic	132.5		

Acre	Square Mile
1	0.0015625



Watershed	Total Area, Acres	Urban Area, acres	Number Residential Parcels	Households	Population	Individual Septic Parcels	Group Septic/Onsite Treatment Households	Notables/ Residential Parcel Adjustment reason	Cattle, 2011	Horses, 2011	Other, 2011
DC	2,783.8		48	48	126	46	2	There is a community with a private treatment system south of Diamond Lake	30	70	26
EC	27,680.5	16,824.4	18,842	20,017	53,880	618			240	226	40
Rush Mainstem	18,470.7	470.8	1,363	1,321	3,712	1,164			619	321	4
Rush South Fork	13,571.4	980.3	2,394	2,500	6,872	798	~186	Maple Hills Estate Mobile Home Park	596	288	52

Fecal Coliform, monthly geomean (200 cfu standard)							
	April	May	June	July	August	September	October
2013	6.71	1	1	28.3	1		
2012	1	1	1	1	1	1.41	1
2011	1	1	1	1	1	1	1
2010	1	1	1	1	1	1	1
2009	1	1	1	1	1	1	1
2008	18.76	1	1	1	1	1	1
2007	1	1	1	1	1	1	1
2006	1	1	1	1	1	1.41	1
2005	5.39	5.2	28.28	20.2	1.41	10.2	1.73
2004	2.83	66.63	46.48	74.83	22.98	178	109
2003	4	2	5.1	18.97	5.29	30.5	3.16
2002	1	1	1	13.56	40	43.82	1.73

E. coli, monthly geomean (126 cfu standard)							
	April	May	June	July	August	September	October
2013	4.2273	0.63	0.63	17.829	0.63	0	0
2012	0.63	0.63	0.63	0.63	0.63	0.8883	0.63
2011	0.63	0.63	0.63	0.63	0.63	0.63	0.63
2010	0.63	0.63	0.63	0.63	0.63	0.63	0.63
2009	0.63	0.63	0.63	0.63	0.63	0.63	0.63
2008	11.8188	0.63	0.63	0.63	0.63	0.63	0.63
2007	0.63	0.63	0.63	0.63	0.63	0.63	0.63
2006	0.63	0.63	0.63	0.63	0.63	0.8883	0.63
2005	3.3957	3.276	17.8164	12.726	0.8883	6.426	1.0899
2004	1.7829	41.9769	29.2824	47.1429	14.4774	112.14	68.67
2003	2.52	1.26	3.213	11.9511	3.3327	19.215	1.9908
2002	0.63	0.63	0.63	8.5428	25.2	27.6066	1.0899

E. coli, cfu/100 mL (126 cfu standard)							
	April	May	June	July	August	September	October
2013	#REF!	19364643	18339176	535871187	18768442	0	0
2012	#REF!	19364643	18339176	18935378	18768442	25555606	18792290
2011	#REF!	19364643	18339176	18935378	18768442	18124543	18792290
2010	#REF!	19364643	18339176	18935378	18768442	18124543	18792290
2009	#REF!	19364643	18339176	18935378	18768442	18124543	18792290
2008	#REF!	19364643	18339176	18935378	18768442	18124543	18792290
2007	18482265	19364643	18339176	18935378	18768442	18124543	18792290
2006	18482265	19364643	18339176	18935378	18768442	25555606	18792290
2005	99619406	100696145	518631894	382494629	26463503	184870339	32510661
2004	52304809	1290266181	852404895	1416934310	431298786	3226168668	2048359559
2003	73929059	38729287	93529797	359204114	99285056	552798564	59383635
2002	18482265	19364643	18339176	256763721	750737660	794217478	32510661

E. coli, Billion cfu/100 mL (126 cfu standard)							
	April	May	June	July	August	September	October
2013	#REF!	0.019	0.018	0.536	0.019	0.000	0.000
2012	#REF!	0.019	0.018	0.019	0.019	0.026	0.019
2011	#REF!	0.019	0.018	0.019	0.019	0.018	0.019
2010	#REF!	0.019	0.018	0.019	0.019	0.018	0.019
2009	#REF!	0.019	0.018	0.019	0.019	0.018	0.019
2008	#REF!	0.019	0.018	0.019	0.019	0.018	0.019
2007	0.018	0.019	0.018	0.019	0.019	0.018	0.019
2006	0.018	0.019	0.018	0.019	0.019	0.026	0.019
2005	0.100	0.101	0.519	0.382	0.026	0.185	0.033
2004	0.052	1.290	0.852	1.417	0.431	3.226	2.048
2003	0.074	0.039	0.094	0.359	0.099	0.553	0.059
2002	0.018	0.019	0.018	0.257	0.751	0.794	0.033
Monthly Avg	#REF!	0.134	0.136	0.257	0.121	0.408	0.192
Yearly Avg	#REF!						

Monthly Flow Totals, MG							
	April	May	June	July	August	September	October
2013	0.768	0.796	0.777	0.796	0.791		
2012	0.775	0.812	0.769	0.794	0.787	0.76	0.788

Monthly Flow Totals, Gallons							
	April	May	June	July	August	September	October
2013	768,000	796,000	777,000	796,000	791,000	0	0
2012	775,000	812,000	769,000	794,000	787,000	760,000	788,000

Monthly Flow Totals, mL							
	April	May	June	July	August	September	October
2013	2,907,194,880	3,013,186,360	2,941,263,570	3,013,186,360	2,994,259,310	0	0
2012	2,933,692,750	3,073,752,920	2,910,980,290	3,005,615,540	2,979,117,670	2,876,911,600	2,982,903,080

Monthly Flow Totals, 100mL							
	April	May	June	July	August	September	October
2013	29,071,949	30,131,864	29,412,636	30,131,864	29,942,593	0	0
2012	29,336,928	30,737,529	29,109,803	30,056,155	29,791,177	28,769,116	29,829,031

Appendix C – Modeling Methods, Input, and Output for Lakes
(including Lake Bathymetry)

1.0 Introduction

This section describes the modeling approach and information used to develop TMDLs for the lakes. It begins with an overview of the Bathtub model, which was the lake response model used for all seven lakes. Also presented are a description of the watershed, atmospheric, and internal loading inputs needed for the Bathtub model, and how those inputs were developed for each lake. The supporting appendix sections present the following detailed information for each lake:

C1 Lake Bathymetry and Bathtub Model Lake Morphometry Inputs

C2 Bathtub Model Tributary Loading Inputs

C3 Bathtub Model Internal and Atmospheric Loading Inputs

C4 Bathtub Model Nutrient Mass Balance

C5 Bathtub Model Calibration (Predicted vs. Observed)

C6 Bathtub Model Load Response Curves

C7 Bathtub Model Inputs and Outputs

The Bathtub model was developed to describe water quality conditions and estimate the assimilative capacity for the impaired lakes within the Elm Creek Watershed. The Bathtub model Version 6.20 developed by William Walker, Jr., Ph. D. for the Environmental Laboratory of the U.S. Army Corp of Engineers Waterways Experimental Station (1985 & 1996) was used for all in-lake response model simulations. The model estimates in-lake water quality conditions based on the lake morphological characteristics and a mass-balance of nutrient loading to the lake. This document was prepared to identify the methodology used for developing the in-lake response model for each impaired lake identified within the Elm Creek Watershed TMDL. The general modeling approach to determine the loading capacity for each impaired lake is outlined below and described in more detail in the following sections.

- Characterize the morphology of each lake as inputs into the Bathtub Model.
- Estimate the various sources of annual loading to the lake as inputs into the Bathtub model.
    - Watershed loading
    - Internal loading
    - Atmospheric loading
- Calibrate the Bathtub model to observed water quality conditions.
- Perform in-lake response model simulations to determine the loading capacity necessary to meet MPCA water quality standards.

The time period modeled was dependent on the availability of reliable monitoring data for years with average precipitation conditions within each lake's watershed. Average conditions for the watershed were defined as approximately 28 inches of total annual precipitation. Due to the differences in the time period of data collection and the amount of precipitation, the years used for model simulations varied for each lake. There were occasions in which the development of the bathtub model was dependent upon the average of multiple years of data collected with average precipitation conditions. The years that were used for development of the bathtub model for each lake are represented within Table C-1.

Table C-1: The years used for development of the Bathtub Model for each lake.

Lake	Modeled Years
Fish	2010-2012
Rice	2010-2012
Diamond	2010-2011
Cowley	2006
Henry	2009 & 2011
Sylvan	2012
Goose	2011-2012

2.0 Bathtub Model Lake Morphometry and Water Quality Inputs

The development of the Bathtub model requires the input of the morphological characteristics for each impaired lake within the Elm Creek Watershed. Each impaired lake was modeled as one segment within the Bathtub model. The morphological parameters that were input into the Bathtub model included the lake surface area, mean depth, mixed layer depth, length, and mean hypolimnetic depth. The mean hypolimnetic depth corresponds to late spring or early summer after the onset of stratification. The Bathtub model morphological characteristics are based on bathymetry measurements collected during aquatic vegetation surveys (Appendix E). Bathymetric maps were developed in ArcMap using Kriging analysis from the depth measurements, and spatial analysis was performed on lakes for determination of morphological characteristics. The Bathtub model bathymetry maps and morphological input for each lake is located Appendix C1.

The Bathtub model also requires the input of observed water quality data for each lake. The observed water quality data input into the Bathtub model was the growing season average for the time period modeled. The time period modeled was dependent on the availability of reliable monitoring data for years with average precipitation conditions. The years used for calculating the average observed water quality varied for each lake (Table C-1). The water quality monitoring data was collected by the Three Rivers Park District or through the Citizens Assisted Monitoring Program. The in-lake water quality data assists with the calibration of the Bathtub model. The Bathtub model is ultimately calibrated to the observed water quality conditions, and process of model calibration is further explained in Section 6.0. The Bathtub model water quality input for each lake is located within the Appendix C5.

3.0 Watershed Loading

The watershed load entered into the Bathtub model was developed from modeling analysis and/or monitoring data. The watershed models developed to estimate tributary loading to impaired lakes were the SWAT model (for areas with agricultural land use) and the P8 model (for areas with urban land use). These watershed models were developed within the Elm Creek hydrologic watershed boundary. The watershed models were calibrated to those areas that had monitored water quality data. Monitored data was occasionally used to represent the tributary loading in the lake response model when quality of the monitoring data was more reliable than watershed modeling results due to model limitations (model limitations further discussed in the Elm Creek SWAT modeling memorandum-Appendix D). The tributary loading data (monitored data versus modeling results) input into the in-lake response model corresponded with the time period that was used to develop the water quality inputs (Table C-1).

Those lakes within the Elm Creek watershed used either the watershed model output and/or water quality monitoring data to generate tributary loading inputs for the in-lake response model. For those lakes outside the Elm Creek hydrologic watershed boundary (Sylvan and Cowley), a unit area load method based on SWAT modeling for similar land uses within the hydrologic watershed was applied to generate watershed nutrient and water loads to each lake. The lakes to which this approach was applied had watershed land uses that were primarily rural/agricultural. An aggregation of the unit area loads per land use type was input as the tributary loading for the in-lake response model.

3.1 Description of Watershed Modeling Approach by Lake

The following sections summarize the watershed modeling approach taken for each lake.

3.1.1 Fish Lake

The Fish Lake watershed is primarily urban land use that has been entirely developed. A P8 model was developed for the entire Fish Lake watershed. The Fish Lake watershed was delineated into eight smaller sub-watersheds that would be used as tributary inputs into the in-lake response model (Figure C-1). A P8 model was developed to represent the loading from each of these sub-watersheds. There were four sub-watersheds that had reliable monitoring data collected in 2011. These sub-watersheds accounted for 62% of the total Fish Lake watershed. The P8 model was calibrated to the flow monitoring data from all four of these sampling sites (FL4, FL5, FL6, and FL7), and then calibrated to nutrient concentrations (i.e. total suspended solids and total phosphorus) from three of these sampling sites (FL4, FL5, and FL7). The P8 model calibration procedures used for the monitored sub-watersheds were then further adjusted for the remaining sub-watersheds in the P8 model. After the P8 model was calibrated, model simulations were performed to determine the annual flow volume and nutrient loading from 2010 through 2012. The model simulations from 2010 through 2012 represented average annual precipitation conditions. The average flow volume and nutrient concentration (2010-2012) from the P8 model simulations were input into the in-lake response model to represent the tributary loading for each sub-watershed (Appendix C2).

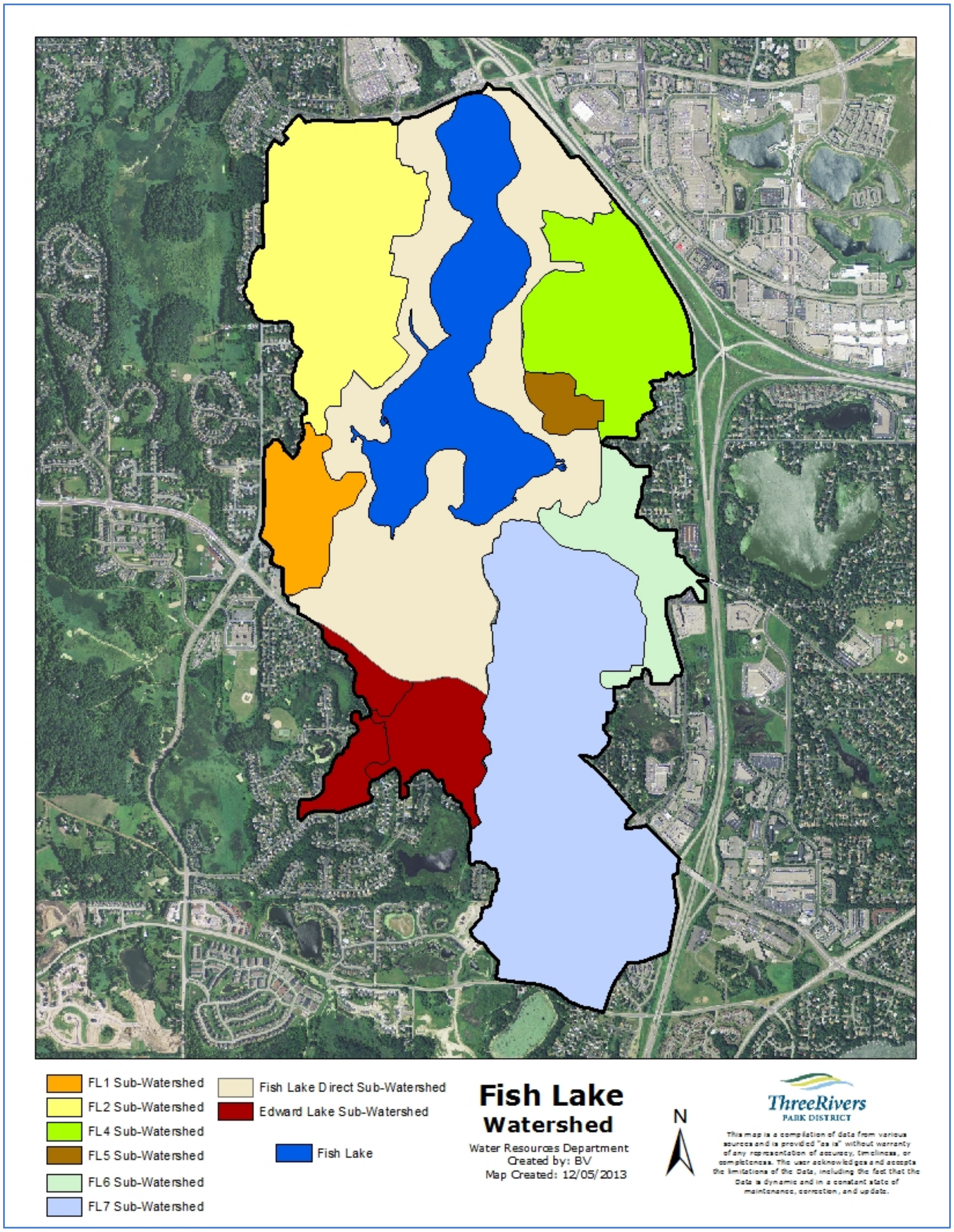


Figure C-1: Fish Lake sub-watershed boundaries for the development of the P8 model.

3.1.2 Rice Lake

The Rice Lake watershed required using modeling results and water quality monitoring data as tributary loading inputs into the in-lake response model. The Rice Lake watershed was divided into six major sub-watersheds (Figure C-2). Monitoring data was used for those sub-watershed areas with reliable flow and nutrient concentration data. The P8 model was used for those urban areas that did not have reliable monitoring data. The nutrient loading from model simulations and monitoring data represented average precipitation conditions from 2010 through 2012. The average flow volumes and nutrient concentrations (2010-2012) were input into the in-lake response model to represent the tributary loading for each sub-watershed (Appendix C2).

The Fish Lake sub-watershed (previously discussed) is a major drainage area that ultimately flows to Rice Lake (Figure C-2) and accounts for 9% of the Rice Lake watershed drainage area. A calibrated P8 model was developed for the entire Fish Lake watershed. It was assumed that the tributary flow volume draining into Fish Lake was similar to the outflow volume from Fish Lake to Rice Lake. The in-lake nutrient concentration for Fish Lake was used to represent the nutrient outlet concentration flowing to Rice Lake (Appendix C2).

The Elm Creek sub-watershed (Figure C-2) accounts for 72% of the entire Rice Lake drainage area. This sub-watershed flows to the west basin of Rice Lake (labeled as Elm Creek – monitored) upstream of the I-94 bridge (Figure C-2). Three Rivers Park District monitored continuous flow volume and nutrient concentrations at monitoring station EC-77 over a 6-year period from 2007-2012 (Figure C-2). The data from this site provided reliable flow and water quality monitoring data that was used to represent the tributary load from this portion of the watershed. There are two smaller sub-watersheds downstream from the EC-77 sampling site that account for approximately 8% of the Rice Lake watershed. These two sub-watersheds include the Weaver Lake sub-watershed and a sub-watershed immediately downstream from EC-77 to Rice Lake West Basin (labeled as Elm Creek to Rice Lake West Bay in Figure C-2). Freshwater Scientific monitored the water quality at a sampling site located at the furthest downstream section of these two sub-watersheds prior to draining into the southeast portion of Rice Lake West Basin (Figure C-2). The nutrient concentrations collected at the Freshwater Scientific sampling site in 2007 and 2008 were very similar to those concentrations monitored at the EC-77 sampling site. Based on similar concentrations from the two sites, it was assumed that nutrient concentrations at the EC-77 sampling site were similar to the Freshwater Scientific sampling site concentrations after 2008. Unfortunately, there was no reliable flow data collected at the Freshwater Scientific sampling site. A P8 model was developed to estimate the flow volume from the two sub-watersheds draining to the southeast portion of Rice Lake West Basin. The nutrient concentrations from the EC-77 sampling site and the P8 model flow volumes were used to represent the tributary (EC-P53) inputs for the in-lake response model (Appendix C2).

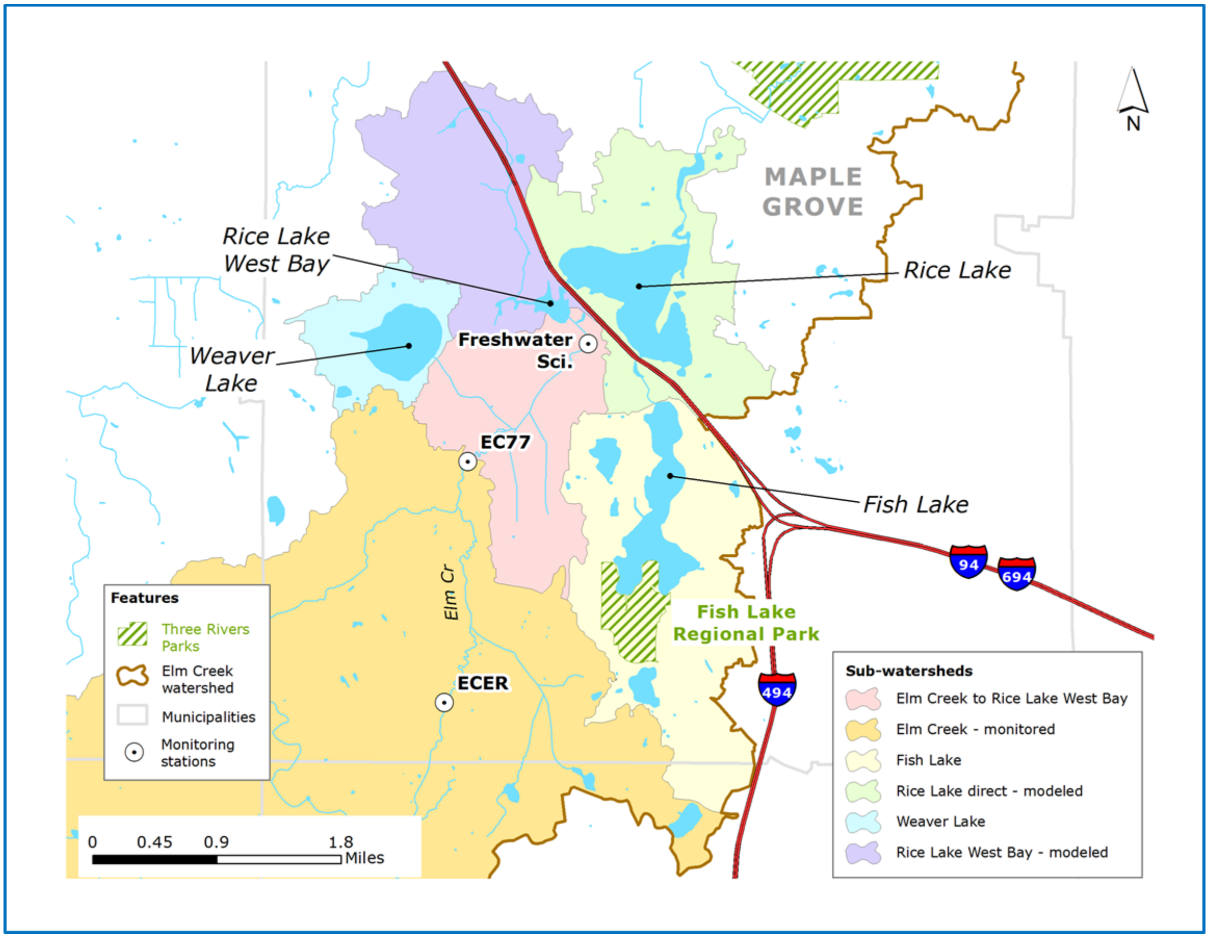


Figure C-2: Rice Lake sub-watersheds input into the in-lake response model.

The sub-watershed that drains the northwest portion of the Rice Lake West Basin accounts for approximately 8% of the Rice Lake watershed area (Figure C-2). This particular sub-watershed includes the direct drainage for the Rice Lake West Basin (labeled as Rice Lake West Bay – modeled). There were no monitoring sites established for this particular sub-watershed. Consequently, a P8 model was developed for the northwest and direct drainage areas to estimate flow volumes and nutrient concentrations. The flow volumes and nutrient concentrations from this sub-watershed represent the tributary loading inputs for the in-lake response model as Rice West Direct (EC-A79) and EC-P78 (Appendix C2).

The remaining sub-watershed includes the direct drainage into the Rice Lake Main Basin. This particular sub-watershed accounts for approximately 5% of the Rice Lake watershed area (Figure C-2). There were no monitoring sites established for this sub-watershed. A P8 model was also developed for this sub-watershed to estimate flow volumes and nutrient concentrations. The flow volumes and nutrient concentrations from this sub-watershed represent the tributary loading inputs for the in-lake response model as Rice Main Direct (EC-A89) and EC-P85 (Appendix C2).

3.1.3 Diamond Lake

The Diamond Lake watershed was primarily agricultural with portions of the watershed that also support industrial, commercial, and residential land uses. A SWAT model was developed for the entire watershed to simulate nutrient loading to Diamond Lake for years with average precipitation conditions (2010-2011). The SWAT model was developed for two sub-watersheds draining to Diamond Lake (Figure C-3). The SWAT model provided estimated flow volumes and nutrient concentrations for the sub-watershed that drains directly to Diamond Lake. The SWAT model was also used to estimate flow volumes and nutrient loads from the Grass Lake sub-watershed. Three Rivers Park District collected grab samples at bi-weekly to monthly intervals in 2013 at the outlet of Grass Lake to compare to SWAT modeling results. It was determined that the SWAT generated concentrations were considerably higher than the monitored nutrient concentrations. Consequently, average monitored nutrient concentrations collected in 2013 were used with the SWAT estimated flow volumes to generate loads from this sub-watershed. The average flow volumes and nutrient concentrations (2010-2011) represented the tributary loading inputs for the in-lake response model (Appendix C2).

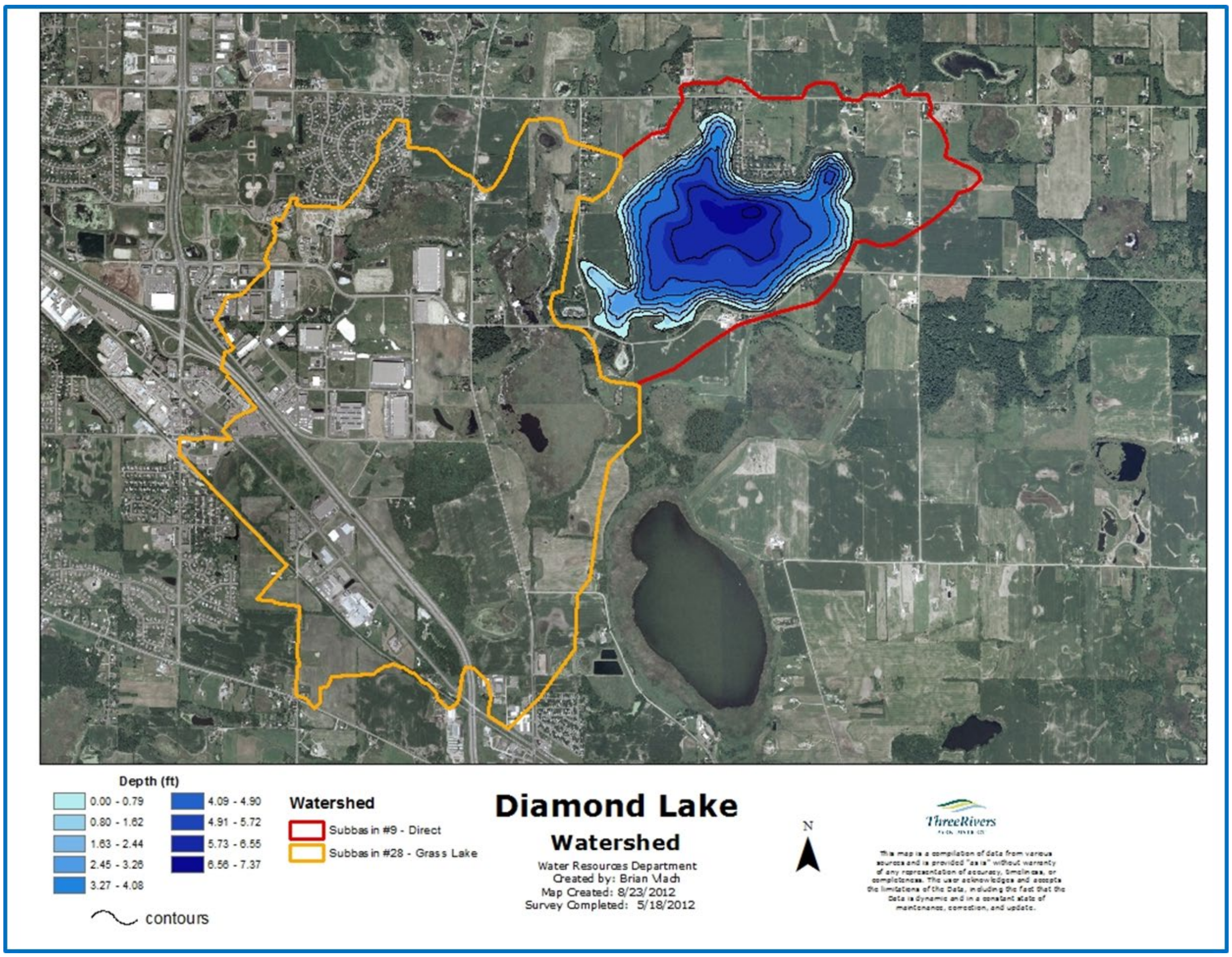


Figure C-3: Diamond Lake sub-watersheds input into the in-lake response model.

3.1.4 Cowley Lake

The Cowley Lake watershed consists of mostly agricultural land use located outside the hydrologic boundary of Elm Creek (Figure C-4). Since Cowley Lake is located outside of the Elm Creek hydrologic boundary, the unit area load method was used to represent the tributary loading within the Cowley Lake response model. Based on the SWAT modeling of similar land uses in the Diamond Creek watershed, an aggregation of the unit area loads per land use type was used to estimate watershed loading for the Cowley Lake response model (Appendix C2). Cowley Lake does not have an extensive in-lake water quality database. Consequently, the most reliable in-lake data available that was representative of average precipitation conditions was 2006.

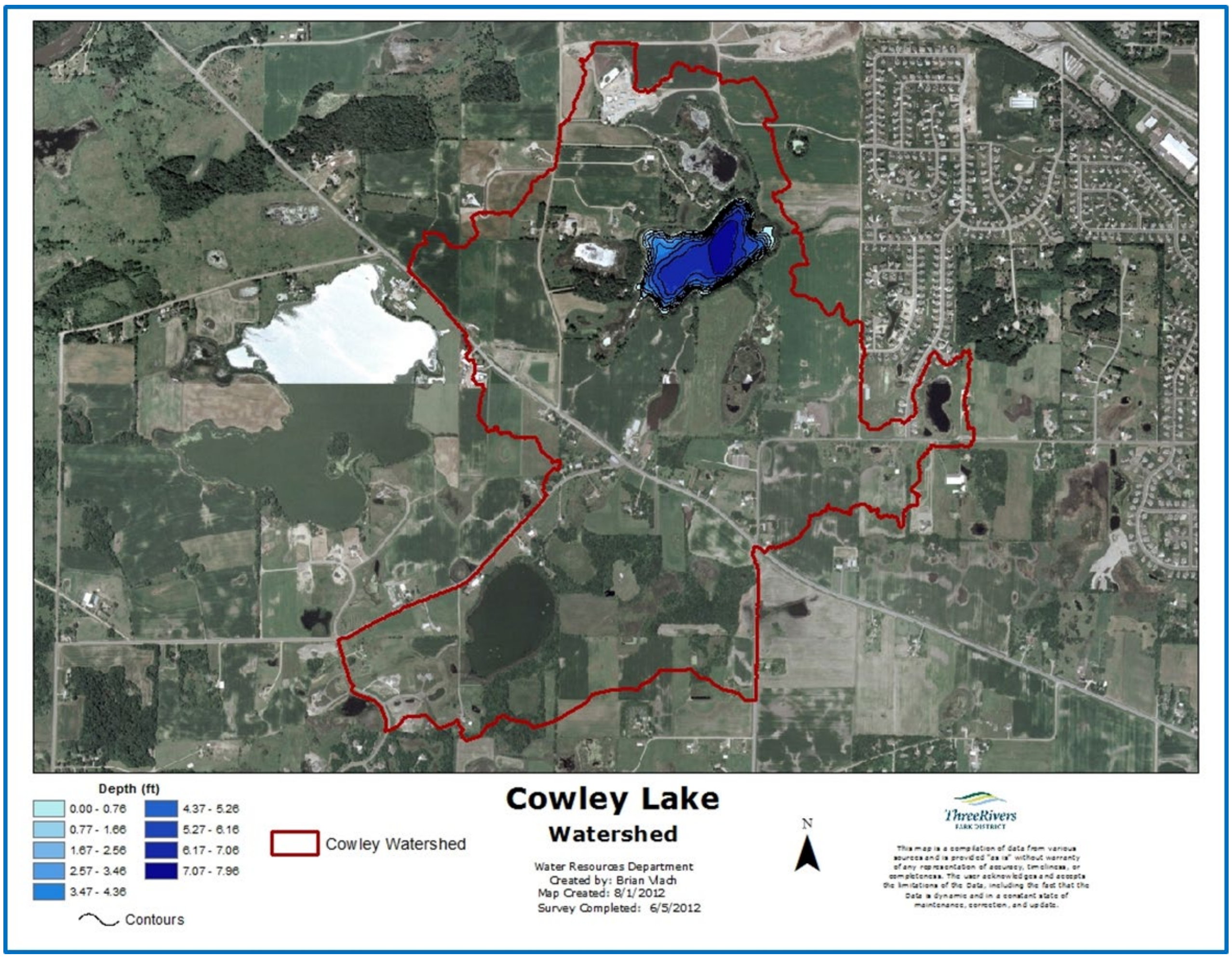


Figure C-4: Cowley Lake watershed.

3.1.5 *Henry Lake*

The Henry Lake watershed consists of primarily agricultural land use (Figure C-5). A SWAT model was developed for the entire watershed to simulate nutrient loading to Henry Lake for years with average precipitation conditions (2009 & 2011). The average flow volumes and nutrient concentrations from the SWAT model simulations (2009 & 2011) were input as tributary loading for the in-lake response model (Appendix C2).

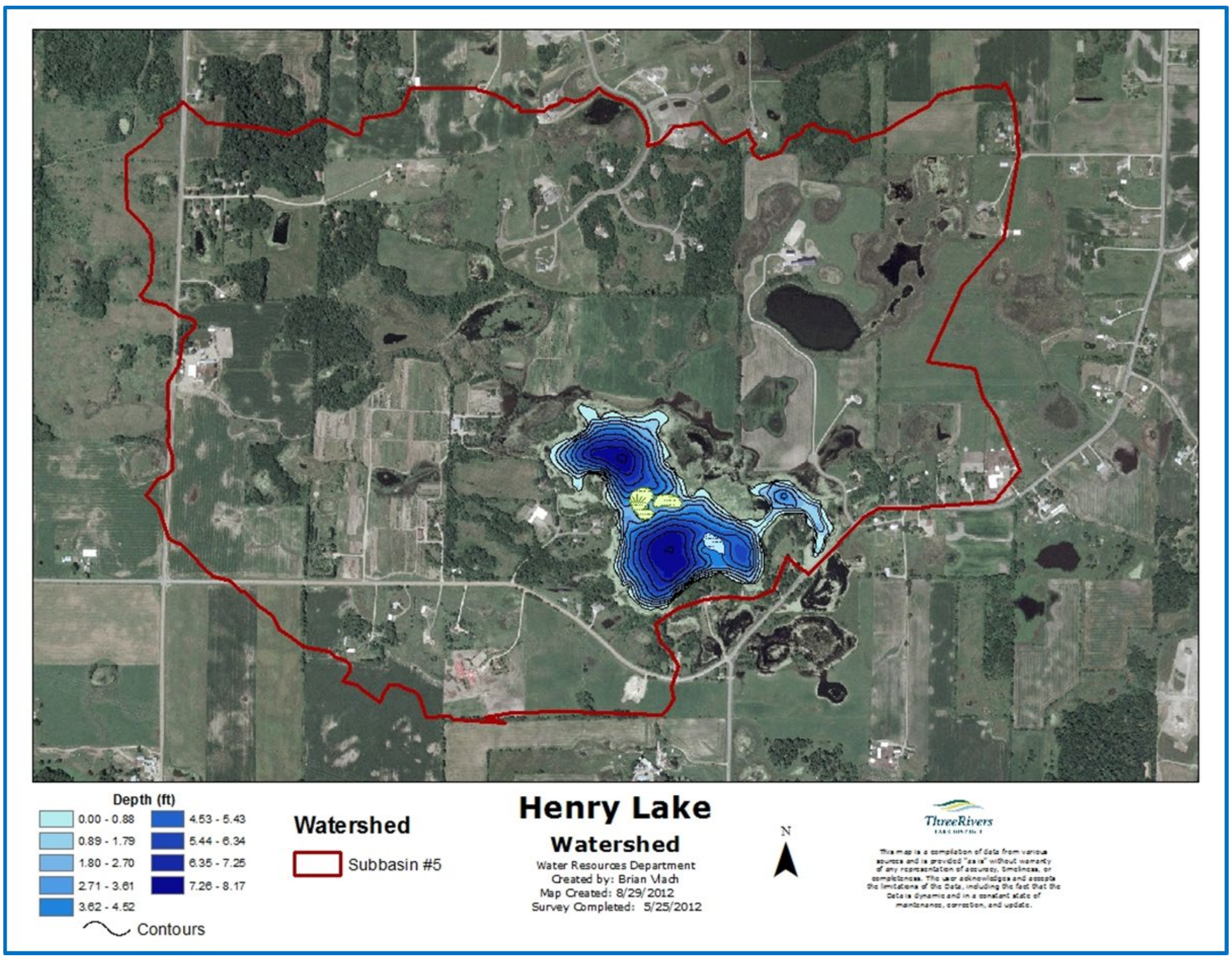


Figure C-5: Henry Lake watershed.

3.1.6 Sylvan Lake

The Sylvan Lake watershed consists of agricultural land use located outside of the Elm Creek hydrologic boundary (Figure C-6). Similar to the approach used for modeling Cowley Lake, the unit area load method was used to generate the tributary loading within the Sylvan Lake response model. Based on SWAT modeling of similar land uses in the Diamond Lake watershed, an aggregation of the unit area loads per land use type was input as the tributary loading for the Sylvan Lake response model (Appendix C2). Sylvan Lake does not have an extensive in-lake water quality database. Consequently, the most reliable in-lake data available that was representative of average precipitation conditions was 2012.

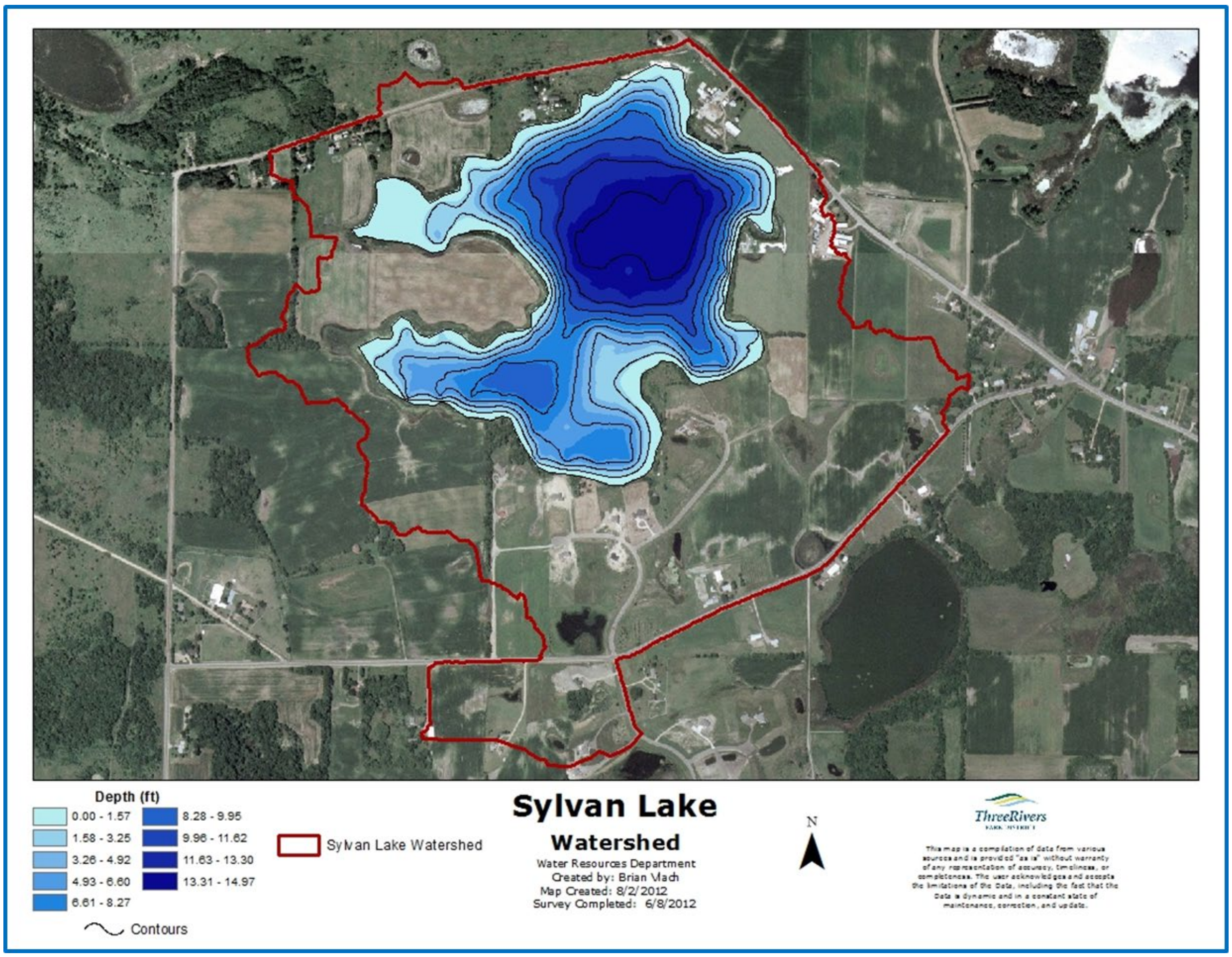


Figure C-6: Sylvan Lake watershed.

3.1.7 Goose Lake

The Goose Lake watershed consists of primarily park and residential land use (Figure C-7). The Goose Lake watershed was delineated into six smaller sub-watersheds. A P8 model was developed to represent the watershed loading for each of these sub-watersheds. There was no watershed monitoring data collected to calibrate the P8 model. The same calibration adjustment factors used for the Fish Lake P8 model were also used for the Goose Lake P8 model. The P8 model was used to determine the annual flow volume and nutrient concentrations for average precipitation conditions in 2011 and 2012. The average flow volume and nutrient concentration (2011 and 2012) from the P8 model simulations were input into the in-lake response model to represent the tributary loading for each sub-watershed (Appendix C2).

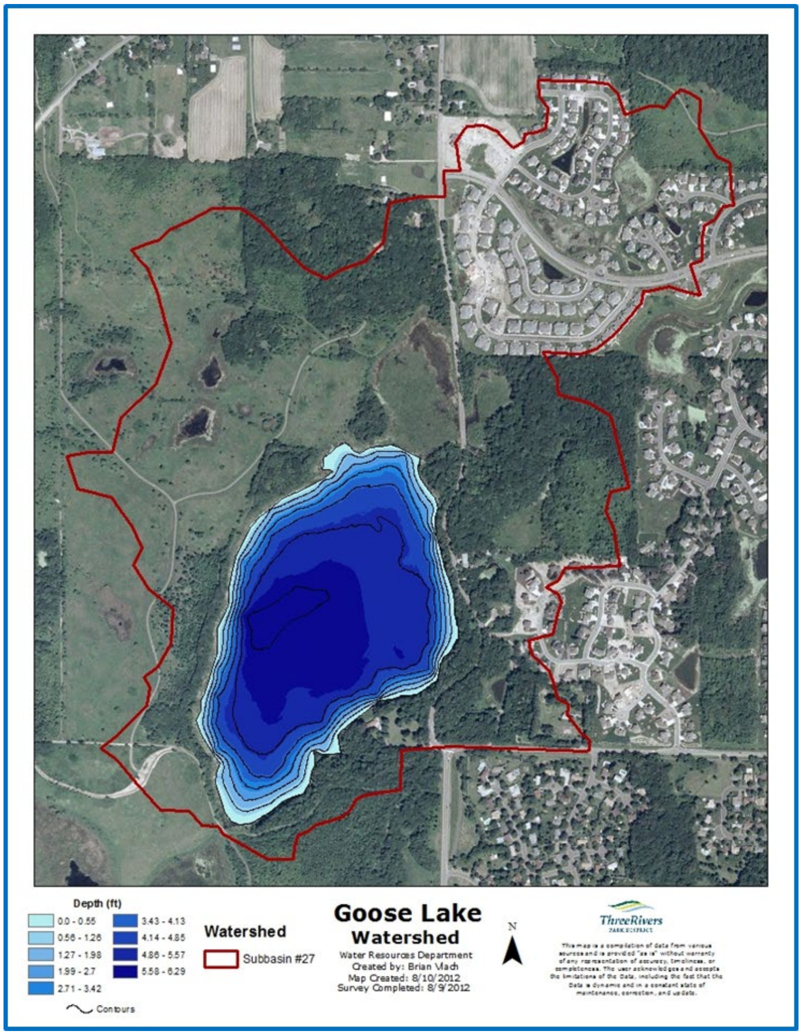


Figure C-7: Goose Lake watershed.

4.0 Internal Loading

There were two primary sources of internal loading that were considered for the in-lake response model. The phosphorus loading from sediment release during anoxia and senescence of curly-leaf pondweed were estimated for each impaired lake. These estimates of internal loading were aggregated and compared to the internal loading estimates used as an input into the Bathtub model. The internal loading estimate input into the Bathtub model was part of the phosphorus calibration of the in-lake response model (see calibration section for more details). The process of estimating the internal load of each source is described below.

Sediment Release of phosphorus due to hypolimnetic anoxia

Sediment release of phosphorus is initiated by hypoxic/anoxic conditions in the hypolimnion during stratification. Phosphorus released from the sediment diffuses throughout the water column as stratification changes throughout the growing season. Typically, wind mixing and temperature changes are mechanisms that exacerbate the internal diffusion of nutrients from the hypolimnion to epilimnion. Phosphorus from sediment release in the hypolimnion was estimated using an approach developed by Nürnberg et al. (1988 and 1994). The Nürnberg equation calculates internal phosphorus load by using sediment release rates (RR) multiplied by an anoxic factor (AF) that is based on the area and duration of hypolymnetic anoxia (Equations 1 & 3). The anoxic factor represents the number of days that a sediment area, equal to the whole-lake surface area, is overlain by anoxic water (<1 mg O_2/L). Nürnberg (1987) developed an equation to estimate the anoxic factor from a data set of lakes in central Ontario and eastern North America (Equation 2). The anoxic factor equation (Equation 2) was used for those lakes that did not have temperature and dissolve oxygen profile data.

Equation 1:

$$\text{Internal Loading Rate (mg/m}^2\text{-yr)} = AF * RR$$

AF = Anoxic Factor (days/year)

RR = Sediment Release Rate (mg/m^2-day)

Equation 2:

$$\text{Anoxic Factor (days/yr)} = -36.2 + 50.1 \log(TP) + 0.762 * Z/A^{0.5}$$

TP = Average summer in-lake TP Concentrations (µg/L)

Z = lake mean depth (m)

A = lake surface (km^2)

Equation 3:

$$\text{Internal Load} = \text{Internal Loading Rate (EQ1)} * \text{Hypolimnetic Anoxia Area (m}^2\text{)}$$

Typically, sediment release rates are derived from laboratory incubation experiments with in-lake sediment cores. Sediment cores were collected on three lakes within Elm Creek watershed (Fish, Rice, and Diamond Lake). Sediment release rates were measured by William James from the University of Wisconsin-Stout in Menomonie, Wisconsin. Those remaining lakes that did not have sediment cores collected (Cowley, Henry, Sylvan, and Goose) required using sediment release rates previously measured from lakes with similar eutrophic water quality conditions (Bischoff and James 2012; data base of 102 lakes). Bischoff and James (2012) documented differences in sediment release rates for shallow lakes that were algal- and plant-dominated (Water Resources Conference 2012). Those lakes that did not have sediment core data were classified as algal or plant dominated shallow lakes based on aquatic vegetation surveys (Appendix E). Internal loading was estimated for these shallow lakes as a minimum (lower quartile – 25th percentile) and maximum (upper quartile – 75th percentile) range based on sediment release rates from Bischoff and James 2012 algal and plant dominated data (Table C-2).

Table C-2: Sediment release rates for plant and algal dominated lakes (Bischoff and James 2012).

	Sediment Release Rates (mg/m^2-day)		
	Anoxic		
Shallow Lake Condition	**Minimum**	**Maximum**	**Oxic**
Plant Dominated	0.5	3.5	0.1
Algal Dominated	5.8	9.8	0.3

Senescence of curly-leaf pondweed

Curly-leaf pondweed is a significant factor inhibiting recreational use as well as potentially degrading the in-lake water quality. Curly-leaf pondweed is an exotic species that typically competes with other native plant species because of its unique life cycle. The plant germinates from turions (seed structures) in early fall when most native plants have died back, and the plant continues to grow slowly during the winter months. Curly-leaf pondweed growth increases substantially after ice-out due to an increase in light availability. The plant begins to die-off (called senescence) after the completion of turion production by the end of June or early July. The senescence of curly-leaf pondweed provides an internal source of nutrients within several impaired lakes of the Elm Creek watershed. Nutrients released from the senescence process are in a soluble form readily available for algae uptake. Consequently, algae blooms frequently develop causing a decrease in water clarity. The senescence of curly-leaf pondweed exacerbates the eutrophication process by causing poor water quality conditions earlier in the season.

To estimate the amount of internal loading from curly-leaf pondweed senescence, Three Rivers Park District performed phosphorus analysis on curly-leaf pondweed biomass samples collected from a 1-m^2 quadrant survey that was performed on a lake (Medicine Lake) with nuisance growth conditions (Vlach and Barten 2004). The survey provided an average estimate of curly-leaf pondweed phosphorus per unit area sampled (grams dry-weight/m^2). This estimate was converted to the average pounds of phosphorus/acre (Table C-3) and multiplied by the acreage of curly-leaf pondweed for a particular lake.

Table C-3: Total Phosphorus Loading estimates from curly-leaf pondweed (Vlach and Barten 2004).

Curly-leaf Pondweed Senescence	**Average Biomass (g dry weight/m^2)**	**Average TP Concentration (mg/g dry weight)**	**Average Load (lbs TP/Acre)**
Minimum Load	38.6	4.91	1.65
Maximum Load	83.4	4.8	3.19

4.1 Description of Internal Load Estimation Approach by Lake

The following sections summarize the internal load estimation approach taken for each lake.

4.1.1 Fish Lake Internal Load

Three Rivers Park District collected sediment cores in two different locations on Fish Lake in 2012. William James from the University of Wisconsin STOUT laboratory analyzed anoxic sediment phosphorus release from the core samples (James 2013) (Table C-4). The oxic sediment release was considered to be minimal and was not analyzed from the sediment cores. The anoxic sediment release rates were similar between the two sampling sites. The Nürnberg equation (1988) was used to estimate the internal loading of Fish Lake using the average anoxic sediment release rates (7.6 mg/m^2/day). Based on the Nürnberg equation, the estimated internal loading from anoxic sediment release for Fish Lake was approximately 1406 pounds of phosphorus (Table C-4). Aquatic vegetation surveys indicated that there doesn't appear to be a significant influence of curly-leaf pondweed senescence on internal load (Appendix E). Therefore, curly-leaf pondweed was not considered a significant component to the total internal load. The internal load that was required to calibrate to the in-lake total phosphorus concentration for the BATHTUB model was approximately 1577 pounds (Appendix C3). This internal load required to calibrate the BATHTUB model was very similar to the estimated internal loading from the Nürnberg equation.

Table C-4: Fish Lake estimated annual internal load from anoxic sediment release rates.

	Total Phosphorus	
Location	**Anoxic Sediment Release Rate (mg/m^2/day)**	**Estimated Internal Load (lbs/year)**
Site 1	6.3	1165.8
Site 2	8.9	1646.9
Average	7.6	1406.3

4.1.2 Rice Lake Internal Load

Three Rivers Park District collected sediment cores at one location on Rice Lake Main Basin in 2012. William James from the University of Wisconsin STOUT laboratory analyzed anoxic and oxic sediment phosphorus release from the core samples (James 2013) (Table C-5). The Nürnberg equation (1988) was used to estimate the internal loading of Rice Lake using the anoxic and oxic sediment release rates. Based on the Nürnberg equation, the estimated internal loading from anoxic sediment release was approximately 1836.6 pounds of phosphorus, and estimated internal loading from oxic sediment release was approximately 247.0 pounds of phosphorus (Table C-5). Aquatic vegetation surveys indicated that curly-leaf pondweed senescence appears to be a significant influence on internal load (Appendix E). The senescence of curly-leaf pondweed may potentially contribute an additional 506.6 to 979.3 pounds of phosphorus to the internal load (Table C-6).

Table C-5: Rice Lake – Main Basin annual internal load estimate from anoxic and oxic sediment release.

Conditions	Total Phosphorus Sediment Release Rate (mg/m2/day)	Total Phosphorus Estimated Internal Load (lbs/year)
Anoxia	9.45	1836.6
Oxic	1.17	247.0
Total		2083.6

Table C-6: Rice Lake – Main Basin annual internal load estimate attributed to curly-leaf pondweed senescence.

Condition	CLP Load (lbs/acre-year)	Surface Area (acres)	Load (lbs/year)
Minimum Load	1.65	330	544.5
Maximum Load	3.19	330	1052.7

The total internal phosphorus load from sediment release and curly-leaf pondweed was estimated to range between 2628.1 and 3136.3 pounds per year. The internal load that was required to calibrate to the in-lake total phosphorus concentration for the BATHTUB model was approximately 3270.3 pounds (Appendix C3). This internal load required to calibrate the BATHTUB model was very similar to the estimated internal loading from the Nürnberg equation and senescence of curly-leaf pondweed.

4.1.3 Diamond Lake Internal Load

Three Rivers Park District collected sediment cores at two locations on Diamond Lake in 2012. William James from the University of Wisconsin STOUT laboratory analyzed anoxic and oxic sediment phosphorus release from core samples (James 2013) (Table C-7). The anoxic and oxic sediment release rates were similar between the two sampling sites. The Nürnberg equation (1988) was used to estimate the internal loading of Diamond Lake using the average anoxic and oxic sediment release rates. Based on the Nürnberg equation, the estimated internal loading from anoxic sediment release was approximately 49.9 pounds of phosphorus, and estimated internal loading from oxic sediment release was approximately 48.4 pounds of phosphorus (Table C-7). Aquatic vegetation surveys indicated that curly-leaf pondweed senescence appears to be a significant influence on internal load. The senescence of curly-leaf pondweed may potentially contribute an additional 641.4 to 1240.0 pounds of phosphorus to the internal load (Table C-8).

Table C-7: Diamond Lake annual internal load estimate from anoxic and oxic sediment release.

Conditions	Total Phosphorus Sediment Release Rate (mg/m2/day)	Total Phosphorus Estimated Internal Load (lbs/year)
Anoxia	3.2	49.9
Oxic	0.1	48.4
Total		98.3

Table C-8: Diamond Lake annual internal load estimate attributed to curly-leaf pondweed senescence.

Condition	CLP Load (lbs/acre-year)	Surface Area (Acres)	Load (lbs/year)
Minimum Load	1.65	388.7	641.4
Maximum Load	3.19	388.7	1240.0

The total internal phosphorus load from sediment release and curly-leaf pondweed was estimated to range from 739.7 and 1338.3 pounds per year. The internal load that was required to calibrate to the in-lake total phosphorus concentration for the BATHTUB model was approximately 796.5 pounds (Appendix C3). This internal load required to calibrate the BATHTUB model was very similar to the estimated internal loading from the Nürnberg equation and senescence of curly-leaf pondweed.

4.1.4 Cowley Lake Internal Loading

Internal loading was estimated for Cowley Lake as a minimum and maximum range based on documented sediment phosphorus release rates from Bischoff and James 2012. Cowley Lake is an algal-dominated shallow lake based on field observations during a point-intercept survey conducted by Three Rivers Park District in 2012 (Appendix E). Consequently, the Nürnberg equation was used to estimate internal loading from sediment release rates that were acquired from similar algal-dominated eutrophic lakes (Bischoff and James 2012). The Nürnberg estimate of internal phosphorus loading ranged between 177.6 and 300.0 pounds per year (Table C-9). Aquatic vegetation surveys also indicated that curly-leaf pondweed senescence appears to be a significant influence on internal loading for Cowley Lake (Appendix E). The senescence of curly-leaf pondweed may potentially contribute an additional 54.3 to 105.0 pounds of phosphorus to the internal load (Table C-9). The Nürnberg and curly-leaf pondweed contributions to the total internal phosphorus load ranged between 231.9 and 405.0 pounds per year. The internal load required to calibrate to the in-lake total phosphorus concentration for the BATHTUB model was approximately 418.7 pounds (Appendix C3). This internal load was similar to the estimated internal loading from the Nürnberg equation and senescence of curly-leaf pondweed.

Table C-9: Cowley Lake annual internal loading estimates.

Internal Loading Source	Total Phosphorus Load (lbs/year)	
	Minimum	**Maximum**
Sediment Release	177.6	300.0
Curly-leaf Pondweed	54.3	105.0
Total	231.9	405.0

4.1.5 Henry Lake Internal Loading

Internal loading was estimated for Henry Lake as a minimum and maximum range based on documented sediment phosphorus release rates from Bischoff and James 2012. Henry Lake is a plant-dominated shallow lake based on a point-intercept survey conducted by Three Rivers Park District in 2012 (Appendix E). Consequently, the Nürnberg equation was used to estimate internal loading from sediment release rates that were acquired from similar plant-dominated eutrophic lakes (Bischoff and James 2012). The Nürnberg estimate of internal phosphorus loading ranged between 13.3 and 74.7 pounds per year (Table C-10). Aquatic vegetation surveys also indicated that curly-leaf pondweed senescence appears to be a significant influence on internal loading for Henry Lake (Appendix E). The senescence of curly-leaf pondweed may potentially contribute an additional 38.8 to 149.9 pounds of phosphorus to the internal load (Table C-10). The Nürnberg and curly-leaf pondweed contributions to the total internal phosphorus load ranged between 52.1 and 224.6 pounds per year (Table C-9). The internal load required to calibrate to the in-lake total phosphorus concentration for the BATHTUB model was approximately 268.7 pounds (Appendix C3). This internal load was similar to the estimated internal loading from the Nürnberg equation and senescence of curly-leaf pondweed.

Table C-10: Henry Lake annual internal loading estimates.

Internal Loading Source	Total Phosphorus Load (lbs/year)	
	Minimum	Maximum
Sediment Release	13.3	74.7
Curly-leaf Pondweed	38.8	149.9
Total	52.1	224.6

4.1.6 Sylvan Lake Internal Loading

Internal loading was estimated for Sylvan Lake as a minimum and maximum range based on documented sediment phosphorus release rates from Bischoff and James 2012. Sylvan Lake is an algal dominated shallow lake based on a point-intercept survey conducted by Three Rivers Park District in 2012 (Appendix E). Consequently, the Nürnberg equation was used to estimate internal loading from sediment release rates that were acquired from similar algal-dominated eutrophic lakes (Bischoff and James 2012). The Nürnberg estimate of internal phosphorus loading ranged between 318.4 and 529.6 pounds per year (Table C-11). Aquatic vegetation surveys also indicated that curly-leaf pondweed senescence appears to be a significant influence on internal loading for Sylvan Lake (Appendix E). The senescence of curly-leaf pondweed may potentially contribute an additional 157.2 to 303.9 pounds of phosphorus to the internal load (Table C-11). The Nürnberg and curly-leaf pondweed contributions to the total internal phosphorus load ranged between 475.6 and 833.6 pounds per year. The internal load required to calibrate to the in-lake total phosphorus concentration for the BATHTUB model was approximately 877.2 pounds (Appendix C3). This internal load was similar to the estimated internal loading from the Nürnberg equation and senescence of curly-leaf pondweed.

Table C-11: Sylvan Lake annual internal loading estimates.

Internal Loading Source	Total Phosphorus Load (lbs/year)	
	Minimum	Maximum
Sediment Release	318.4	529.6
Curly-leaf Pondweed	157.2	303.9
Total	475.6	833.5

4.1.7 Goose Lake Internal Loading

Internal loading was estimated for Goose Lake as a minimum and maximum range based on documented sediment phosphorus release rates from Bischoff and James 2012. Goose Lake is an algal dominated shallow lake based on a point-intercept survey conducted by Three Rivers Park District in 2012 (Appendix E). Consequently, the Nürnberg equation was used to estimate internal loading from sediment release rates that were acquired from similar algal-dominated eutrophic lakes (Bischoff and James 2012). The Nürnberg estimate of internal phosphorus loading ranged between 131.6 and 270.2 pounds per year (Table C-12). Aquatic vegetation surveys indicated that there doesn't appear to be a significant influence of curly-leaf pondweed senescence on internal load. Therefore, curly-leaf pondweed was not considered a significant component to the total internal load. The internal load required to calibrate to the in-lake total phosphorus concentration for the BATHTUB model was approximately 71.2 pounds (Appendix C3). This internal load was below the estimated internal loading from the Nürnberg equation. Bischoff and James (2012) have documented that there are some algal-dominated lakes that have unusually low sediment phosphorus release rates. The mechanisms responsible for these unusual sediment release rates are currently unknown. Goose Lake may have unusually low sediment phosphorus release rates, which may account for the difference between the Nürnberg estimates and internal load used to calibrate the Bathtub model.

Table C-12: Goose Lake annual internal loading estimates.

Internal Loading Source	Total Phosphorus Load (lbs/year)	
	Minimum	Maximum
Sediment Release	131.6	270.2
Curly-leaf Pondweed	0	0
Total	131.6	270.2

5.0 Atmospheric Loading

The atmospheric depositional loading was estimated within the Bathtub model. The default Bathtub value for atmospheric deposition was 0.27 lbs/acre-year (30 mg/m^2-yr). The Bathtub default value was similar to other atmospheric total phosphorus loading rates reported in a technical memorandum to the Minnesota Pollution Control Agency (2007). The total surface area of the lake is multiplied by the atmospheric depositional load to determine the load delivered to the lake. The atmospheric depositional loading was included in the overall lake nutrient balance and is identified in the Bathtub model as precipitation loading. The atmospheric loading was documented in the Appendix C3.

6.0 Bathtub Model Calibration

The Bathtub model is calibrated to the observed in-lake water quality conditions. Bathtub is an empirical model that estimates lake and reservoir eutrophication using several different algorithms. The algorithms selected for the different in-lake parameters were based on the model that best predicted the observed in-lake conditions. Although the algorithms used for estimating in-lake water quality conditions varied for each lake, the calibration approach and methodology was consistent among all of the lakes. All of the Bathtub model simulations were performed for years that were representative of average annual precipitation conditions. The predicted and observed in-lake water quality conditions were documented within the Appendix C5.

The Bathtub model was initially calibrated to the in-lake total phosphorus concentration. There are essentially eight different total phosphorus algorithms available for selection within the model. The algorithm selected was based on the model that provided the best estimate of in-lake total phosphorus concentration that was similar to observed conditions. All of the models calculate in-lake phosphorus concentration based on the lake morphological characteristics and the different sources of phosphorus loading (watershed, internal, and atmospheric). An average rate of internal loading is implicit for each model since each algorithm is based on empirical data from lakes that have natural internal loading. However, the impaired lakes within the Elm Creek Watershed have excessive nutrients with rates of internal loading that are higher than the implicit background levels. Consequently, an additional internal loading component was necessary to calibrate to the in-lake phosphorus concentration. The internal loading rate was adjusted (in the segment portion of the Bathtub model) to the observed in-lake total phosphorus concentration. The additional internal load required to calibrate to the in-lake phosphorus concentration was compared to the estimated internal load from the Nürnberg equation and curly-leaf pondweed senescence. The internal load required to calibrate the Bathtub model for each lake seemed reasonable when comparing to the manual estimates of internal load (Appendix C3). The estimated internal load to calibrate the Bathtub model was used in the overall lake nutrient balance (Appendix C4).

The Bathtub model was calibrated to chlorophyll-*a* and secchi depth transparency after the overall nutrient balance was established through the calibration process of total phosphorus (Appendix C4). The chlorophyll-*a* and secchi depth transparency are considered water clarity response variables that are influenced by the overall phosphorus balance in each lake. The procedure for calibration of the water clarity response variables simply provided a more robust model that simulated the existing impaired water quality conditions, but was not used to simulate the water clarity changes in response to achieving the assimilative phosphorus capacity of each lake to meet the MPCA standards. There are six different chlorophyll-*a* algorithms available for selection within the model, and there are four different secchi depth transparency algorithms available for selection within the model. The Bathtub model was initially calibrated to chlorophyll-*a* because of the influence it has on water clarity. The chlorophyll-*a* and secchi depth algorithms were selected based on the model that best predicted the observed in-lake condition (Appendix C5). The chlorophyll-*a* and secchi depth model coefficients were adjusted incrementally to further calibrate to the observed in-lake water quality conditions.

7.0 Loading Capacity Determination

The Bathtub model load-response function was used to evaluate the in-lake water quality response to varying phosphorus loads from the watershed. The load-response analysis was conducted to determine the watershed load reductions necessary to meet the in-lake MPCA standard. The impaired lakes within the Elm Creek Watershed are located within the North Central Hardwoods Forest Ecoregion. The MPCA water quality standard for the eco-region is dependent upon whether the lake is classified as a shallow or deep lake. The load-response function was performed on each lake to meet the in-lake total phosphorus standard (Appendix C6). It was assumed that the water clarity response variable (chlorophyll-*a* and secchi depth transparency) standards would be achieved if the in-lake total phosphorus standard was met. The load-response function incrementally adjusts the inflow phosphorus concentrations for all of the tributaries and estimates the change in the in-lake water quality conditions.

The impaired lakes within the Elm Creek Watershed are extremely eutrophic due to the past excessive amounts of nutrient loading. The internal load seems to have a significant influence on water quality conditions and has accounted for a significant portion of the nutrient balance for all of the impaired lakes (Appendix C4). The majority of the load response simulations indicated that the long-term in-lake phosphorus standard was not attainable with the internal loading components in the model. The long-term in-lake water quality standards most likely would be attainable if the excess internal loading were controlled or managed. It was assumed that the internal loading would have to be controlled in order for the lakes to meet water quality standards. To determine the loading capacity necessary to achieve the long-term water quality standards, the internal loading was subsequently removed from the Bathtub model for majority of the lakes. There was only one lake (Fish Lake) that was able to achieve the phosphorus standard while performing the load response function with internal loading remaining in the model. This particular lake was currently close to already meeting the phosphorus standard.

The loading capacity is defined as the maximum load that a specific lake can receive and still meet water quality standards. The Bathtub model provides a load response curve that reflected the relationship between watershed loading and in-lake water quality. The model does not take into account the atmospheric load and any internal load remaining in the model (i.e. Fish Lake) at the time the load response curve was developed. Consequently, the atmospheric load and any internal load that remained in the model were added to the watershed load to determine the total loading capacity for each lake. The load response simulations to determine individual lake loading capacity was further identified within the Appendix C6. The total loading capacity for each lake was then used for the development of the TMDL equation.

8.0 Literature Cited

Barr Engineering Company. 2007. Detail Assessment of Phosphorus Sources to Minnesota Watersheds–Atmospheric Deposition: 2007 Update. Technical Memorandum prepared for Minnesota Pollution Control Agency.

Bischoff, J., and James, W.F. 2012. Anoxic and Oxic Release of Phosphorus from Sediments in Minnesota Lakes. Paper presented at the Minnesota Water Resources Conference, Saint Paul RiverCentre, St. Paul, Minnesota 2012.

James, W.F. 2013. Alum Dosage Considerations for Fish Lake, Hennepin County, Minnesota. Report submitted by University of Wisconsin – Stout Laboratory. Sustainability Science Institute. Prepared for Three Rivers Park District. February 2013.

James, W.F. 2013. Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Rice Lake, Minnesota. Report submitted by University of Wisconsin-Stout Laboratory. Sustainability Science Institute. Prepared for Three Rivers Park District. February 2013.

James, W.F. 2013. Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Diamond Lake, Minnesota. Report submitted by University of Wisconsin-Stout Laboratory. Sustainability Science Institute. Prepared for Three Rivers Park District. February 2013.

Nürnberg, G.K. 1987. A comparison of internal phosphorus loads in lakes with anoixic hypolimnia: laboratory incubations versus hypolimnetic phosphorus accumulation. Limnological Oceanography. 32: 1160-1164.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Canadian Journal of Fisheries Aquatic Sciences 45: 453-462.

Nürnberg, G.K. 1994. Phosphorus release from anoxic sediments: What we know and how we can deal with it. Lemnetica. 10(1): 1-4.

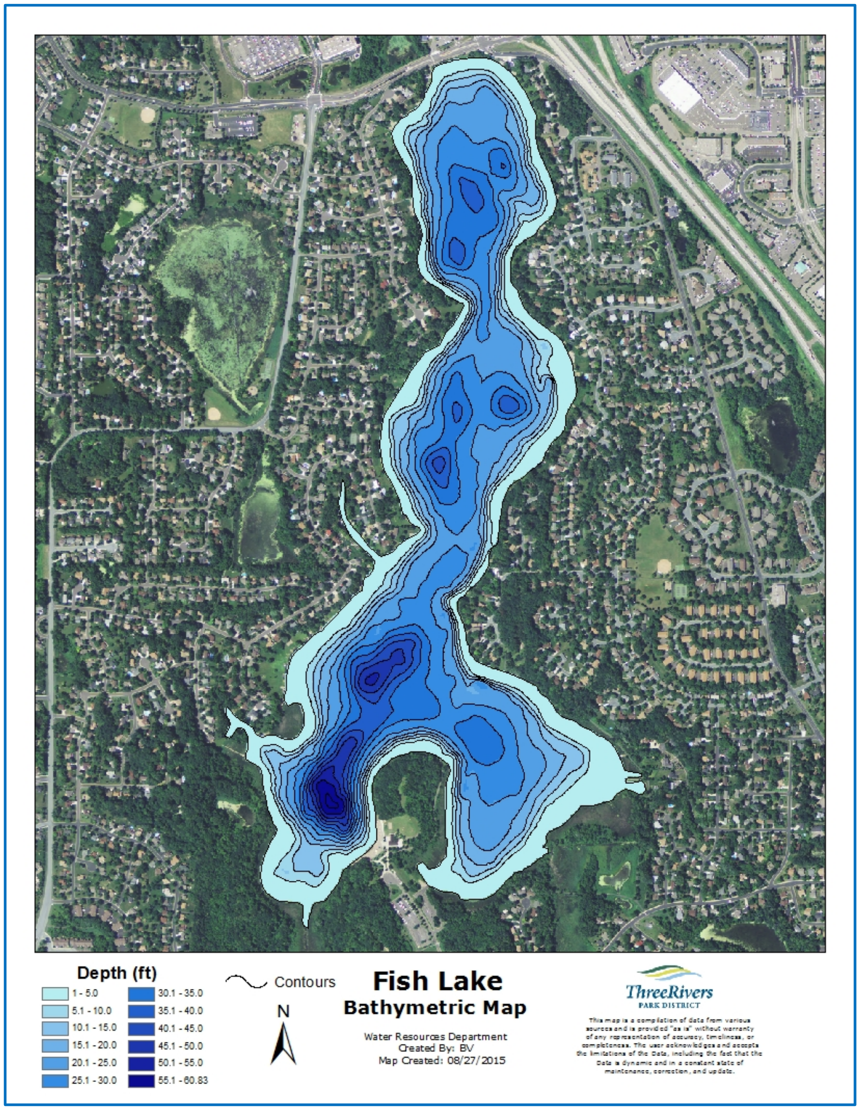
Vlach, B.R., and Barten, J.M. 2007. Medicine Lake Endothall Treatment to Control Curlyleaf Pondweed 2004 – 2007. Status Report prepared by Three Rivers Park District. March 2008.

Walker, William W., “Empirical Methods for Predicting Eutrophication in Impoundments – Report 3: Model Refinements”, prepared for Office, Chief of Engineers, U.S. Army, Washington, D.C., Technical Report E-81-9, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, draft 1983, published March 1985.

Walker, William, W., Simplified Procedures for Eutrophication Assessment & Prediction: User Manual Instruction Report W-96-2 USAE Waterways Experiment Station, Vicksburg, Mississippi, 1996 (Updated September 1999)

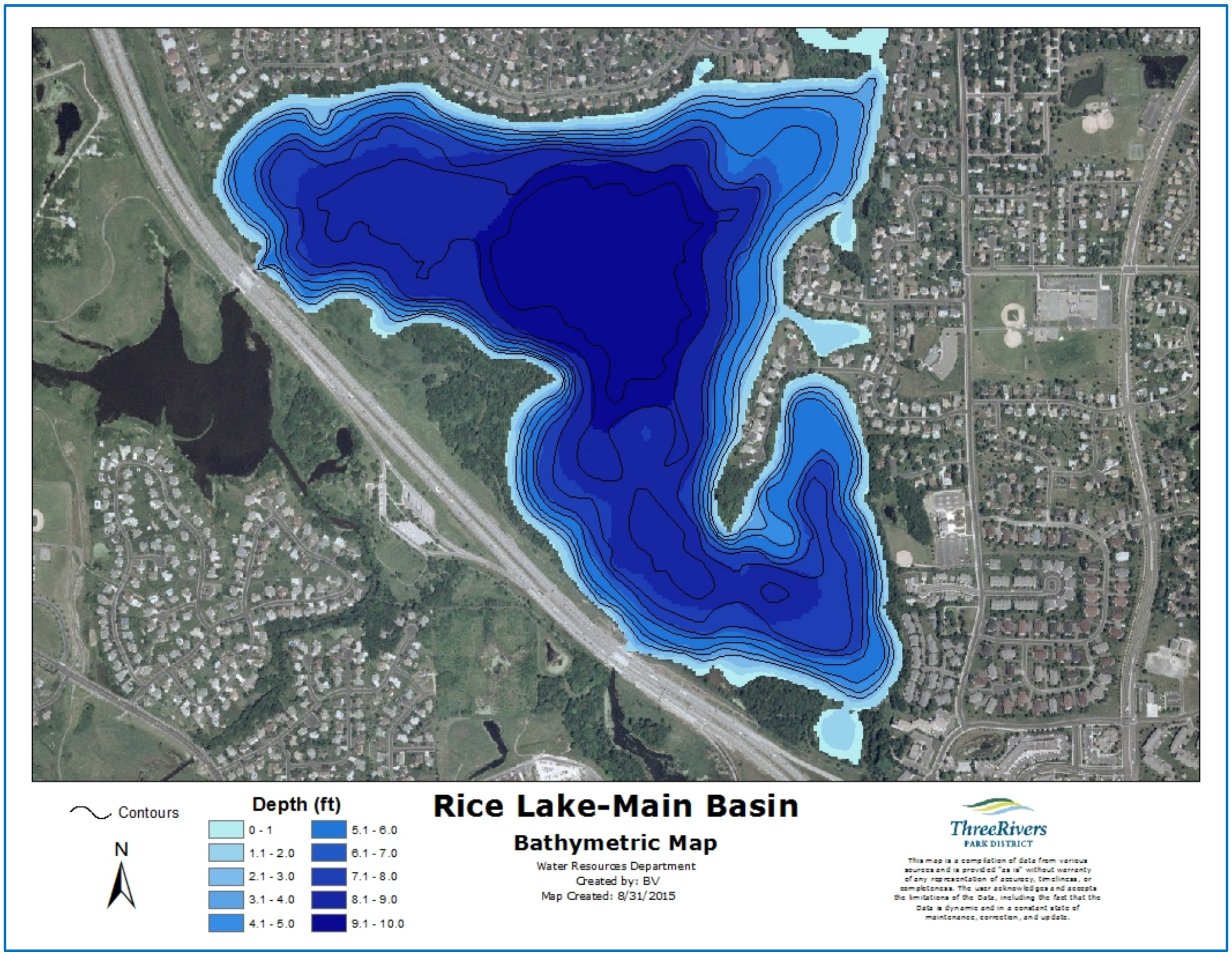
Appendix C1
Lake Bathymetry and Bathtub Model Morphometry Inputs

Fish Lake



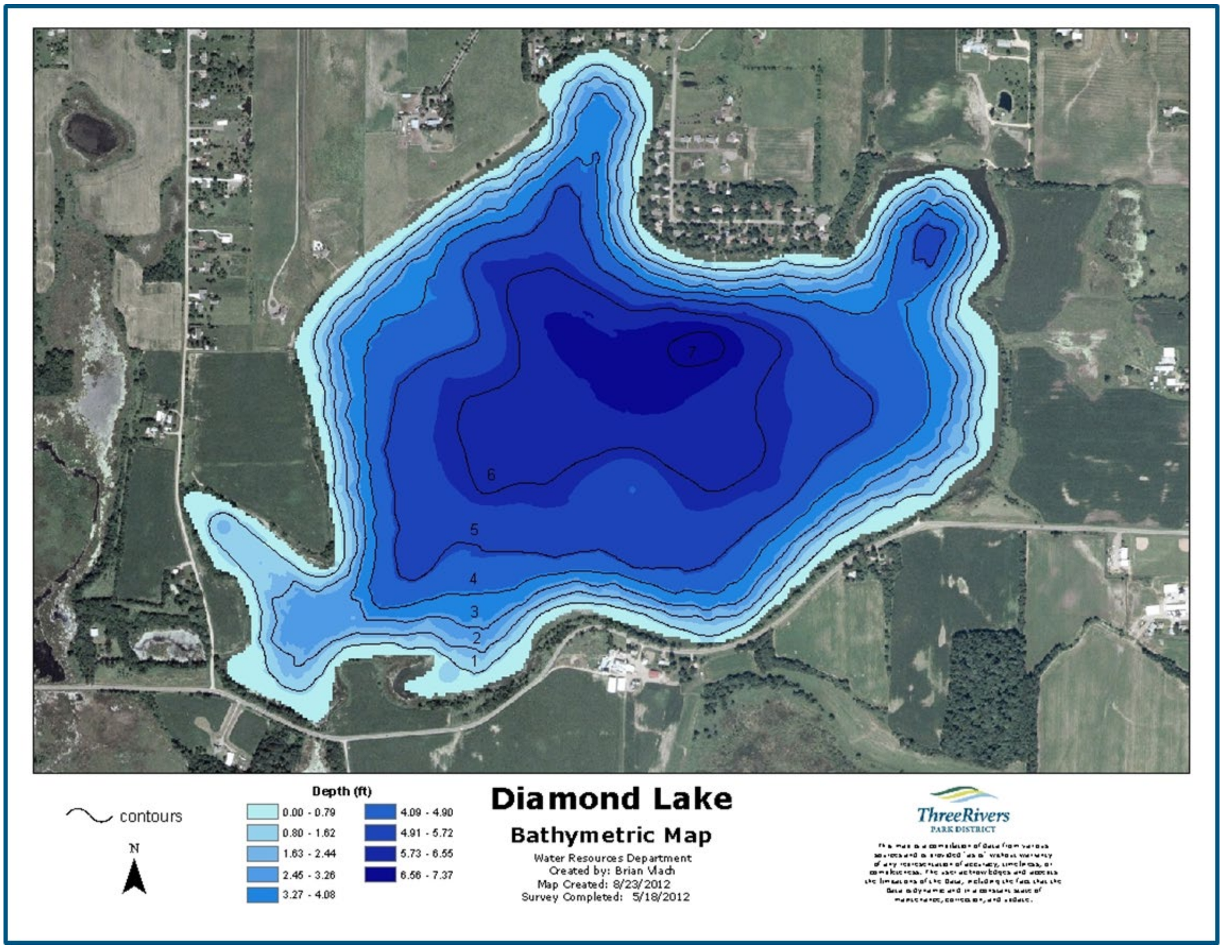
Fish Lake Characteristics	
DNR ID	27-118-00
Lake Area	0.96 km^2 (238 acres)
% Littoral (≤ 15 ft in depth)	39%
Mean Depth	5.72 m
Maximum Depth	18.5 m
Mixed Layer Depth	4.80 m
Hypolimnetic Depth	2.62 m
Length	2.35 km
Classification	Deep Lake

Rice Lake – Main Basin



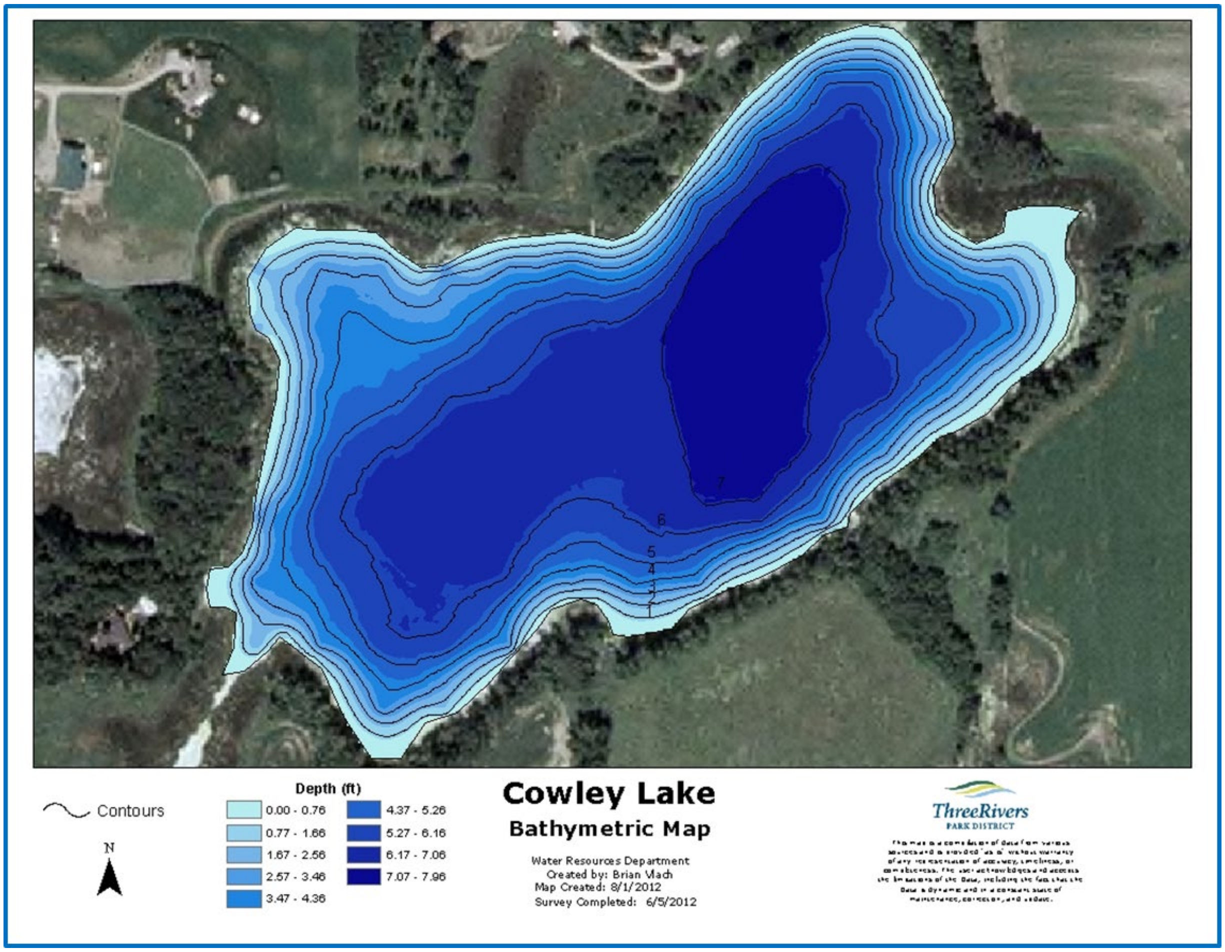
Rice Lake (Main Basin) Characteristics	
DNR ID	27-116-01
Lake Area	1.34 km^2 (330 acres)
% Littoral (≤ 15 ft in depth)	100%
Mean Depth	2.14 m
Maximum Depth	3.4 m
Mixed Layer Depth	2.14 m
Length	1.6 km
Classification	Shallow Lake
Condition/State	Algal Dominated

Diamond Lake



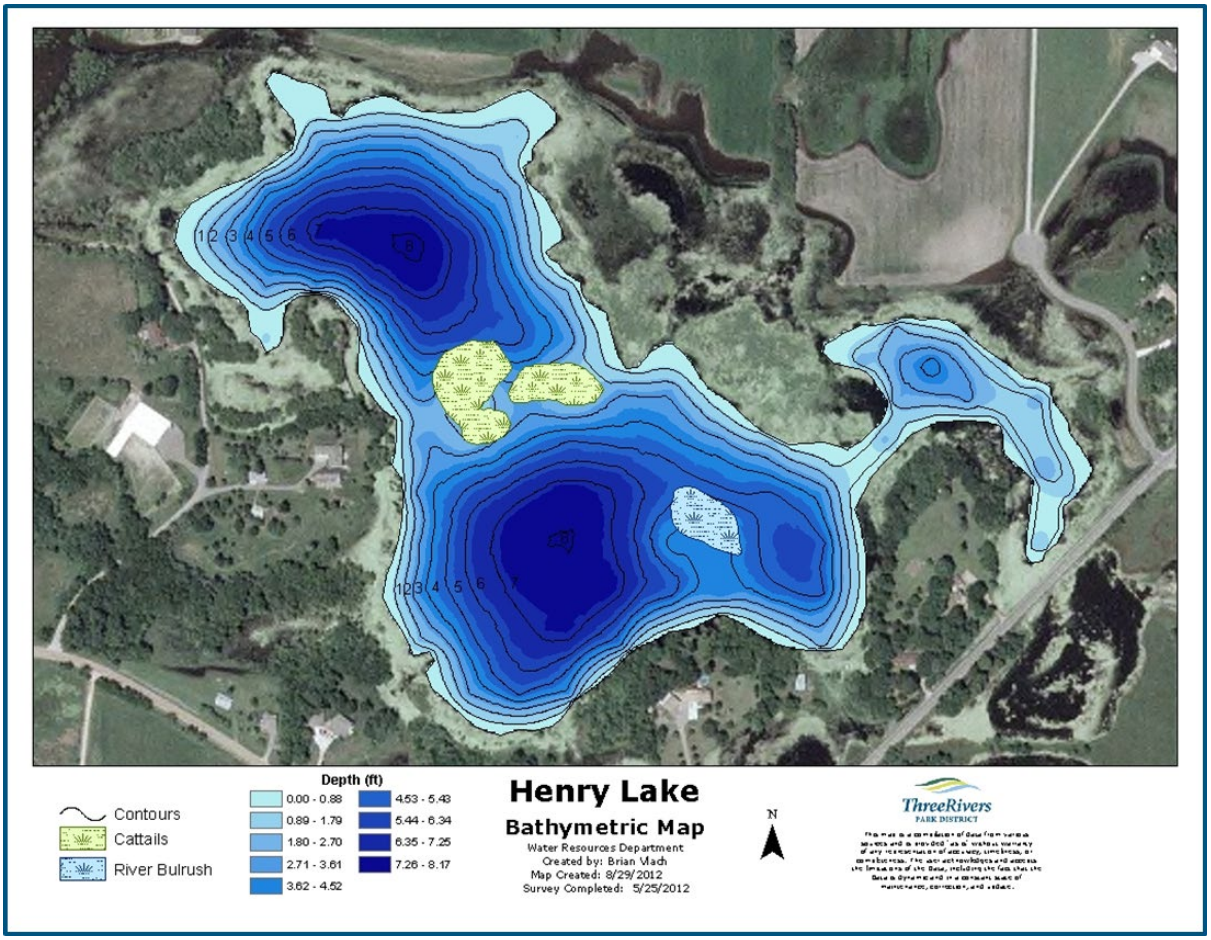
Diamond Lake	
DNR ID	27-0125-00
Lake Area	1.57 km^2 (388.7 Acres)
% Littoral (≤ 15 ft in depth)	100%
Mean Depth	1.21 m
Maximum Depth	2.25 m
Mixed Layer Depth	1.21 m
Length	1.63 km
Classification	Shallow Lake
Condition / State	Algal/Plant Dominated

Cowley Lake



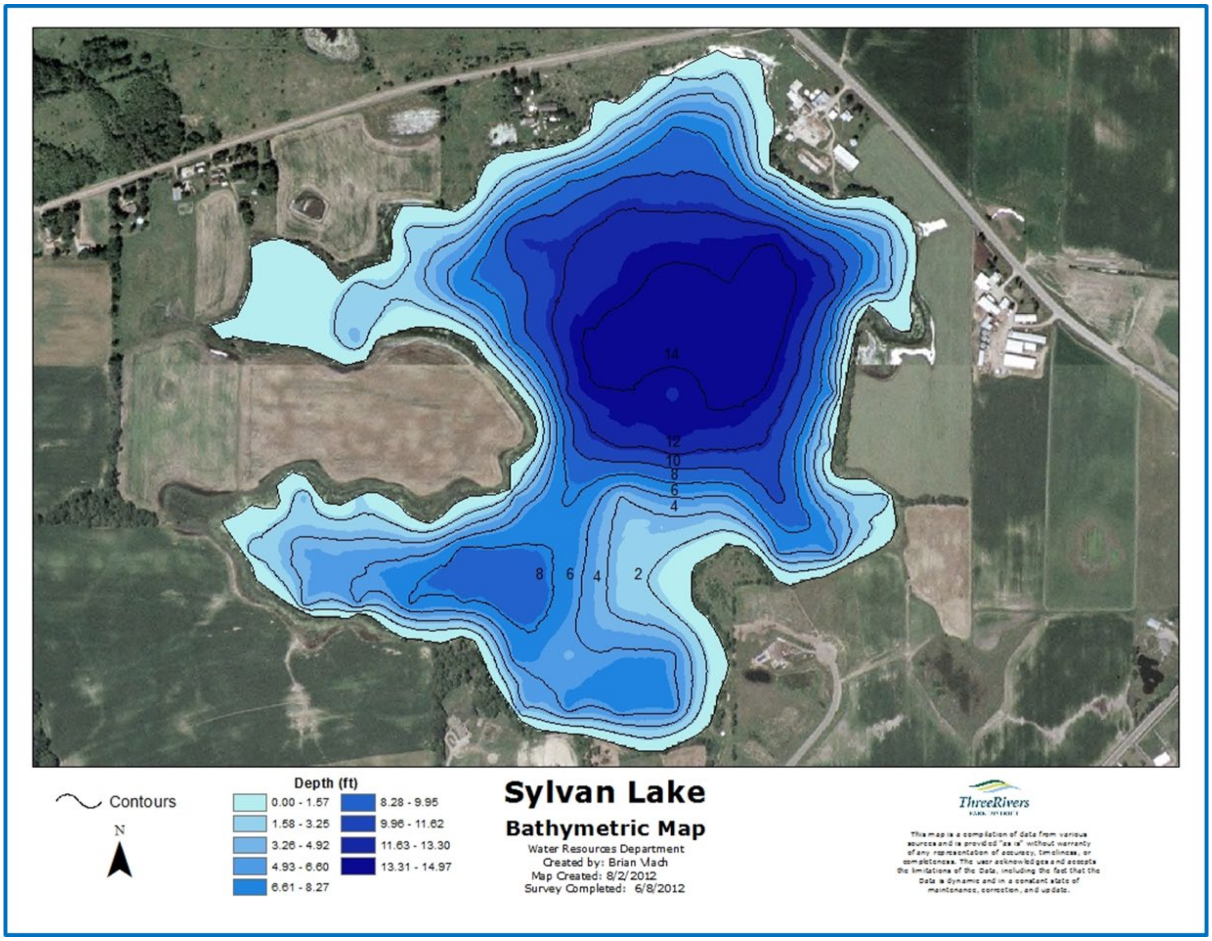
Cowley Lake	
DNR ID	27-0169-00
Lake Area	0.133 km^2 (32.9 Acres)
% Littoral (≤ 15 ft in depth)	100%
Mean Depth	1.46 m
Maximum Depth	2.43 m
Mixed Layer Depth	1.46 m
Length	0.51 m
Classification	Shallow Lake
Condition / State	Algal Dominated

Henry Lake



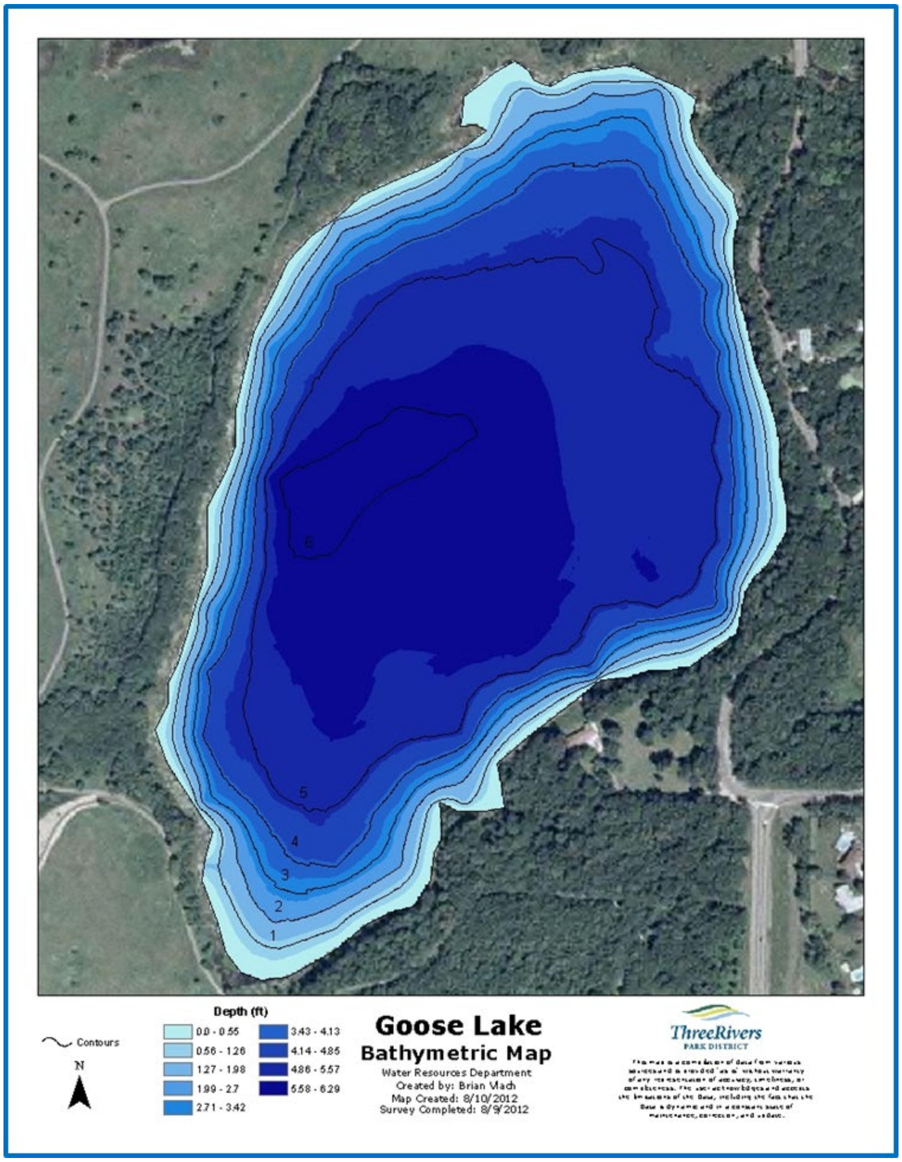
Henry Lake	
DNR ID	27-0175-00
Lake Area	0.190 km^2 (47.0 Acres)
% Littoral (≤ 15 ft in depth)	100%
Mean Depth	0.86 m
Maximum Depth	2.49 m
Mixed Layer Depth	0.86 m
Length	0.36 km
Classification	Shallow Lake
Condition / State	Plant Dominated

Sylvan Lake



Sylvan Lake	
DNR ID	27-0171-00
Lake Area	0.60 km^2 (148.1 Acres)
% Littoral (≤ 15 ft in depth)	100%
Mean Depth	2.15 m
Maximum Depth	4.56 m
Mixed Layer Depth	2.15 m
Length	1.07 km
Classification	Shallow Lake
Condition / State	Algal Dominated

Goose Lake



Goose Lake	
DNR ID	27-0122-00
Lake Area	0.26 km^2 (64.3 Acres)
% Littoral (≤ 15 ft in depth)	100%
Mean Depth	1.29 m
Maximum Depth	1.92 m
Mixed Layer Depth	1.29 m
Classification	Shallow Lake
Condition / State	Algal Dominated

Appendix C2
Bathtub Model Tributary Loading Inputs

Fish Lake Watershed Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
FL1	0.287	0.057	226.5
FL2	1.005	0.194	240.8
FL4	0.697	0.151	197.1
FL5	0.091	0.020	262.4
FL6	0.362	0.091	166.1
FL7	1.872	0.361	210.3
Edward Lake (FL-A13)	0.074	0.018	273.6
Edward Lake	0.398	0.050	114.9
Direct (FL-A34)	1.566	0.298	266.5
Direct (FL-A15)	0.187	0.034	182.8

Rice Lake-Main Watershed Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Fish Lake	8.02	1.22	42.5
EC-77	47.47	11.68	275.0
EC-P53	5.68	0.87	275.0
EC-P78	4.47	1.16	198.0
Rice West Direct (EC-A79)	1.57	0.28	365.0
EC-P85	0.16	0.064	199.4
Rice Main Direct (EC-A89)	3.29	0.95	377.7

Diamond Lake Wateshed Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Diamond-Direct	2.03	0.212	437.3
Grass Lake	8.41	2.696	301.7

Cowley Lake Watershed Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Cowley-Direct	3.35	0.585	324.7

Henry Lake Wateshed Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Henry-Direct	3.28	0.486	645.0

Sylvan Lake Wateshed Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
Sylvan-Direct	1.3	0.249	1198.0

Goose Lake Watershed Inputs			
	Area	Flow Volume	Total Phosphorus
Tributary	km^2	hm^3/yr	µg/L
8T-1.1	0.012	0.0036	300
8T-4.2	0.013	0.0016	273.5
8T-3P	0.093	0.0061	86.6
8T-1P	0.301	0.077	104.2
8T-4P	0.055	0.0098	100.8
Goose Direct	0.497	0.037	250.5

Appendix C3
Internal and Atmospheric Loading for Bathtub Models

The annual internal load input into the Bathtub model compared to the minimum and maximum estimated annual internal load from the Nürnberg equation and curly-leaf pondweed senescence.

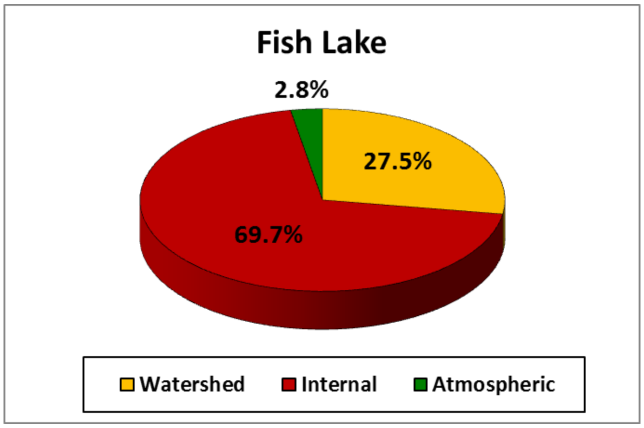
Lake	Internal Load (lbs/year)		
	Estimated		Bathtub
	Minimum	Maximum	Model
Fish	1165.8	1646.9	1577.0
Rice-Main	2628.1	3136.3	3270.3
Diamond	739.7	1338.3	796.5
Cowley	231.9	405.0	418.7
Henry	52.1	224.6	268.7
Sylvan	475.6	833.6	504.4
Goose	131.6	270.2	71.2

The annual atmospheric load input into the Bathtub model.

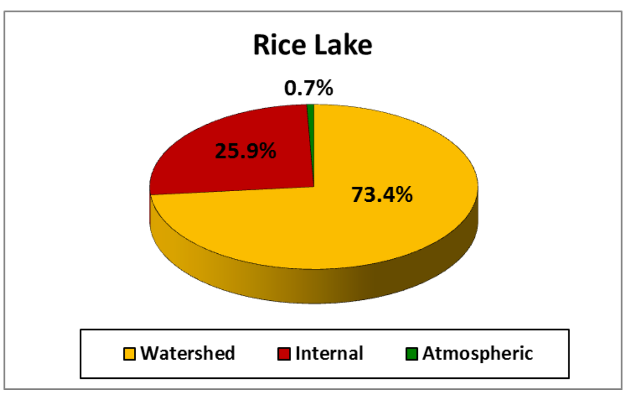
Lake	Atmospheric Load (lbs/year)
Fish	63.5
Rice-Main	88.4
Diamond	103.8
Cowley	8.8
Henry	12.6
Sylvan	39.7
Goose	17.2

Appendix C4
Bathtub Model Nutrient Mass Balance

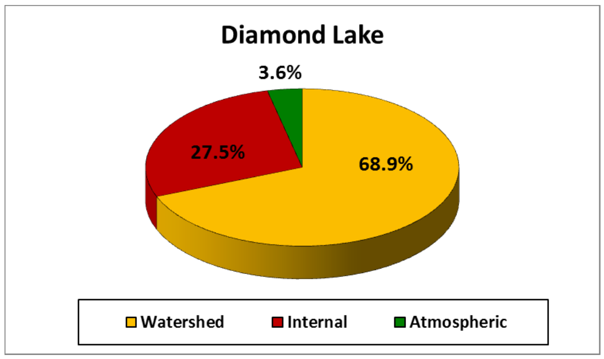
Fish Lake			
	Annual TP Load		
Load	kg/yr	lbs/yr	%
Watershed	282.0	621.7	27.5%
Internal	715.3	1577.0	69.7%
Atmospheric	28.8	63.5	2.8%
Total	1026.1	2262.2	100.0



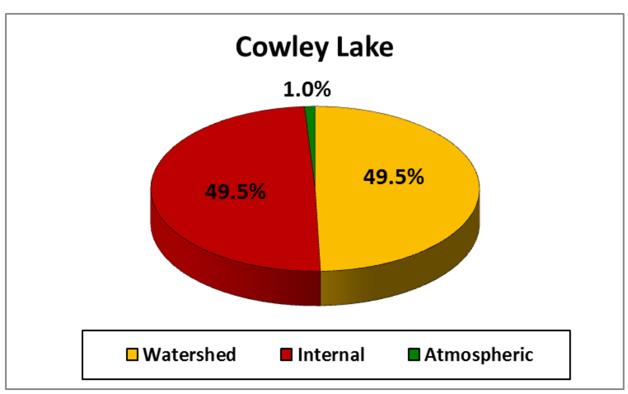
Rice Lake			
	Annual TP Load		
Load	kg/yr	lbs/yr	%
Watershed	4206.6	9274.0	73.4%
Internal	1483.4	3270.3	25.9%
Atmospheric	40.1	88.4	0.7%
Total	5730.1	12632.7	100.0



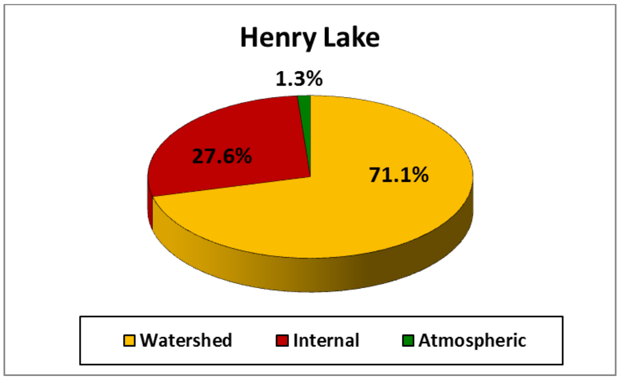
Diamond Lake			
	Annual TP Load		
Load	kg/yr	lbs/yr	%
Watershed	906.1	1997.6	68.9%
Internal	361.3	796.5	27.5%
Atmospheric	47.1	103.8	3.6%
Total	1314.5	2898.0	100.0



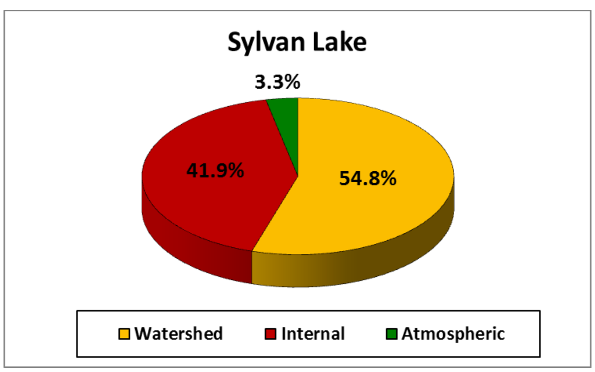
Cowley Lake			
	Annual TP Load		
Load	kg/yr	lbs/yr	%
Watershed	189.9	418.7	49.5%
Internal	189.9	418.7	49.5%
Atmospheric	4.0	8.8	1.0%
Total	383.8	846.1	100.0



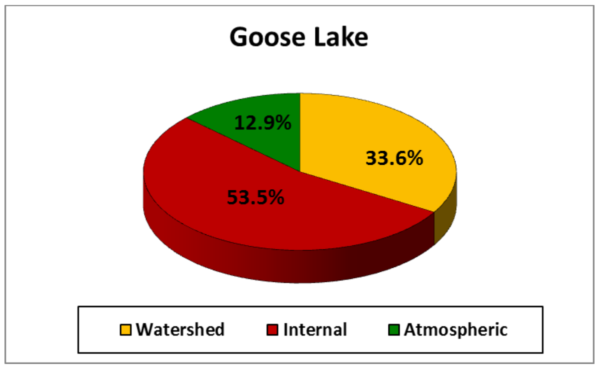
Henry Lake			
	Annual TP Load		
Load	kg/yr	lbs/yr	%
Watershed	313.5	691.1	71.1%
Internal	121.9	268.7	27.6%
Atmospheric	5.7	12.6	1.3%
Total	441.1	972.5	100.0



Sylvan Lake			
	Annual TP Load		
Load	kg/yr	lbs/yr	%
Watershed	298.8	658.7	54.8%
Internal	228.8	504.4	41.9%
Atmospheric	18.0	39.7	3.3%
Total	545.6	1202.8	100.0



Goose Lake			
	Annual TP Load		
Load	kg/yr	lbs/yr	%
Watershed	20.3	44.8	33.6%
Internal	32.3	71.2	53.5%
Atmospheric	7.8	17.2	12.9%
Total	60.4	133.2	100.0



Appendix C5
Bathtub Model Calibration (Predicted versus Observed)

Fish Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	42.0	42.0	2nd Order, Fixed
Chlorophyll-a (µg/L)	21.0	21.0	P, Carlson TSI
Secchi (m)	1.4	1.4	Chlorophyll-a & Turbidity

Rice Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	326.0	326.0	Settling Velocity
Chlorophyll-a (µg/L)	100.4	100.4	P, Linear
Secchi (m)	0.8	0.8	Chlorophyll-a & Turbidity

Diamond Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	145.4	145.3	Canfield & Bachman, Lakes
Chlorophyll-a (µg/L)	42.9	43.0	P, Linear
Secchi (m)	1.3	1.3	Chlorophyll-a & Turbidity

Cowley Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	533.5	533.6	Settling Velocity
Chlorophyll-a (µg/L)	135.9	135.6	P, Linear
Secchi (m)	0.8	0.8	Chlorophyll-a vs Turbidity

Henry Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	149.8	149.9	2nd Order, Fixed
Chlorophyll-a (µg/L)	38.2	38.4	P, Linear
Secchi (m)	0.7	0.7	Chlorophyll-a & Turbidity

Sylvan Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	353.4	353.4	First Order
Chlorophyll-a (µg/L)	69.6	69.8	P, N, Light, T
Secchi (m)	0.3	0.3	Chlorophyll-a & Turbidity

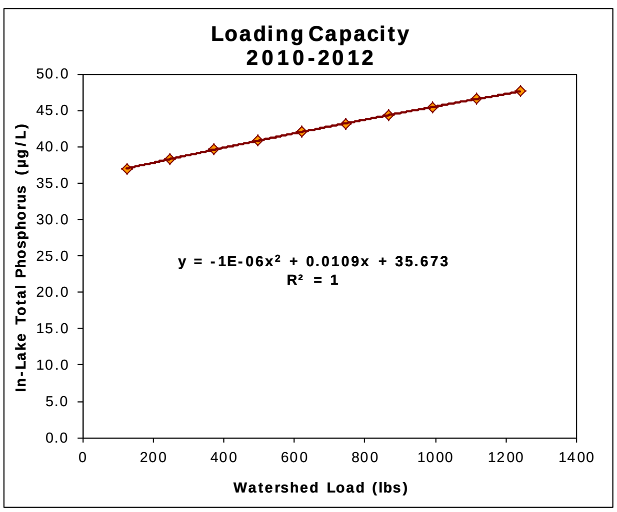
Goose Lake Bathtub Calibration Model Estimates			
Variable	**Predicted**	**Observed**	**Model**
Total Phosphorus (µg/L)	179.7	180.6	2nd Order, Decay
Chlorophyll-a (µg/L)	114.6	114.5	P,N, Low-Turbidity
Secchi (m)	0.3	0.3	Chlorophyll-a & Turbidity

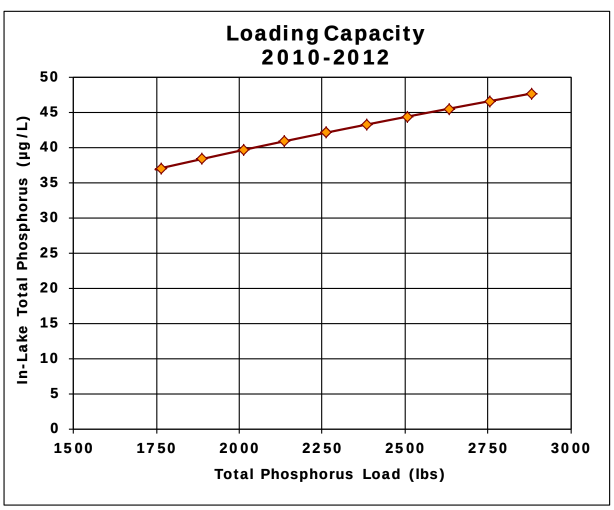
Appendix C6
Bathtub Model Load Response Curves

Fish Lake
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Fish Lake\Fish Lake 2010-2012 (6-3-2015).btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m³	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	1.3	282.0	221.3	42.0	0.21	34.6	51.1	620.336621	2260.797
0.20	1.3	56.4	44.3	37.0	0.21	30.5	44.9	124.067331	1764.527
0.40	1.3	112.8	88.5	38.3	0.21	31.6	46.5	248.134662	1888.595
0.60	1.3	169.2	132.8	39.6	0.21	32.6	48.1	372.20206	2012.662
0.80	1.3	225.6	177.1	40.8	0.21	33.6	49.6	496.269324	2136.729
1.00	1.3	282.0	221.3	42.0	0.21	34.6	51.1	620.336621	2260.797
1.20	1.3	338.4	265.6	43.2	0.21	35.6	52.5	744.40412	2384.864
1.40	1.3	394.8	309.9	44.3	0.21	36.5	53.9	868.471283	2508.931
1.60	1.3	451.2	354.1	45.5	0.22	37.4	55.2	992.538647	2632.999
1.80	1.3	507.5	398.4	46.5	0.22	38.3	56.6	1116.60601	2757.066
2.00	1.3	563.9	442.7	47.6	0.22	39.2	57.9	1240.67324	2881.133

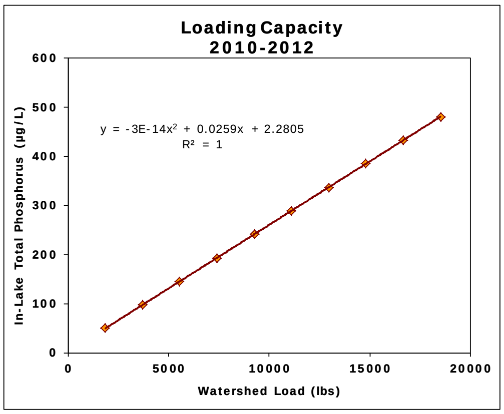
Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
100.0	36.8	1740.46
125.0	37.0	1765.46
150.0	37.3	1790.46
175.0	37.5	1815.46
200.0	37.8	1840.46
225.0	38.1	1865.46
250.0	38.3	1890.46
275.0	38.6	1915.46
300.0	38.9	1940.46
325.0	39.1	1965.46
350.0	39.4	1990.46
375.0	39.6	2015.46
400.0	39.9	2040.46
415.0	40.0	2055.46
425.0	40.1	2065.46
450.0	40.4	2090.46
475.0	40.6	2115.46
495.0	40.8	2135.46
500.0	40.9	2140.46
525.0	41.1	2165.46
550.0	41.4	2190.46
575.0	41.6	2215.46
600.0	41.9	2240.46
620.3	42.0	2260.81
650.0	42.3	2290.46
675.0	42.6	2315.46
700.0	42.8	2340.46
725.0	43.0	2365.46
750.0	43.3	2390.46
775.0	43.5	2415.46
800.0	43.8	2440.46
825.0	44.0	2465.46
850.0	44.2	2490.46
875.0	44.4	2515.46
900.0	44.7	2540.46
925.0	44.9	2565.46
950.0	45.1	2590.46
975.0	45.3	2615.46
1000.0	45.6	2640.46
1025.0	45.8	2665.46
1050.0	46.0	2690.46
1075.0	46.2	2715.46
1100.0	46.5	2740.46

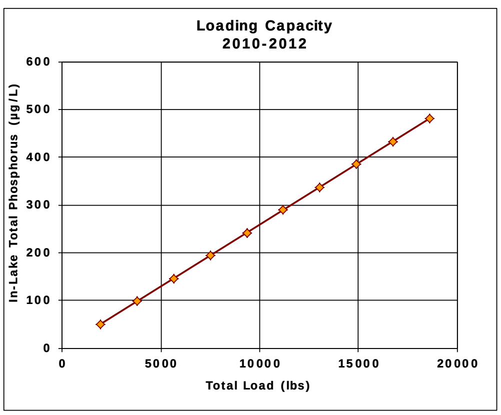




Rice Lake
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Rice Lake\Rice Lake 2010-2012 (8-17-2015).btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m³	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	16.2	4206.6	259.3	241.6	0.16	208.8	279.7	9254.52	9342.92
0.20	16.2	841.3	51.9	50.2	0.15	43.5	57.9	1850.90	1939.30
0.40	16.2	1682.6	103.7	98.0	0.16	84.8	113.3	3701.81	3790.21
0.60	16.2	2524.0	155.6	145.9	0.16	126.1	168.7	5552.71	5641.11
0.80	16.2	3365.3	207.4	193.8	0.16	167.5	224.2	7403.62	7492.02
1.00	16.2	4206.6	259.3	241.6	0.16	208.8	279.7	9254.52	9342.92
1.20	16.2	5047.9	311.1	289.5	0.16	250.1	335.1	11105.42	11193.82
1.40	16.2	5889.2	363.0	337.4	0.16	291.4	390.6	12956.33	13044.73
1.60	16.2	6730.6	414.9	385.2	0.16	332.7	446.1	14807.23	14895.63
1.80	16.2	7571.9	466.7	433.1	0.16	374.0	501.5	16658.14	16746.54
2.00	16.2	8413.2	518.6	481.0	0.16	415.3	557.0	18509.04	18597.44

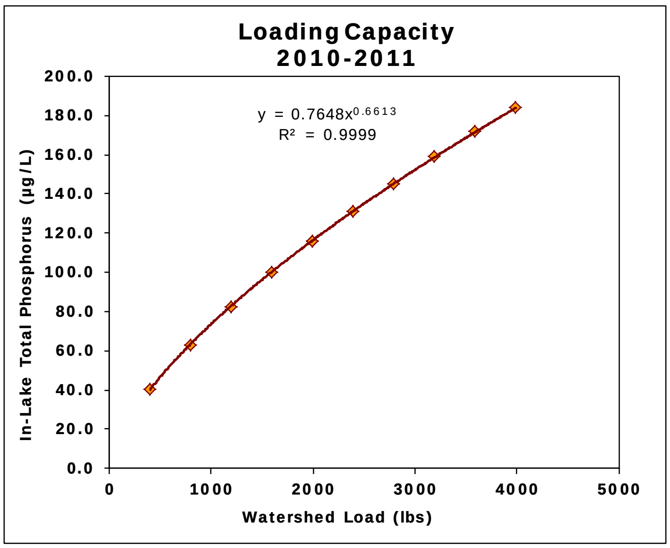


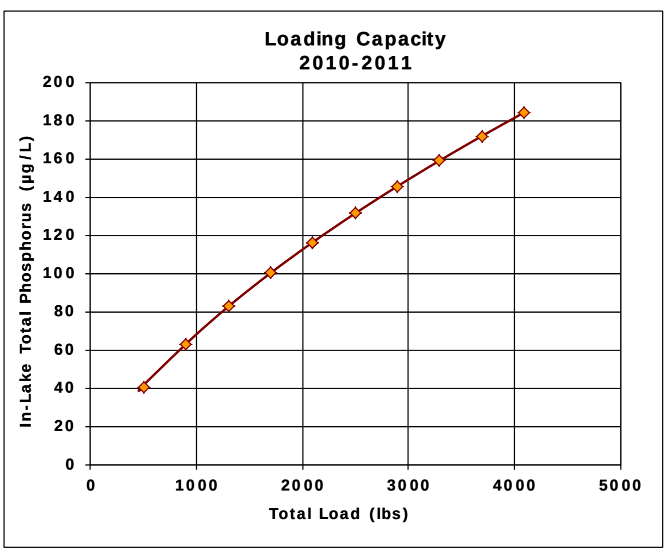


Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
2000	54.1	2088.4
2100	56.7	2188.4
2200	59.3	2288.4
2227	60.0	2315.4
2300	61.9	2388.4
2400	64.4	2488.4
2500	67.0	2588.4
2600	69.6	2688.4
2700	72.2	2788.4
2800	74.8	2888.4
2900	77.4	2988.4
3000	80.0	3088.4
3100	82.6	3188.4
3200	85.2	3288.4
3300	87.8	3388.4
3400	90.3	3488.4
3500	92.9	3588.4
3600	95.5	3688.4
3700	98.1	3788.4
3765	99.8	3853.4
3900	103.3	3988.4
4000	105.9	4088.4
4100	108.5	4188.4
4200	111.1	4288.4
4300	113.7	4388.4
4400	116.2	4488.4
4500	118.8	4588.4
4600	121.4	4688.4
4700	124.0	4788.4
4800	126.6	4888.4
4900	129.2	4988.4
5000	131.8	5088.4
5100	134.4	5188.4
5200	137.0	5288.4
5300	139.6	5388.4
5400	142.1	5488.4
5500	144.7	5588.4
5600	147.3	5688.4
5700	149.9	5788.4
5800	152.5	5888.4
5900	155.1	5988.4
6000	157.7	6088.4
6100	160.3	6188.4
6200	162.9	6288.4
6300	165.5	6388.4
6400	168.0	6488.4
6500	170.6	6588.4
6600	173.2	6688.4
6700	175.8	6788.4
6800	178.4	6888.4
6900	181.0	6988.4
7000	183.6	7088.4
7100	186.2	7188.4
7200	188.8	7288.4
7300	191.4	7388.4
7400	193.9	7488.4
7500	196.5	7588.4
7600	199.1	7688.4
7700	201.7	7788.4
7800	204.3	7888.4
7900	206.9	7988.4
8000	209.5	8088.4
8100	212.1	8188.4
8200	214.7	8288.4
8300	217.3	8388.4
8400	219.8	8488.4
8500	222.4	8588.4
8600	225.0	8688.4
8700	227.6	8788.4
8800	230.2	8888.4
8900	232.8	8988.4
9000	235.4	9088.4
9100	238.0	9188.4
9200	240.6	9288.4
9300	243.2	9388.4
9400	245.7	9488.4
9500	248.3	9588.4
9600	250.9	9688.4
9700	253.5	9788.4
9800	256.1	9888.4
9900	258.7	9988.4
10000	261.3	10088.4
10100	263.9	10188.4
10200	266.5	10288.4
10300	269.1	10388.4
10400	271.6	10488.4
10500	274.2	10588.4
10600	276.8	10688.4
10700	279.4	10788.4
10800	282.0	10888.4
10900	284.6	10988.4
11000	287.2	11088.4
11100	289.8	11188.4
11200	292.4	11288.4
11300	295.0	11388.4
11400	297.5	11488.4
11500	300.1	11588.4
11600	302.7	11688.4
11700	305.3	11788.4
11800	307.9	11888.4
11900	310.5	11988.4
12000	313.1	12088.4
12100	315.7	12188.4
12200	318.3	12288.4
12300	320.9	12388.4
12400	323.4	12488.4
12500	326.0	12588.4
12600	328.6	12688.4

Diamond Lake
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Diamond Lake\Diamond Lake 2010-2011 Grass Lake Outlet (8-18-2015).btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m^3	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	2.9	906.1	311.6	116.2	0.29	90.4	149.5	1993.40	2097.24
0.20	2.9	181.2	62.3	40.4	0.23	32.8	49.7	398.68	502.52
0.40	2.9	362.4	124.6	63.0	0.25	50.4	78.7	797.36	901.20
0.60	2.9	543.7	187.0	82.5	0.27	65.3	104.4	1196.04	1299.88
0.80	2.9	724.9	249.3	100.1	0.28	78.4	127.8	1594.72	1698.56
1.00	2.9	906.1	311.6	116.2	0.29	90.4	149.5	1993.40	2097.24
1.20	2.9	1087.3	373.9	131.3	0.29	101.5	169.8	2392.08	2495.92
1.40	2.9	1268.5	436.2	145.4	0.30	111.9	189.1	2790.76	2894.60
1.60	2.9	1449.7	498.5	158.9	0.31	121.7	207.5	3189.44	3293.28
1.80	2.9	1631.0	560.9	171.7	0.31	131.1	225.0	3588.12	3691.96
2.00	2.9	1812.2	623.2	184.0	0.31	140.0	241.9	3986.80	4090.64



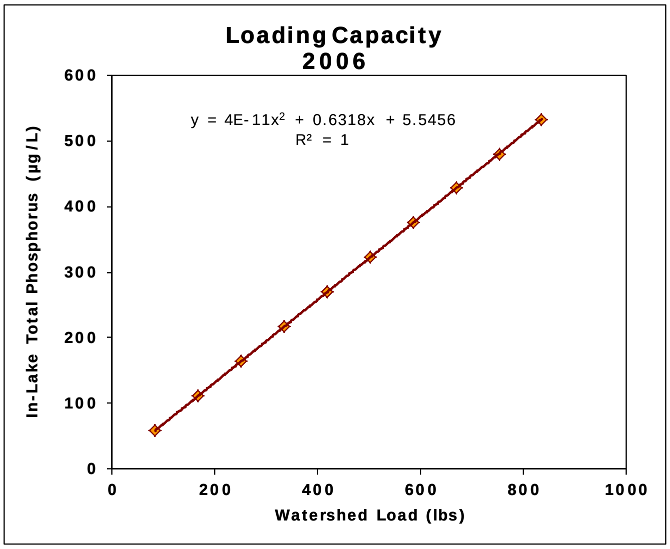


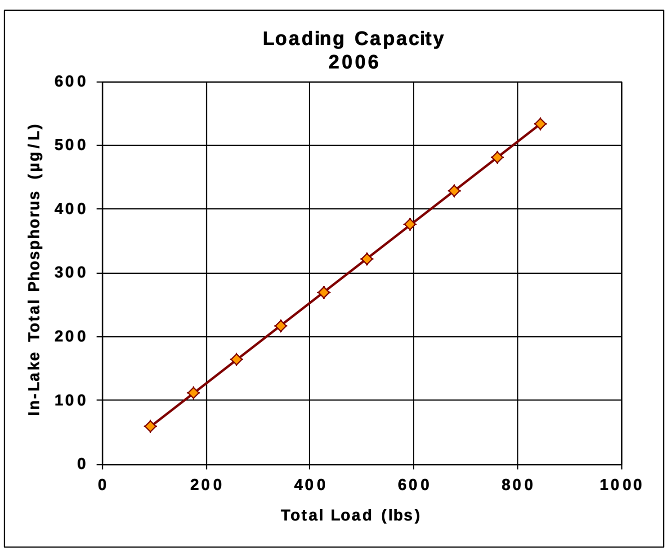
Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
550.0	49.6	653.8
600.0	52.6	703.8
650.0	55.4	753.8
700.0	58.2	803.8
732.0	60.0	835.8
753.0	61.1	856.8
800.0	63.6	903.8
850.0	66.2	953.8
900.0	68.7	1003.8
950.0	71.2	1053.8
1000.0	73.7	1103.8
1050.0	76.1	1153.8
1100.0	78.5	1203.8
1150.0	80.8	1253.8
1200.0	83.1	1303.8
1250.0	85.4	1353.8
1300.0	87.7	1403.8
1350.0	89.9	1453.8
1400.0	92.1	1503.8
1450.0	94.2	1553.8
1500.0	96.4	1603.8
1550.0	98.5	1653.8
1575.9	99.6	1679.7
1600.0	100.6	1703.8
1650.0	102.6	1753.8
1700.0	104.7	1803.8
1750.0	106.7	1853.8
1800.0	108.7	1903.8
1850.0	110.7	1953.8
1900.0	112.7	2003.8
1950.0	114.6	2053.8
2000.0	116.6	2103.8
2050.0	118.5	2153.8
2100.0	120.4	2203.8
2150.0	122.3	2253.8
2200.0	124.1	2303.8
2250.0	126.0	2353.8
2300.0	127.8	2403.8
2350.0	129.7	2453.8
2400.0	131.5	2503.8
2450.0	133.3	2553.8
2500.0	135.1	2603.8
2550.0	136.9	2653.8
2600.0	138.6	2703.8
2650.0	140.4	2753.8
2700.0	142.1	2803.8
2750.0	143.9	2853.8
2800.0	145.6	2903.8
2850.0	147.3	2953.8
2900.0	149.0	3002.1

Cowley Lake
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Cowley Lake\Cowley 2006 (8-19-2015).btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m3	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	0.6	189.9	324.7	269.6	0.08	248.8	292.0	417.89	426.71
0.20	0.6	38.0	64.9	58.3	0.10	53.3	63.9	83.58	92.40
0.40	0.6	76.0	129.9	111.1	0.09	102.3	120.8	167.16	175.98
0.60	0.6	114.0	194.8	163.9	0.08	151.2	177.8	250.73	259.55
0.80	0.6	152.0	259.8	216.8	0.08	200.0	234.9	334.31	343.13
1.00	0.6	189.9	324.7	269.6	0.08	248.8	292.0	417.89	426.71
1.20	0.6	227.9	389.6	322.4	0.08	297.6	349.2	501.47	510.29
1.40	0.6	265.9	454.6	375.2	0.08	346.4	406.3	585.04	593.86
1.60	0.6	303.9	519.5	428.0	0.08	395.2	463.5	668.62	677.44
1.80	0.6	341.9	584.5	480.8	0.08	443.9	520.6	752.20	761.02
2.00	0.6	379.9	649.4	533.6	0.08	492.7	577.8	835.78	844.60

Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
85.0	59.2	93.8
86.2	60.0	95.0
90.0	62.4	98.8
100.0	68.7	108.8
110.0	75.0	118.8
120.0	81.4	128.8
130.0	87.7	138.8
140.0	94.0	148.8
150.0	100.3	158.8
160.0	106.6	168.8
170.0	113.0	178.8
180.0	119.3	188.8
190.0	125.6	198.8
200.0	131.9	208.8
210.0	138.2	218.8
220.0	144.5	228.8
230.0	150.9	238.8
240.0	157.2	248.8
250.0	163.5	258.8
260.0	169.8	268.8
270.0	176.1	278.8
280.0	182.4	288.8
290.0	188.8	298.8
300.0	195.1	308.8
310.0	201.4	318.8
320.0	207.7	328.8
330.0	214.0	338.8
340.0	220.4	348.8
350.0	226.7	358.8
360.0	233.0	368.8
370.0	239.3	378.8
380.0	245.6	388.8
390.0	251.9	398.8
400.0	258.3	408.8
410.0	264.6	418.8
420.0	270.9	428.8
430.0	277.2	438.8
440.0	283.5	448.8
450.0	289.9	458.8
460.0	296.2	468.8
470.0	302.5	478.8
480.0	308.8	488.8

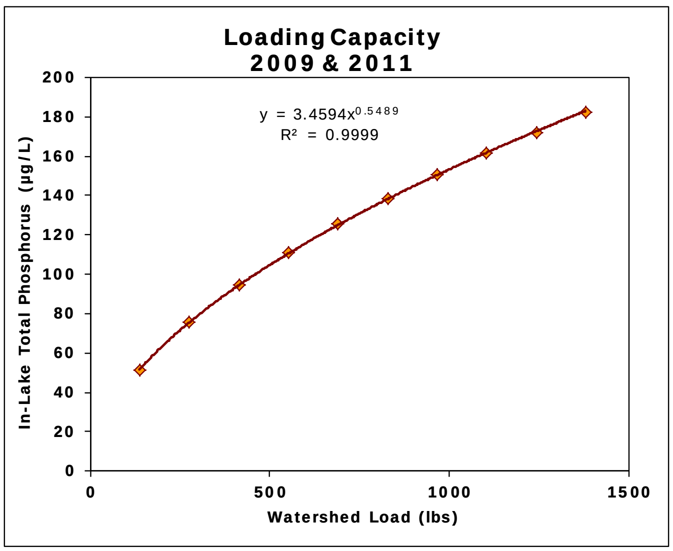


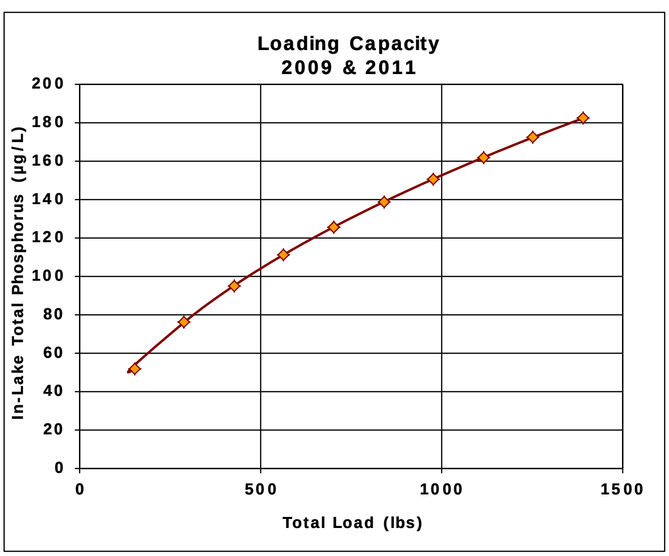


Henry Lake
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Henry Lake\Henry Lake 2009 & 2011 (8-19-2015).btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m^3	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	0.5	313.5	645.0	125.4	0.20	104.8	150.1	689.63	702.23
0.20	0.5	62.7	129.0	51.4	0.17	43.8	60.3	137.93	150.53
0.40	0.5	125.4	258.0	75.7	0.18	63.9	89.7	275.85	288.45
0.60	0.5	188.1	387.0	94.8	0.19	79.6	112.9	413.78	426.38
0.80	0.5	250.8	516.0	111.1	0.19	93.0	132.7	551.71	564.31
1.00	0.5	313.5	645.0	125.4	0.20	104.8	150.1	689.63	702.23
1.20	0.5	376.2	774.0	138.4	0.20	115.5	166.0	827.56	840.16
1.40	0.5	438.9	903.0	150.4	0.20	125.3	180.6	965.49	978.09
1.60	0.5	501.6	1032.0	161.6	0.20	134.5	194.2	1103.41	1116.01
1.80	0.5	564.2	1161.0	172.1	0.20	143.1	207.0	1241.34	1253.94
2.00	0.5	626.9	1290.0	182.1	0.20	151.3	219.2	1379.27	1391.87

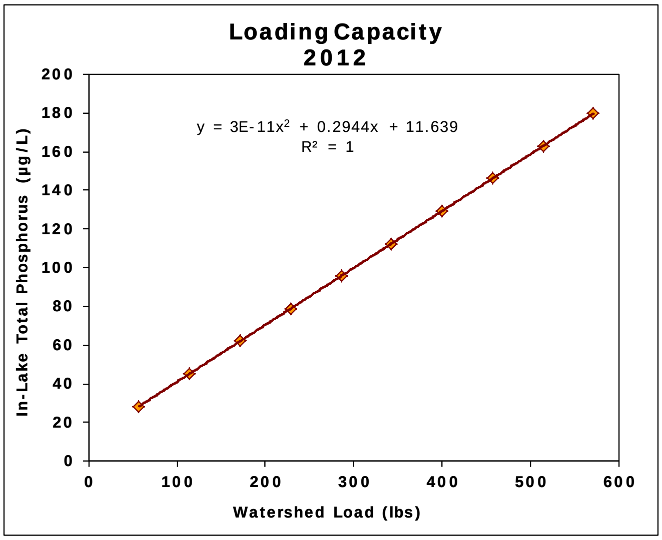
Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
150.0	54.1	162.6
175.0	58.9	187.6
181.0	60.0	193.6
200.0	63.4	212.6
225.0	67.6	237.6
250.0	71.7	262.6
275.0	75.5	287.6
300.0	79.2	312.6
325.0	82.8	337.6
350.0	86.2	362.6
375.0	89.5	387.6
400.0	92.7	412.6
425.0	95.9	437.6
450.0	98.9	462.6
475.0	101.9	487.6
500.0	104.8	512.6
525.0	107.7	537.6
550.0	110.5	562.6
575.0	113.2	587.6
600.0	115.9	612.6
625.0	118.5	637.6
650.0	121.1	662.6
675.0	123.6	687.6
700.0	126.1	712.6
725.0	128.5	737.6
750.0	131.0	762.6
775.0	133.3	787.6
800.0	135.7	812.6
825.0	138.0	837.6
850.0	140.3	862.6
875.0	142.5	887.6
900.0	144.7	912.6
925.0	146.9	937.6
950.0	149.1	962.6
975.0	151.2	987.6
1000.0	153.4	1012.6
1025.0	155.4	1037.6
1050.0	157.5	1062.6
1075.0	159.6	1087.6
1100.0	161.6	1112.6
1125.0	163.6	1137.6
1150.0	165.6	1162.6

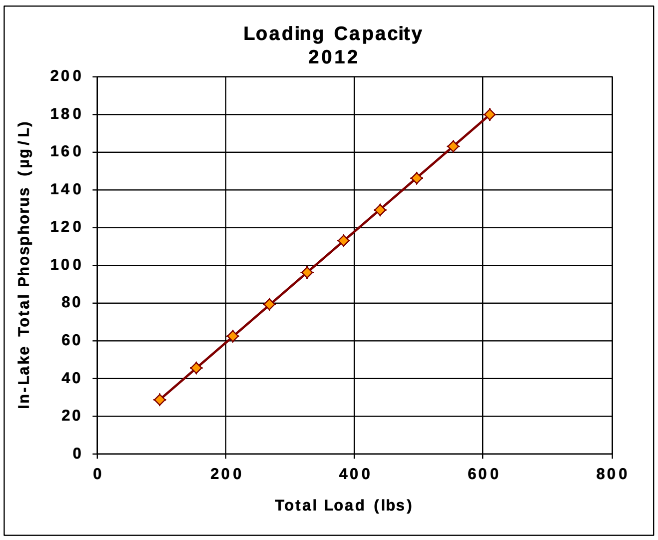




Sylvan Lake
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Sylvan\Sylvan Lake 9-10-2015.btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc TOTAL P MG/M3 mg/m^3	Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	0.2	129.8	520.5	95.7	0.37	69.8	131.3	285.60	325.28
0.20	0.2	26.0	104.1	28.5	0.42	20.0	40.4	57.12	96.80
0.40	0.2	51.9	208.2	45.3	0.39	32.6	62.8	114.24	153.92
0.60	0.2	77.9	312.3	62.1	0.38	45.1	85.6	171.36	211.04
0.80	0.2	103.9	416.4	78.9	0.37	57.4	108.4	228.48	268.16
1.00	0.2	129.8	520.5	95.7	0.37	69.8	131.3	285.60	325.28
1.20	0.2	155.8	624.6	112.5	0.37	82.2	154.2	342.72	382.40
1.40	0.2	181.7	728.8	129.4	0.37	94.5	177.1	399.84	439.52
1.60	0.2	207.7	832.9	146.2	0.37	106.8	200.0	456.96	496.64
1.80	0.2	233.7	937.0	163.0	0.37	119.1	223.0	514.08	553.76
2.00	0.2	259.6	1041.1	179.8	0.37	131.5	245.9	571.20	610.88

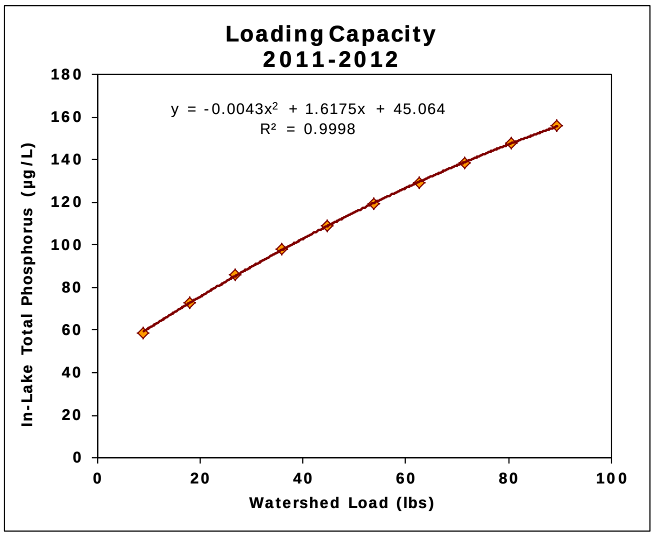


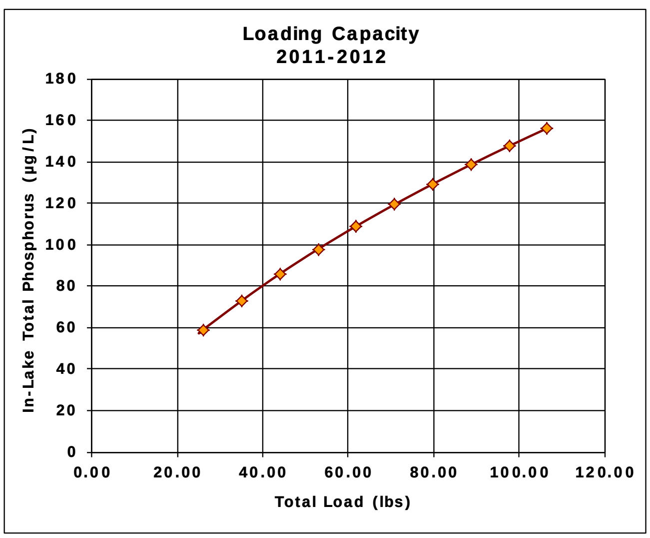


Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
150.0	55.8	189.7
160.0	58.7	199.7
164.3	60.0	204.0
170.0	61.7	209.7
180.0	64.6	219.7
200.0	70.5	239.7
220.0	76.4	259.7
240.0	82.3	279.7
260.0	88.2	299.7
280.0	94.1	319.7
300.0	100.0	339.7
320.0	105.8	359.7
340.0	111.7	379.7
360.0	117.6	399.7
380.0	123.5	419.7
400.0	129.4	439.7
420.0	135.3	459.7
440.0	141.2	479.7
460.0	147.1	499.7
480.0	153.0	519.7
500.0	158.8	539.7
520.0	164.7	559.7
540.0	170.6	579.7
560.0	176.5	599.7
580.0	182.4	619.7
600.0	188.3	639.7
620.0	194.2	659.7
640.0	200.1	679.7
660.0	205.9	699.7
680.0	211.8	719.7
700.0	217.7	739.7
720.0	223.6	759.7
740.0	229.5	779.7
760.0	235.4	799.7
780.0	241.3	819.7
800.0	247.2	839.7
820.0	253.0	859.7
840.0	258.9	879.7
860.0	264.8	899.7
880.0	270.7	919.7
900.0	276.6	939.7
920.0	282.5	959.7

Goose Lake
File: C:\Documents and Settings\nri\My Documents\BATHTUB\Elm Creek\Goose Lake\Goose Lake with TN 9-8-2014.btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m^3	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	0.1	20.3	150.4	108.9	0.37	79.8	148.8	44.72	61.92
0.20	0.1	4.1	30.1	58.6	0.45	40.3	85.1	8.94	26.14
0.40	0.1	8.1	60.2	72.9	0.41	51.7	102.8	17.89	35.09
0.60	0.1	12.2	90.3	85.9	0.39	61.9	119.2	26.83	44.03
0.80	0.1	16.3	120.4	97.8	0.37	71.2	134.5	35.77	52.97
1.00	0.1	20.3	150.4	108.9	0.37	79.8	148.8	44.72	61.92
1.20	0.1	24.4	180.5	119.4	0.36	87.8	162.3	53.66	70.86
1.40	0.1	28.5	210.6	129.2	0.36	95.3	175.2	62.60	79.80
1.60	0.1	32.5	240.7	138.6	0.35	102.5	187.4	71.55	88.75
1.80	0.1	36.6	270.8	147.6	0.35	109.4	199.1	80.49	97.69
2.00	0.1	40.7	300.9	156.2	0.35	115.9	210.4	89.43	106.63





Watershed Load lbs / yr	TP µg / L	Total Load lbs / yr
8.0	57.7	25.2
9.0	59.3	26.2
9.5	60.0	26.7
10.0	60.8	27.2
11.0	62.3	28.2
12.0	63.9	29.2
13.0	65.4	30.2
14.0	66.9	31.2
15.0	68.4	32.2
16.0	69.8	33.2
17.0	71.3	34.2
18.0	72.8	35.2
19.0	74.2	36.2
20.0	75.7	37.2
21.0	77.1	38.2
22.0	78.6	39.2
23.0	80.0	40.2
24.0	81.4	41.2
25.0	82.8	42.2
26.0	84.2	43.2
27.0	85.6	44.2
28.0	87.0	45.2
29.0	88.4	46.2
30.0	89.7	47.2
31.0	91.1	48.2
32.0	92.4	49.2
33.0	93.8	50.2
34.0	95.1	51.2
35.0	96.4	52.2
36.0	97.7	53.2
37.0	99.0	54.2
38.0	100.3	55.2
39.0	101.6	56.2
40.0	102.9	57.2
41.0	104.2	58.2
42.0	105.4	59.2
43.0	106.7	60.2
44.0	107.9	61.2
45.0	109.1	62.2
46.0	110.4	63.2
47.0	111.6	64.2
48.0	112.8	65.2

Appendix C7
Bathtub Model Inputs and Outputs

Fish Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Fish Lake\Fish Lake 2010-2012 (6-3-2015).btb**

Description:

one segment

suggested default values for model options & model coefficients

nitrogen budgets not modeled

phosphorus budgets based upon total P only
availability factors ignored

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	3	2ND ORDER, FIXED
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	6	P, CARLSON TSI
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Fish Lake	0	1	0.96	5.73	2.35	4.8	0.12	2.27	0	0.08	0.2	0	0	2.04	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	42	0	0	0	21	0	1.42	0	0	0	0	0	105	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1.07	0	0.85	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	FL5	1	1	0.091	0.02	0.1	0	0	262.4	0.2	0	0	0	0	0	0
2	FL4	1	1	0.697	0.151	0.1	0	0	197.1	0.2	0	0	0	0	0	0
3	FL7	1	1	1.872	0.361	0.1	0	0	210.3	0.2	0	0	0	0	0	0
4	FL6	1	1	0.362	0.091	0	0	0	166.1	0	0	0	0	0	0	0
5	Direct (FL-A34)	1	1	1.566	0.298	0	0	0	266.5	0	0	0	0	0	0	0
6	Direct (FL-A15)	1	1	0.187	0.034	0	0	0	182.8	0	0	0	0	0	0	0
7	Edward Lake (FL-A13)	1	1	0.074	0.018	0	0	0	273.6	0	0	0	0	0	0	0
8	FL1	1	1	0.287	0.057	0	0	0	226.5	0	0	0	0	0	0	0
9	FL2	1	1	1.005	0.194	0	0	0	240.8	0	0	0	0	0	0	0
10	Edward Lake	1	1	0.398	0.05	0	0	0	114.9	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Fish Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Fish Lake\Fish Lake 2010-2012 (6-3-2015).btb

Segment Mass Balance Based Upon Predicted Concentrations

Component:		**TOTAL P**		**Segment:**	**1**	**Fish Lake**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
1	1	FL5	0.0	1.0%	5.2	0.5%	262
2	1	FL4	0.2	7.7%	29.8	2.9%	197
3	1	FL7	0.4	18.4%	75.9	7.4%	210
4	1	FL6	0.1	4.7%	15.1	1.5%	166
5	1	Direct (FL-A34)	0.3	15.2%	79.4	7.7%	267
6	1	Direct (FL-A15)	0.0	1.7%	6.2	0.6%	183
7	1	Edward Lake (FL-A13)	0.0	0.9%	4.9	0.5%	274
8	1	FL1	0.1	2.9%	12.9	1.3%	227
9	1	FL2	0.2	9.9%	46.7	4.6%	241
10	1	Edward Lake	0.1	2.6%	5.7	0.6%	115
PRECIPITATION			0.7	34.9%	28.8	2.8%	42
INTERNAL LOAD			0.0	0.0%	715.3	69.7%	
TRIBUTARY INFLOW			1.3	65.1%	282.0	27.5%	221
***TOTAL INFLOW			2.0	100.0%	1026.1	100.0%	524
ADVECTIVE OUTFLOW			1.3	65.7%	54.0	5.3%	42
***TOTAL OUTFLOW			1.3	65.7%	54.0	5.3%	42
***EVAPORATION			0.7	34.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	972.1	94.7%	

Hyd. Residence Time =	4.2816	yrs
Overflow Rate =	1.3	m/yr
Mean Depth =	5.7	m

Fish Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Fish Lake\Fish Lake 2010-2012 (6-3-2015).btb**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Fish Lake**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	42.0	0.21	44.2%	42.0		44.2%
CHL-A MG/M3	21.0	0.40	85.3%	21.0		85.2%
SECCHI M	1.4	0.37	63.4%	1.4		64.1%
ORGANIC N MG/M3	642.9	0.33	72.5%			
TP-ORTHO-P MG/M3	35.3	0.46	56.7%			
HOD-V MG/M3-DAY	485.0	0.25	99.3%	105.0		66.1%
MOD-V MG/M3-DAY	264.9	0.33	97.2%			
ANTILOG PC-1	391.7	0.72	64.0%	386.3		63.6%
ANTILOG PC-2	13.8	0.08	92.6%	13.9		92.8%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.4	0.23	0.3%	0.4	0.23	0.3%
ZMIX / SECCHI	3.4	0.38	28.4%	3.4	0.12	27.7%
CHL-A * SECCHI	29.5	0.12	93.3%	29.8		93.5%
CHL-A / TOTAL P	0.5	0.28	93.0%	0.5		93.0%
FREQ(CHL-a>10) %	81.3	0.22	85.3%	81.2		85.2%
FREQ(CHL-a>20) %	41.0	0.62	85.3%	40.8		85.2%
FREQ(CHL-a>30) %	18.9	0.93	85.3%	18.8		85.2%
FREQ(CHL-a>40) %	8.9	1.18	85.3%	8.9		85.2%
FREQ(CHL-a>50) %	4.4	1.38	85.3%	4.4		85.2%
FREQ(CHL-a>60) %	2.3	1.55	85.3%	2.3		85.2%
CARLSON TSI-P	58.1	0.05	44.2%	58.0		44.2%
CARLSON TSI-CHLA	60.5	0.07	85.3%	60.5		85.2%
CARLSON TSI-SEC	55.1	0.10	36.6%	54.9		35.9%

Rice Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Rice Lake\Rice Lake 2010-2012 (8-17-2015).btb**

Description:

one segment

suggested default values for model options & model coefficients

nitrogen budgets not modeled

phosphorus budgets based upon total P only
availability factors ignored

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km²-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	7	SETTLING VELOCITY
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	4	P, LINEAR
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Rice Lake	0	1	1.336	2.14	1.6	2.14	0.12	0	0	0.08	0.2	0	0	3.04	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	326	0	0	0	100.4	0	0.81	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1.1	0	2	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	EC-77	1	1	47.47	11.68	0.1	0	0	275	0.2	0	0	0	0	0	0
2	EC-P53	1	1	5.68	0.87	0.1	0	0	275	0.2	0	0	0	0	0	0
3	EC-P78	1	1	4.47	1.16	0.1	0	0	198.03	0.2	0	0	0	0	0	0
4	Rice West Direct (EC-A79)	1	1	1.57	0.28	0	0	0	365.03	0	0	0	0	0	0	0
5	Rice Main Direct (EC-A89)	1	1	3.29	0.95	0	0	0	377.7	0	0	0	0	0	0	0
6	EC-P85	1	1	0.16	0.064	0	0	0	199.4	0	0	0	0	0	0	0
7	Fish Lake	1	1	8.02	1.22	0	0	0	42.5	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Rice Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Rice Lake\Rice Lake 2010-2012 (8-17-2015).btb

Segment Mass Balance Based Upon Predicted Concentrations

Component:		**TOTAL P**	**Segment:**		**1**	**Rice Lake**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	EC-77	11.7	68.0%	3212.0	56.1%	275
2	1	EC-P53	0.9	5.1%	239.3	4.2%	275
3	1	EC-P78	1.2	6.8%	229.7	4.0%	198
4	1	Rice West Direct (EC-A79)	0.3	1.6%	102.2	1.8%	365
5	1	Rice Main Direct (EC-A89)	0.9	5.5%	358.8	6.3%	378
6	1	EC-P85	0.1	0.4%	12.8	0.2%	199
7	1	Fish Lake	1.2	7.1%	51.9	0.9%	43
PRECIPITATION			1.0	5.5%	40.1	0.7%	42
INTERNAL LOAD			0.0	0.0%	1483.4	25.9%	
TRIBUTARY INFLOW			16.2	94.5%	4206.6	73.4%	259
***TOTAL INFLOW			17.2	100.0%	5730.1	100.0%	334
ADVECTIVE OUTFLOW			16.2	94.6%	5294.5	92.4%	326
***TOTAL OUTFLOW			16.2	94.6%	5294.5	92.4%	326
***EVAPORATION			0.9	5.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	435.6	7.6%	

Hyd. Residence Time =	0.1761	yrs
Overflow Rate =	12.2	m/yr
Mean Depth =	2.1	m

Rice Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Rice Lake\Rice Lake 2010-2012 (8-17-2015).btb**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Rice Lake**

Variable	Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P MG/M3	326.0	0.12	98.3%	326.0		98.3%
CHL-A MG/M3	100.4	0.29	99.9%	100.4		99.9%
SECCHI M	0.8	0.29	32.9%	0.8		35.3%
ORGANIC N MG/M3	2452.6	0.29	99.9%			
TP-ORTHO-P MG/M3	176.5	0.33	96.9%			
ANTILOG PC-1	3009.6	0.54	97.2%	2877.4		97.0%
ANTILOG PC-2	24.7	0.08	99.5%	25.7		99.6%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.2	0.23	0.0%	0.2	0.23	0.0%
ZMIX / SECCHI	2.8	0.32	17.5%	2.6	0.12	15.5%
CHL-A * SECCHI	77.5	0.10	99.8%	81.3		99.8%
CHL-A / TOTAL P	0.3	0.26	76.1%	0.3		76.1%
FREQ(CHL-a>10) %	100.0	0.00	99.9%	100.0		99.9%
FREQ(CHL-a>20) %	98.9	0.01	99.9%	98.9		99.9%
FREQ(CHL-a>30) %	94.9	0.05	99.9%	94.9		99.9%
FREQ(CHL-a>40) %	88.0	0.10	99.9%	88.0		99.9%
FREQ(CHL-a>50) %	79.2	0.16	99.9%	79.2		99.9%
FREQ(CHL-a>60) %	69.9	0.22	99.9%	69.9		99.9%
CARLSON TSI-P	87.6	0.02	98.3%	87.6		98.3%
CARLSON TSI-CHLA	75.8	0.04	99.9%	75.8		99.9%
CARLSON TSI-SEC	63.7	0.07	67.1%	63.0		64.7%

Diamond Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Diamond Lake\Diamond Lake 2010-2011 Grass Lake Outlet (8-18-2015).btb

Description:

Diamond Lake Model for 2010-2011

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.69	0.0
Evaporation (m)	0.7	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	5	BACHMAN FLUSHING
Chlorophyll-a	4	P, LINEAR
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Diamond Lake	0	1	1.57	1.21	1.63	1.21	0	1	0	0.08	0	0	0	0.63	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	145.3	0	2000	0	43	0	1.3	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	0.28	0	1.055	0	1.5	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	Flow CV	Conserv. Mean	Conserv. CV	Total P (ppb) Mean	Total P (ppb) CV	Total N (ppb) Mean	Total N (ppb) CV	Ortho P (ppb) Mean	Ortho P (ppb) CV	Inorganic N (ppb) Mean	Inorganic N (ppb) CV
1	Diamond-Direct	1	1	2.03	0.212	0	0	0	437.3	0	2780	0	161.1	0	0	0
2	Upstream-Grass Lake	1	1	8.41	2.696	0	0	0	301.7	0	1690	0	111	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Diamond Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Diamond Lake\Diamond Lake 2010-2011 Grass Lake Outlet (8-18-2015).btb

Segment Mass Balance Based Upon Predicted Concentrations

Component: TOTAL P **Segment: 1 Diamond Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Diamond-Direct	0.2	5.3%	92.7	7.1%	437
2	1	Upstream-Grass Lake	2.7	67.5%	813.4	61.9%	302
PRECIPITATION			1.1	27.1%	47.1	3.6%	43
INTERNAL LOAD			0.0	0.0%	361.3	27.5%	
TRIBUTARY INFLOW			2.9	72.9%	906.1	68.9%	312
***TOTAL INFLOW			4.0	100.0%	1314.5	100.0%	329
ADVECTIVE OUTFLOW			2.9	72.5%	420.4	32.0%	145
***TOTAL OUTFLOW			2.9	72.5%	420.4	32.0%	145
***EVAPORATION			1.1	27.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	894.1	68.0%	

Hyd. Residence Time = 0.6568 yrs
Overflow Rate = 1.8 m/yr
Mean Depth = 1.2 m

Component: TOTAL N **Segment: 1 Diamond Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Diamond-Direct	0.2	5.3%	589.4	8.8%	2780
2	1	Upstream-Grass Lake	2.7	67.5%	4556.2	67.8%	1690
PRECIPITATION			1.1	27.1%	1570.0	23.4%	1449
TRIBUTARY INFLOW			2.9	72.9%	5145.6	76.6%	1769
***TOTAL INFLOW			4.0	100.0%	6715.6	100.0%	1683
ADVECTIVE OUTFLOW			2.9	72.5%	5786.3	86.2%	2001
***TOTAL OUTFLOW			2.9	72.5%	5786.3	86.2%	2001
***EVAPORATION			1.1	27.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	929.3	13.8%	

Hyd. Residence Time = 0.6568 yrs
Overflow Rate = 1.8 m/yr
Mean Depth = 1.2 m

Diamond Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Diamond Lake\Diamond Lake 2010-2011 Grass Lake Outlet (8-18-2015).btb**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Diamond Lake**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	145.4	0.30	89.1%	145.3		89.1%
TOTAL N MG/M3	2000.6	0.14	86.0%	2000.0		86.0%
C.NUTRIENT MG/M3	105.8	0.18	91.3%	105.7		91.3%
CHL-A MG/M3	42.9	0.40	97.6%	43.0		97.6%
SECCHI M	1.3	0.38	59.7%	1.3		59.6%
ORGANIC N MG/M3	1142.0	0.36	95.8%			
TP-ORTHO-P MG/M3	74.2	0.44	83.0%			
HOD-V MG/M3-DAY	1572.6	0.25	100.0%			
MOD-V MG/M3-DAY	629.1	0.33	99.9%			
ANTILOG PC-1	1344.0	0.59	90.3%	828.0		82.4%
ANTILOG PC-2	19.2	0.09	98.1%	21.0		98.8%
(N - 150) / P	12.7	0.34	33.6%	12.7		33.6%
INORGANIC N / P	12.1	0.76	18.3%			
TURBIDITY 1/M	0.1		1.1%	0.1		1.1%
ZMIX * TURBIDITY	0.1		0.0%	0.1		0.0%
ZMIX / SECCHI	0.9	0.38	0.2%	0.9		0.2%
CHL-A * SECCHI	55.8	0.10	99.2%	55.9		99.2%
CHL-A / TOTAL P	0.3	0.26	74.1%	0.3		74.1%
FREQ(CHL-a>10) %	97.9	0.03	97.6%	97.9		97.6%
FREQ(CHL-a>20) %	82.2	0.20	97.6%	82.2		97.6%
FREQ(CHL-a>30) %	60.6	0.41	97.6%	60.7		97.6%
FREQ(CHL-a>40) %	42.2	0.59	97.6%	42.3		97.6%
FREQ(CHL-a>50) %	28.9	0.76	97.6%	29.0		97.6%
FREQ(CHL-a>60) %	19.8	0.90	97.6%	19.8		97.6%
CARLSON TSI-P	75.9	0.06	89.1%	75.9		89.1%
CARLSON TSI-CHLA	67.5	0.06	97.6%	67.5		97.6%
CARLSON TSI-SEC	56.2	0.10	40.3%	56.2		40.4%

Cowley Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Cowley Lake\Cowley 2006 (8-19-2015).btb**

Description:

Observed WQ data is from 2006
Unit Area Loads from SWAT model are from 2006

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.0
Evaporation (m)	0.7	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	7	SETTLING VELOCITY
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	4	P, LINEAR
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Cowley Lake	0	1	0.133	1.46	0.51	1.46	0	0	0	0.08	0	0	0	3.95	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	533.6	0	3300	0	135.6	0	0.79	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	0.91	0	2.8	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Cowley-Direct	1	1	3.35	0.585	0	0	0	324.7	0	0.85	0	104.8	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Cowley Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Cowley Lake\Cowley 2006 (8-19-2015).btb

Segment Mass Balance Based Upon Predicted Concentrations

Component: TOTAL P **Segment: 1 Cowley Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Cowley-Direct	0.6	86.1%	189.9	49.2%	325
PRECIPITATION			0.1	13.9%	4.0	1.0%	42
INTERNAL LOAD			0.0	0.0%	191.9	49.7%	
TRIBUTARY INFLOW			0.6	86.1%	189.9	49.2%	325
***TOTAL INFLOW			0.7	100.0%	385.8	100.0%	568
ADVECTIVE OUTFLOW			0.6	86.3%	314.5	81.5%	536
***TOTAL OUTFLOW			0.6	86.3%	314.5	81.5%	536
***EVAPORATION			0.1	13.7%	0.0	0.0%	
***RETENTION			0.0	0.0%	71.3	18.5%	

Hyd. Residence Time =	0.3311	yrs
Overflow Rate =	4.4	m/yr
Mean Depth =	1.5	m

Cowley Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Cowley Lake\Cowley 2006 (8-19-2015).btb**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Cowley Lake**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	536.2	0.08	99.6%	533.6		99.6%
TOTAL N MG/M3	3300.0		96.9%	3300.0		96.9%
C.NUTRIENT MG/M3	235.8	0.02	99.1%	235.5		99.1%
CHL-A MG/M3	136.6	0.27	100.0%	135.6		100.0%
SECCHI M	0.8	0.28	34.7%	0.8		34.0%
ORGANIC N MG/M3	3278.3	0.29	100.0%			
TP-ORTHO-P MG/M3	241.0	0.31	98.6%			
ANTILOG PC-1	7482.9	0.38	99.5%	3917.4		98.3%
ANTILOG PC-2	30.9	0.09	99.9%	30.8		99.9%
(N - 150) / P	5.9	0.08	5.9%	5.9		6.0%
INORGANIC N / P	0.1	15.10	0.0%			
TURBIDITY 1/M	0.1		1.1%	0.1		1.1%
ZMIX * TURBIDITY	0.1		0.0%	0.1		0.0%
ZMIX / SECCHI	1.8	0.28	4.9%	1.8		5.2%
CHL-A * SECCHI	109.4	0.10	100.0%	107.1		100.0%
CHL-A / TOTAL P	0.3	0.26	66.0%	0.3		65.8%
FREQ(CHL-a>10) %	100.0	0.00	100.0%	100.0		100.0%
FREQ(CHL-a>20) %	99.7	0.00	100.0%	99.7		100.0%
FREQ(CHL-a>30) %	98.4	0.02	100.0%	98.3		100.0%
FREQ(CHL-a>40) %	95.3	0.04	100.0%	95.1		100.0%
FREQ(CHL-a>50) %	90.5	0.08	100.0%	90.3		100.0%
FREQ(CHL-a>60) %	84.6	0.12	100.0%	84.3		100.0%
CARLSON TSI-P	94.8	0.01	99.6%	94.7		99.6%
CARLSON TSI-CHLA	78.8	0.03	100.0%	78.8		100.0%
CARLSON TSI-SEC	63.2	0.06	65.3%	63.4		66.0%

Henry Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Henry Lake\Henry Lake 2009 & 2011 (8-19-2015).btb

Description:

Model calibrated to the average water quality conditions for 2009 and 2011.
Loadings are the average flow and concentration for 2009 and 2011.

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.713	0.0
Evaporation (m)	0.7	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	3	2ND ORDER, FIXED
Nitrogen Balance	4	BACHMAN VOL. LOAD
Chlorophyll-a	4	P, LINEAR
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Henry Lake	0	1	0.19	0.863	0.363	0.86	0	0	0	0.47	0	0	0	1.757	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	149.9	0	1800	0	38.4	0	0.7	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	0.727	0	0.91	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km²	Flow (hm³/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Henry-Direct	1	1	3.28	0.486	0	0	0	645	0	3000	0	208	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Henry Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Henry Lake\Henry Lake 2009 & 2011 (8-19-2015).btb

Segment Mass Balance Based Upon Predicted Concentrations

Component: TOTAL P **Segment: 1 Henry Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Henry-Direct	0.5	78.2%	313.5	71.1%	645
PRECIPITATION			0.1	21.8%	5.7	1.3%	42
INTERNAL LOAD			0.0	0.0%	121.9	27.6%	
TRIBUTARY INFLOW			0.5	78.2%	313.5	71.1%	645
***TOTAL INFLOW			0.6	100.0%	441.1	100.0%	710
ADVECTIVE OUTFLOW			0.5	78.6%	73.2	16.6%	150
***TOTAL OUTFLOW			0.5	78.6%	73.2	16.6%	150
***EVAPORATION			0.1	21.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	367.9	83.4%	

Hyd. Residence Time =	0.3357	yrs
Overflow Rate =	2.6	m/yr
Mean Depth =	0.9	m

Component: TOTAL N **Segment: 1 Henry Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Henry-Direct	0.5	78.2%	1458.0	88.5%	3000
PRECIPITATION			0.1	21.8%	190.0	11.5%	1403
TRIBUTARY INFLOW			0.5	78.2%	1458.0	88.5%	3000
***TOTAL INFLOW			0.6	100.0%	1648.0	100.0%	2652
ADVECTIVE OUTFLOW			0.5	78.6%	871.2	52.9%	1784
***TOTAL OUTFLOW			0.5	78.6%	871.2	52.9%	1784
***EVAPORATION			0.1	21.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	776.8	47.1%	

Hyd. Residence Time =	0.3357	yrs
Overflow Rate =	2.6	m/yr
Mean Depth =	0.9	m

Henry Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Henry Lake\Henry Lake 2009 & 2011 (8-19-2015).btb**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment:	**1**	**Henry Lake**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	149.8	0.20	89.7%	149.9		89.8%
TOTAL N MG/M3	1783.6	0.26	81.6%	1800.0		82.0%
C.NUTRIENT MG/M3	100.7	0.18	90.3%	101.3		90.4%
CHL-A MG/M3	38.2	0.33	96.6%	38.4		96.6%
SECCHI M	0.7	0.24	28.6%	0.7		28.4%
ORGANIC N MG/M3	1062.6	0.29	94.3%			
TP-ORTHO-P MG/M3	75.0	0.33	83.3%			
ANTILOG PC-1	1597.4	0.43	92.4%	1324.2		90.1%
ANTILOG PC-2	11.6	0.13	87.0%	12.0		88.2%
(N - 150) / P	10.9	0.35	25.7%	11.0		26.2%
INORGANIC N / P	9.6	0.83	12.9%			
TURBIDITY 1/M	0.5		38.4%	0.5		38.4%
ZMIX * TURBIDITY	0.4		0.4%	0.4		0.4%
ZMIX / SECCHI	1.2	0.24	1.0%	1.2		1.0%
CHL-A * SECCHI	26.8	0.15	91.4%	26.9		91.4%
CHL-A / TOTAL P	0.3	0.26	66.0%	0.3		66.3%
FREQ(CHL-a>10) %	96.8	0.04	96.6%	96.9		96.6%
FREQ(CHL-a>20) %	76.8	0.21	96.6%	77.1		96.6%
FREQ(CHL-a>30) %	53.1	0.39	96.6%	53.5		96.6%
FREQ(CHL-a>40) %	35.0	0.56	96.6%	35.3		96.6%
FREQ(CHL-a>50) %	22.8	0.70	96.6%	23.1		96.6%
FREQ(CHL-a>60) %	14.9	0.83	96.6%	15.2		96.6%
CARLSON TSI-P	76.4	0.04	89.7%	76.4		89.8%
CARLSON TSI-CHLA	66.3	0.05	96.6%	66.4		96.6%
CARLSON TSI-SEC	65.1	0.05	71.4%	65.1		71.6%

Sylvan Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Sylvan\Sylvan Lake 9-10-2015.btb

Description:

Model is calibrated to 2012 conditions.

Global Variables	**Mean**	**CV**
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.0
Evaporation (m)	0.7	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	**Mean**	**CV**
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	**Code**	**Description**
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	6	FIRST ORDER
Nitrogen Balance	5	BACHMAN FLUSHING
Chlorophyll-a	1	P, N, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	**Name**	**Segment**	**Group**	**km^2**	**m**	**km**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1	Sylvan Lake	0	1	0.599	2.15	1.07	2.15	0	0	0	1.38	0	0	0	1.8185	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1	0	0	353.4	0	3356	0	69.8	0	0.32	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1	1	0	1	0	1.14	0	1.088	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	Sylvan-Direct	1	1	1.3	0.249391	0	0	0	520.54	0	6660	0	180.11	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Sylvan Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Sylvan\Sylvan Lake 9-10-2015.btb

Segment Mass Balance Based Upon Predicted Concentrations

Component: TOTAL P **Segment: 1 Sylvan Lake**

Trib	Type	Location	Flow hm³/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m³
1	1	Sylvan-Direct	0.2	36.9%	129.8	23.8%	521
PRECIPITATION			0.4	63.1%	18.0	3.3%	42
INTERNAL LOAD			0.0	0.0%	397.9	72.9%	
TRIBUTARY INFLOW			0.2	36.9%	129.8	23.8%	521
***TOTAL INFLOW			0.7	100.0%	545.6	100.0%	808
ADVECTIVE OUTFLOW			0.3	37.9%	90.5	16.6%	353
***TOTAL OUTFLOW			0.3	37.9%	90.5	16.6%	353
***EVAPORATION			0.4	62.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	455.1	83.4%	

Hyd. Residence Time = 5.0287 yrs
Overflow Rate = 0.4 m/yr
Mean Depth = 2.2 m

Component: TOTAL N **Segment: 1 Sylvan Lake**

Trib	Type	Location	Flow hm³/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m³
1	1	Sylvan-Direct	0.2	36.9%	1660.9	73.5%	6660
PRECIPITATION			0.4	63.1%	599.0	26.5%	1406
TRIBUTARY INFLOW			0.2	36.9%	1660.9	73.5%	6660
***TOTAL INFLOW			0.7	100.0%	2259.9	100.0%	3346
ADVECTIVE OUTFLOW			0.3	37.9%	857.9	38.0%	3350
***TOTAL OUTFLOW			0.3	37.9%	857.9	38.0%	3350
***EVAPORATION			0.4	62.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	1402.0	62.0%	

Hyd. Residence Time = 5.0287 yrs
Overflow Rate = 0.4 m/yr
Mean Depth = 2.2 m

Sylvan Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Sylvan\Sylvan Lake 9-10-2015.btb**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Sylvan Lake**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	353.4	0.37	98.7%	353.4		98.7%
TOTAL N MG/M3	3350.0	0.36	97.0%	3356.0		97.1%
C.NUTRIENT MG/M3	212.9	0.28	98.7%	213.1		98.7%
CHL-A MG/M3	69.6	0.28	99.5%	69.8		99.5%
SECCHI M	0.3	0.19	5.5%	0.3		5.5%
ORGANIC N MG/M3	1848.9	0.27	99.6%			
TP-ORTHO-P MG/M3	152.6	0.28	95.7%			
ANTILOG PC-1	6100.9	0.42	99.3%	4842.7		98.9%
ANTILOG PC-2	9.7	0.14	78.4%	9.7		78.6%
(N - 150) / P	9.1	0.53	17.7%	9.1		17.8%
INORGANIC N / P	7.5	1.05	8.3%			
TURBIDITY 1/M	1.4		82.4%	1.4		82.4%
ZMIX * TURBIDITY	3.0		46.9%	3.0		46.9%
ZMIX / SECCHI	6.7	0.19	72.1%	6.7		72.2%
CHL-A * SECCHI	22.3	0.16	86.6%	22.3		86.6%
CHL-A / TOTAL P	0.2	0.42	50.3%	0.2		50.5%
FREQ(CHL-a>10) %	99.8	0.00	99.5%	99.8		99.5%
FREQ(CHL-a>20) %	95.6	0.04	99.5%	95.6		99.5%
FREQ(CHL-a>30) %	85.3	0.12	99.5%	85.4		99.5%
FREQ(CHL-a>40) %	72.1	0.21	99.5%	72.2		99.5%
FREQ(CHL-a>50) %	58.9	0.30	99.5%	59.0		99.5%
FREQ(CHL-a>60) %	47.2	0.38	99.5%	47.4		99.5%
CARLSON TSI-P	88.8	0.06	98.7%	88.8		98.7%
CARLSON TSI-CHLA	72.2	0.04	99.5%	72.2		99.5%
CARLSON TSI-SEC	76.4	0.04	94.5%	76.4		94.5%

Goose Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Goose Lake\Goose Lake with TN 9-8-2014.btb

Description:

Goose Lake Bathtub model
P8 Model Tributary Load
Average from 2010-2012

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.7112	0.2
Evaporation (m)	0.7	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	2	2ND ORDER, DECAY
Nitrogen Balance	6	FIRST ORDER
Chlorophyll-a	3	P, N, LOW-TURBIDITY
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Goose Lake	0	1	0.26	1.29	0.84	1.29	0.12	0	0	0.08	0.2	0	0	0.34	0	1.365	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	180.6	0	3600	0	114.5	0	0.3	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1.07	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	8T-1.1 Pipe	1	1	0.0119	0.0036	0.1	0	0	300	0.2	1390	0	99	0	0	0
2	8T-4.2 Pipe	1	1	0.0126	0.0016	0.1	0	0	273.5	0.2	1280	0	99	0	0	0
3	8T-3P	1	1	0.109	0.0061	0.1	0	0	86.6	0.2	520	0	84.2	0	0	0
4	8T-1P	1	1	0.301	0.077	0	0	0	104.2	0	620	0	99	0	0	0
5	8T-4P	1	1	0.055	0.0098	0	0	0	100.8	0	606	0	99	0	0	0
6	Goose Direct	1	1	0.465	0.037	0	0	0	250.5	0	1170	0	99	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Goose Lake

File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Goose Lake\Goose Lake with TN 9-8-2014.btb

Segment Mass Balance Based Upon Predicted Concentrations

Component: TOTAL P **Segment: 1 Goose Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	8T-1.1 Pipe	0.0	1.1%	1.1	1.8%	300
2	1	8T-4.2 Pipe	0.0	0.5%	0.4	0.7%	274
3	1	8T-3P	0.0	1.9%	0.5	0.9%	87
4	1	8T-1P	0.1	24.1%	8.0	13.3%	104
5	1	8T-4P	0.0	3.1%	1.0	1.6%	101
6	1	Goose Direct	0.0	11.6%	9.3	15.3%	251
PRECIPITATION			0.2	57.8%	7.8	12.9%	42
INTERNAL LOAD			0.0	0.0%	32.3	53.4%	
TRIBUTARY INFLOW			0.1	42.2%	20.3	33.6%	150
***TOTAL INFLOW			0.3	100.0%	60.4	100.0%	189
ADVECTIVE OUTFLOW			0.1	43.1%	24.8	41.1%	180
***TOTAL OUTFLOW			0.1	43.1%	24.8	41.1%	180
***EVAPORATION			0.2	56.9%	0.0	0.0%	
***RETENTION			0.0	0.0%	35.6	58.9%	

Hyd. Residence Time = 2.4302 yrs
Overflow Rate = 0.5 m/yr
Mean Depth = 1.3 m

Component: TOTAL N **Segment: 1 Goose Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	8T-1.1 Pipe	0.0	1.1%	5.0	1.0%	1390
2	1	8T-4.2 Pipe	0.0	0.5%	2.0	0.4%	1280
3	1	8T-3P	0.0	1.9%	3.2	0.6%	520
4	1	8T-1P	0.1	24.1%	47.7	9.6%	620
5	1	8T-4P	0.0	3.1%	5.9	1.2%	606
6	1	Goose Direct	0.0	11.6%	43.3	8.7%	1170
PRECIPITATION			0.2	57.8%	260.0	52.3%	1406
INTERNAL LOAD			0.0	0.0%	129.6	26.1%	
TRIBUTARY INFLOW			0.1	42.2%	107.2	21.6%	793
***TOTAL INFLOW			0.3	100.0%	496.8	100.0%	1553
ADVECTIVE OUTFLOW			0.1	43.1%	496.8	100.0%	3600
***TOTAL OUTFLOW			0.1	43.1%	496.8	100.0%	3600
***EVAPORATION			0.2	56.9%	0.0	0.0%	
***RETENTION			0.0	0.0%	0.0	0.0%	

Hyd. Residence Time = 2.4302 yrs
Overflow Rate = 0.5 m/yr
Mean Depth = 1.3 m

Goose Lake

File: **\\admn-file-vm03\users$\101782\Documents\BATHTUB\Elm Creek\Goose Lake\Goose Lake with TN 9-8-2014.btb**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Goose Lake**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	179.7	0.34	92.9%	180.6		93.0%
TOTAL N MG/M3	3599.8	0.55	97.7%	3600.0		97.7%
C.NUTRIENT MG/M3	152.4	0.38	96.5%	152.9		96.6%
CHL-A MG/M3	114.6	0.55	99.9%	114.5		99.9%
SECCHI M	0.3	0.53	6.4%	0.3		4.6%
ORGANIC N MG/M3	2775.2	0.53	100.0%			
TP-ORTHO-P MG/M3	201.7	0.57	97.8%			
ANTILOG PC-1	7443.9	0.95	99.5%	8226.2		99.6%
ANTILOG PC-2	16.3	0.08	96.1%	12.9		90.8%
(N - 150) / P	19.2	0.38	57.1%	19.1		56.8%
INORGANIC N / P	824.6	1.51	100.0%			
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.1	0.23	0.0%	0.1	0.23	0.0%
ZMIX / SECCHI	3.8	0.55	34.8%	4.3	0.12	42.9%
CHL-A * SECCHI	38.9	0.10	97.1%	34.4		95.7%
CHL-A / TOTAL P	0.6	0.31	96.8%	0.6		96.8%
FREQ(CHL-a>10) %	100.0	0.00	99.9%	100.0		99.9%
FREQ(CHL-a>20) %	99.4	0.01	99.9%	99.4		99.9%
FREQ(CHL-a>30) %	96.8	0.06	99.9%	96.8		99.9%
FREQ(CHL-a>40) %	91.7	0.14	99.9%	91.7		99.9%
FREQ(CHL-a>50) %	84.8	0.24	99.9%	84.8		99.9%
FREQ(CHL-a>60) %	76.8	0.34	99.9%	76.8		99.9%
CARLSON TSI-P	79.0	0.06	92.9%	79.1		93.0%
CARLSON TSI-CHLA	77.1	0.07	99.9%	77.1		99.9%
CARLSON TSI-SEC	75.6	0.10	93.6%	77.3		95.4%

LimnoTech
Water | Scientists
Environment | Engineers

501 Avis Drive
Ann Arbor, MI 48108
734.332.1200
www.limno.com

Memorandum

From: Pranesh Selvendiran, Chelsie Boles, Todd Redder and Hans Holmberg

Date: October 17, 2014

CC: Brian Vlach (TRPD)
Amy Timm (TRPD)

To: Rich Brasch (TRPD)

Project: Elm Creek Watershed SWAT Modeling

Subject: Development, calibration and confirmation of the Elm Creek Watershed SWAT model

Statement of Purpose

This memorandum has been prepared for the Three Rivers Park District (TRPD) to document Tasks 1 – 2 as outlined in the Elm Creek Watershed Scope of Work. The purpose of Task 1 is to acquire data and complete development of a Soil and Water Assessment Tool (SWAT) model for the Elm Creek Watershed. The purpose of Task 2 is to perform calibration and confirmation of the Elm Creek Watershed SWAT model (ECWSWAT). The calibration components include hydrology, sediments and nutrients, including total nitrogen and total phosphorus. The purpose of this memorandum is to describe data sources and model set-up, and to document the results of the ECWSWAT model calibration and confirmation.

Project Background

The Minnesota Pollution Control Agency (MPCA) is intending to develop a watershed-wide, multi-parameter Total Maximum Daily Load (TMDL) Protection Plan and Implementation Plan that will collectively address all water quality impairments throughout the Elm Creek watershed. To support the TMDL development, a suite of modeling tools has been identified for the assessment of landscape and instream/in-lake processes. The SWAT model was chosen as one of the modeling tools to simulate watershed hydrology and water quality to in the Elm Creek watershed. TRPD's intended use of the SWAT model was to primarily quantify landscape contributions of water, sediment and nutrients in the Elm Creek Watershed. Landscape loads from SWAT model will be utilized as an input to other modeling tools (e.g., AQUATOX and BATHTUB) to support the simulation of in-stream/in-lake processes in the Elm Creek Watershed. LimnoTech was contracted by TRPD for the development and calibration of a SWAT model for the Elm Creek Watershed.

The scope of work was organized into two major tasks:

- Task 1: Data acquisition and model set-up; and
- Task 2: Model calibration and confirmation for hydrology, sediment and nutrients, including total nitrogen and total phosphorus

The results of Tasks 1 and 2 are documented in this memorandum.

Watershed Characteristics

The Elm Creek Watershed (Figure 1), which is located in the Metropolitan region of Minnesota, is part of the Mississippi River-Twin Cities watershed (8-digit HUC: 07010206). The Elm Creek Watershed lies wholly within the north central part of Hennepin County. The Crow and Mississippi Rivers demarcate the northern boundary. Within the legal boundaries of the Elm Creek Watershed, some portions of the areas in the north drain to the Crow and Mississippi Rivers (ECWMC, 2003).

The Elm Creek hydrologic watershed has a surface area of approximately 66,400 acres, and it drains land from the following municipalities: Champlin, Corcoran, Dayton, Maple Grove, Medina, Plymouth and Rogers. Land use throughout the watershed is highly variable and ranges from rural (predominantly row crop agricultural) to high density urban and commercial development. The watershed includes three major stream systems (Elm, Rush, and Diamond Creeks) that total over 41 stream miles. Major lake systems within the watershed include French, Diamond, Rice, Fish, Weaver, Henry, Goose, Mud Lakes and the Mill Pond.

The climate of the Elm Creek Watershed is characterized by wide variations in temperature, ample rainfall, and moderate snowfall. The average annual precipitation is approximately 27 inches. The average annual temperature is 44 degrees Fahrenheit, with the extremes ranging from 112 to –37 degrees Fahrenheit. Topography varies from nearly level to gently and moderately sloping. The highest elevations in the area rise to elevations of approximately 1,030-1,050 feet near Rogers, in southern Corcoran, and in Medina. The lowest elevations of approximately 840-850 feet are located near the northern border of the watershed near the Crow and Mississippi Rivers. Land use within the Elm Creek Watershed has been influenced by agricultural activities and rural residential and higher density development pressure. The Elm Creek Watershed has many natural areas, water resources, and local parks that provide recreational value and habitat for fish and wildlife.

Hydrology in the watershed is influenced by wetland complexes, several large depressions, and the stream network. Water is generally directed from the south and west to the northeast via four main stream networks: Rush Creek, South Fork Rush Creek, Diamond Creek, and Elm Creek. These stream networks converge in the Elm Creek Regional Park and enter Hayden Lake. Water is eventually discharged to the Mississippi River just downstream of the Mill Pond in Champlin.

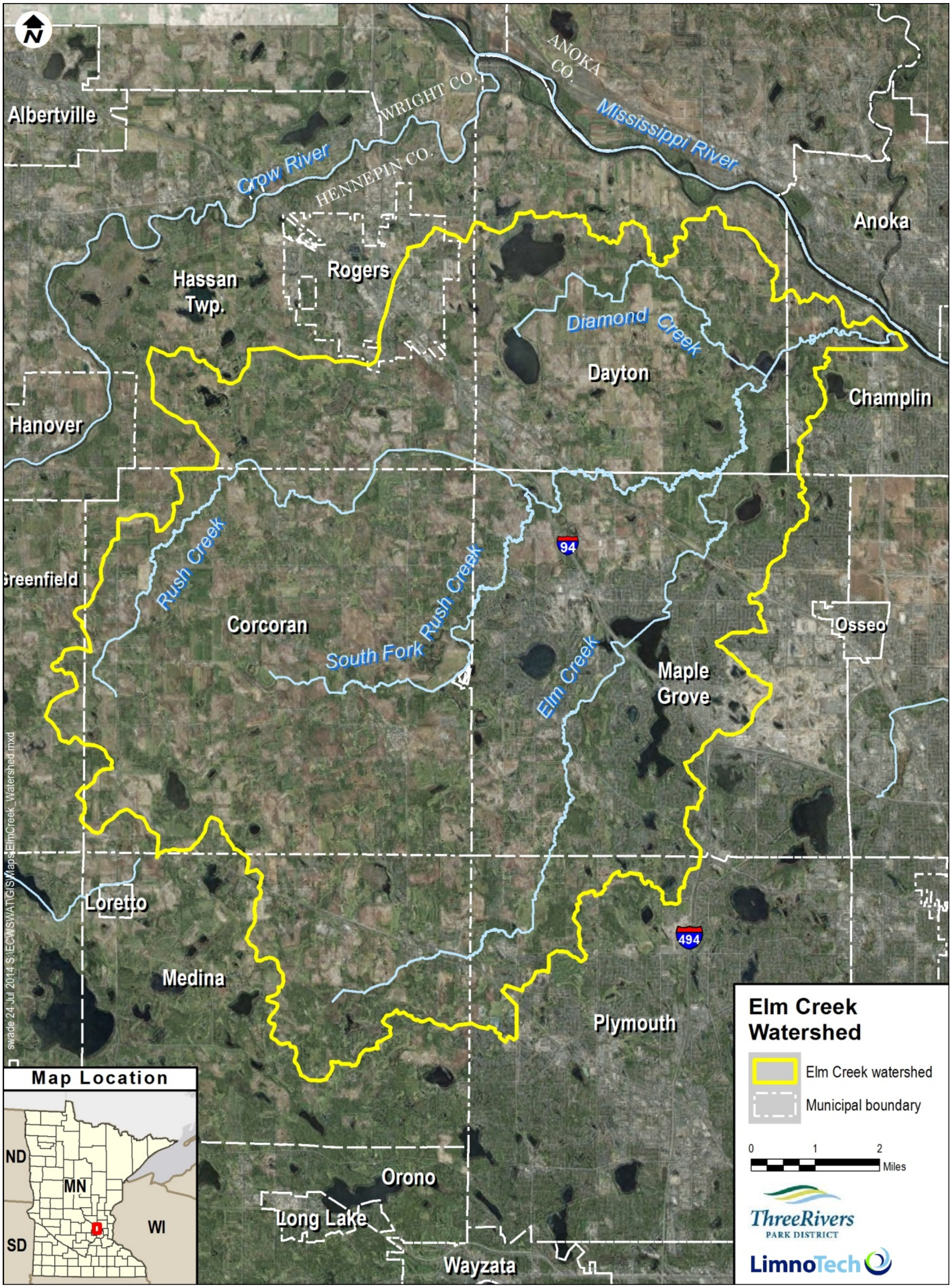


Figure 1. Map of the Elm Creek Watershed

Overview of the Soil and Water Assessment Tool (SWAT)

SWAT is a watershed scale continuous simulation model that operates on a daily time step. SWAT simulates environmental processes in watersheds and receiving waters. The general features of SWAT include simulation of watershed hydrology, sediment loading, nutrient loading, and reach routing. Important features include the simulation of return flow (baseflow or volume of streamflow from groundwater), ponds/reservoirs/wetlands, point sources, channel erosion, crop growth and irrigation, tile drains, rural and agricultural management practices, and the calculation of sediment and nutrient loadings from urban areas. Agency support for SWAT is provided by the United States Department of Agriculture.

SWAT can be applied to watersheds that range from very small watersheds with areas of a few square miles to large, complex watersheds with areas greater than several thousand square miles. The conceptual construct of SWAT is based on a watershed that is divided into multiple subwatersheds or subbasins, which are then further subdivided into hydrologic response units (HRUs) that are homogeneous in land use, soil characteristics, and land management practices. Specifically, individual fields with the same type of land use, soil, and suite of land management practices scattered throughout a subbasin are lumped together and combined to form a single HRU (Neitsch et al. 2011). Each HRU represents a portion of a subbasin area that is not spatially explicit within the subbasin; however, an individual subbasin is spatially explicit and possesses a specific geographic location within the overall watershed representation in SWAT. A subbasin will contain at least one (1) HRU, a tributary channel (i.e., a "virtual" tributary channel associated with an HRU where lagging takes place prior to delivery to the main reach) and a main channel or reach. Surface runoff and, sediment and nutrients loads are generated at the HRU level, aggregated to the subbasin levels, and routed through the river network to the watershed outlet.

Simulation of watershed hydrology is separated into the land and the routing phase of the hydrological cycle. Sediment yields are estimated with the Modified Universal Soil Loss Equation (MUSLE) (Williams 1975). SWAT simulates both N and P cycles, which are associated with simulated management practices. Both nutrients are divided in the soil into two parts, each associated with organic and inorganic N and P transport and transformations. Agricultural management practices such as planting, harvesting, tillage implement, irrigation, grazing and nutrient applications can be simulated for each cropping system with specific dates and by explicitly defining the appropriate management parameters for each HRU (e.g. tillage depth, N and P fractions in fertilizer, quantity of fertilizer, manure types, etc.). A detailed description of SWAT capabilities are provided in Nietsch et al. (2011).

Elm Creek Watershed SWAT Model Development

In the SWAT model, the watershed is divided into 77 subbasins (Figure 2), with an average area per subbasin of 852 acres. The subbasins are further divided into HRUs to represent unique land use/cover conditions and soil and slope characteristics within the subbasins. The model contains a total of 948 HRUs, and the average area per HRU is 69.2 acres. The total watershed drainage area represented by the model is 67,437 acres.

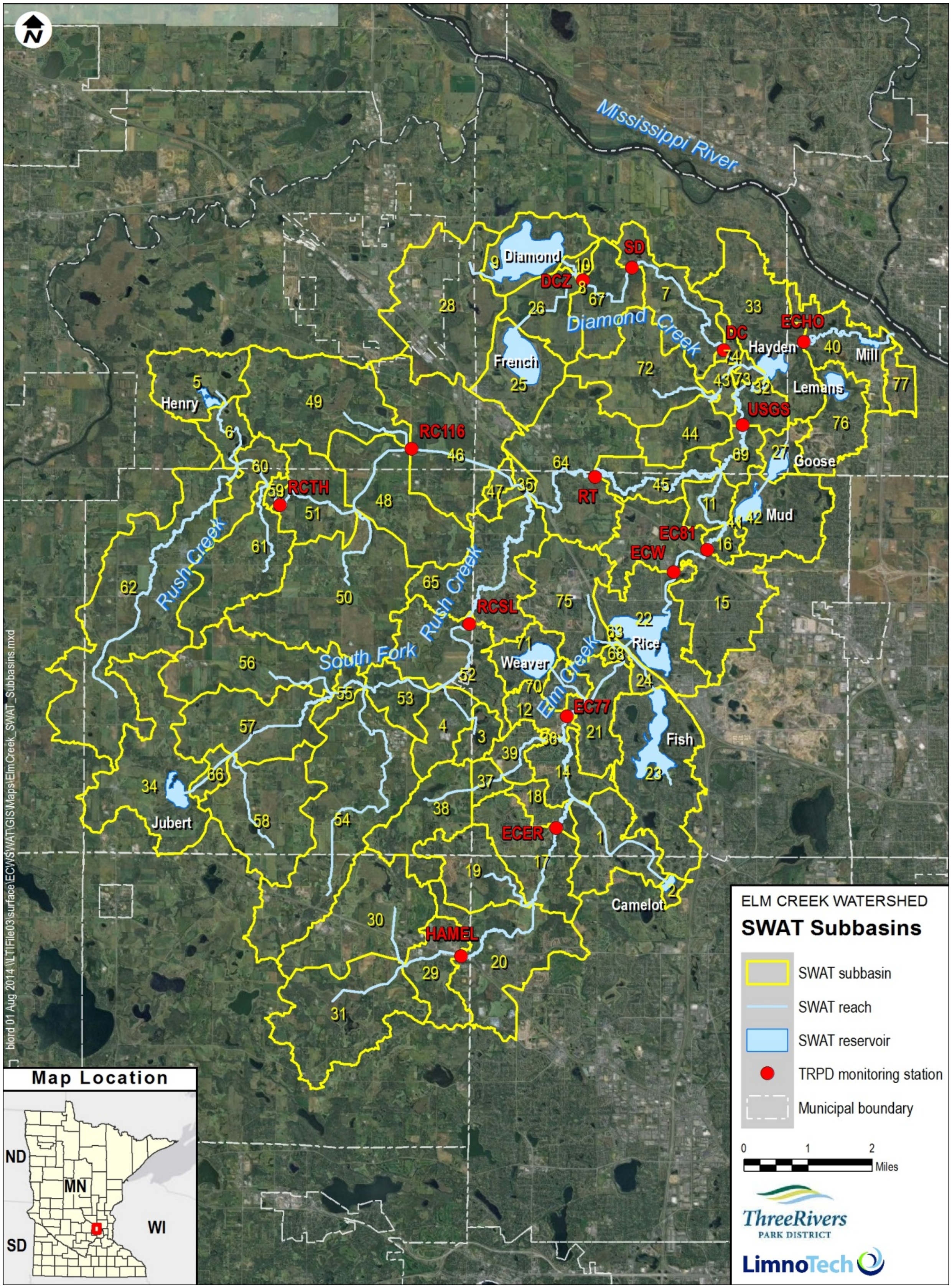


Figure 2. Map of the Elm Creek Watershed SWAT subbasins and stream network

The drainage system within the Elm Creek watershed includes lakes, upland depressions and flow-through riparian depressions (i.e., ponds and wetlands). These hydrologic features were represented to the extent possible by utilizing the following built-in capabilities with SWAT: reservoirs, wetlands and "WATR" (water) HRUs.

Water bodies that are located on the stream network and are large enough to affect the flow at the daily timescale are modeled using the "reservoir" option in SWAT. A total of 13 water bodies within the Elm Creek watershed are explicitly represented as reservoirs (Figure 2; Table 1). Reservoirs receive water contributed to the channel network from all upstream subbasins. The water balance for reservoirs includes inflow, outflow, rainfall on the surface, evaporation, and seepage from the bottom of the reservoir into underlying soils.

Table 1. Reservoirs represented in the ECWSWAT model

Subbasin	Reservoir	Area (acres)	Source
2	Camelot Lake	22	MDNR*
5	Henry Lake	32	MDNR*
9	Diamond Lake	397.0	TRPD
22	Rice Lake	339	TRPD
23	Fish Lake	232	TRPD
25	French Lake	215	TRPD
27	Goose Lake	78	TRPD
33	Hayden Lake	90	MDNR*
34	Jubert Lake	64	MDNR*
40	Mill Pond	29	TRPD
42	Mud Lake	148.3	TRPD
71	Weaver Lake	153	TRPD
76	Lehman Lake	43	TRPD

*Minnesota Department of Natural Resources (MDNR) Lake Finder database. http://www.dnr.state.mn.us/lakefind/index.html

The "wetland" option in SWAT is used to represent: 1) detention ponds in urban areas documented by municipal surface water management plans (SWMPs), and 2) in-channel shallow wetlands. Water flowing into these waterbodies only originates from subbasins in which they are located, based on the representation available in SWAT. Only one wetland segment can be represented per subbasin in SWAT. Therefore, multiple detention ponds or in-channel wetlands are represented as a single "wetland" within a subbasin.

To configure the wetlands, subbasins were first categorized into "urban", "rural" or "urban/rural" (TRPD, personnel comm.). In each urban subbasin, the total SWMP detention pond acreage is represented as wetland area. Information regarding SWMP detention ponds was obtained by TRPD from the respective municipal administration. In each rural subbasin, the total in-channel wetland acreage is represented as wetlands. In-channel wetland areas were identified using the National Wetland Inventory (NWI) spatial layer (Source: TRPD). In urban/rural subbasins both SWMP detention ponds and NWI in-channel wetland areas were represented as wetlands. The information used to configure wetlands in the ECWSWAT model is provided in Appendix A.

Major input requirements for wetlands include subbasin drainage area, surface area and volume. SWAT-simulated hydrologic processes associated with the "wetlands" include inflow, outflow, storage, evapotranspiration (ET), and percolation loss. Sediment and nutrient transformations simulated in wetlands and reservoirs are limited to removal by settling; other transformation processes are ignored.

In addition to reservoirs, SWMP ponds, and wetlands, other off-channel depressions are present within the watershed. These offline depressions are represented as local “WATR” (water) HRUs that will not generate any hydrologic feedback to the reach (i.e., do not contribute flow to reach).

Land uses represented in the model include agriculture (row crops), forest, pasture and urban (Table 2). Agriculture (27%), urban (24%) and pasture (20%) are the most prominent land uses in the watershed. The row crops represented include corn and soybean.

Table 2. Land uses represented in the ECWSWAT model

Land Use	Area	%
Agriculture (row crops)	18,090	27%
Forest	2,990	5%
Pasture (alfalfa)	13,393	20%
Rangeland	773	1%
Urban Low Density	12,095	18%
Urban Medium Density	3,505	5%
Urban High Density	431	1%
Urban Transportation	68	0.1%
Reservoir	1,813	3%
Wetland (SWMP ponds/in-channel wetlands)	7,110	11%
WATR (off-channel depression)	6,066	9%
Total	***66,334***	***100%***

The framework of the agriculture management schedules defined in the model includes crop rotations, tillage operations and fertilizer applications. Information on cropping and tillage patterns in the Elm Creek watershed was provided by Jim Kujawa, Hennepin County Department of Environmental Services (personal comm.). The row crops are represented by a corn-soybean (C-S) rotation system. The rotation scheme is randomized across the cropland HRUs such that in a given year the acreage of row-crop cultivation is split equally between corn and soybean.

Planting of corn and soybean typically occurs in May, with harvesting occurring in October. Tillage is implemented during pre-planting and post-harvest periods for both corn and soybean rotations. Fertilizer is applied in the form of both commercial and manure fertilizer during corn cultivation. The major form of commercial fertilizer in the Elm Creek watershed region is urea (Bierman et al., 2011). As reported in Bierman et al. (2009) an average N application of 129 lb N/acre (which translates to urea application at 280.4 lb/acre) was specified in the model. A livestock inventory of total manure generated in the watershed during 2006, 2008 and 2011 was provided by TRPD. Using livestock inventory manure data for 2006, 2008 and 2011, average annual manure generated in the watershed was calculated. Manure application was considered at the subbasin level. Information regarding spatial distribution of livestock manure production was utilized to determine total annual manure generated by animal type within each subbasin. Livestock manure generated in a subbasin is applied to the available corn, soybean and alfalfa areas within that subbasin. SWAT model requires specification of manure application rates on a dry weight basis. Manure application rates were calculated for each subbasin based on the assumptions that:

1) 80% of the annual manure generated is recovered for application; 2) all cropland and alfalfa areas receive manure treatment; and 3) manure is disposed onto the land regardless of crop nutrient requirements. Manure application is specified in the model once during fall. The management practices associated with a typical C-S rotation represented in the model are shown in Table 3.

Urban areas were represented by growing Kentucky Bluegrass[1]. Low and medium density residential HRUs were fertilized with 25-0-3 at *The Andersons Turf Products* recommended "low" rate of 4 lbs/1,000 square feet (194 kg/ha). A harvest-only operation was scheduled in the middle of the growing season to simulate lawn cutting. At the end of the growing season, all low and medium density residential HRU biomass was converted to residue. The few high density urban and urban-transportation HRUs were simulated with auto-applications of nitrogen fertilizer and end-of-season kill operations to convert their biomass to residue.

Table 3. Management schedule representing a typical C-S crop rotation

Year / Crop Type	Date	Operation Type	Description
1 CORN	29-Apr	Tillage	Field Cultivator Ge15ft
	30-Apr	Tillage	Field Cultivator Ge15ft
	3-May	Planting	Corn
	24-May	Fertilizer	Urea
	17-Oct	Harvest & Kill	Corn
	22-Oct	Tillage	Chisel Plow Gt21ft
	27-Oct	Tillage	Manure
2 SOYBEAN	15-May	Tillage	Field Cultivator Ge15ft
	20-May	Planting	Soybean
	15-Oct	Harvest & Kill	Soybean
	4-Nov	Tillage	Chisel Plow Gt21ft
	9-Nov	Fertilizer	Manure

Hydrologic soil groups (HSGs) represented in the Elm Creek watershed model consist of 4% HSG type A (well drained), 59% HSG type B (moderately well drained), 28% HSG type C (moderately poor to poorly drained) and 9% HSG type D (poorly to very poorly drained). Croplands are present in HRUs with HSG type B and C soils. Subsurface tile drainage was assumed to be present in cropland HRUs with HSG type C soils. Approximately 36% of the cropland areas (or 11% of the total watershed area) are assumed to be tile drained.

SWAT allows the user to input loadings of water, sediment and nutrients from point sources to the main channel network. These loadings are routed through the channel network along with the loadings generated by the land areas. One point source, Maple Hill Estates, is located within subbasin 4 of the Elm Creek watershed. Monthly loadings of water, sediment and nutrients were developed for the Maple Hill Estates based on data provided by TRPD from MPCA. These loadings were directly added to the stream reach of subbasin 4.

[1] Kentucky Bluesgrass is a common lawn grass in Minnesota. Source: http://www.extension.umn.edu/garden/yard-garden/lawns/seeding-and-sodding-home-lawns/

Model Calibration and Confirmation Approach

This section describes the model calibration and confirmation approach, including an overview of the data available for model calibration/confirmation and a description of the visual and statistical metrics and targets used to evaluate model performance.

Calibration and Confirmation Data

The following section describes the key observed streamflow data utilized to support the calibration and confirmation of the ECWSWAT model. The locations of streamflow monitoring stations in the Elm Creek watershed are shown in Figure 2. A total of eight monitoring stations were selected for the purpose of hydrology model calibration and confirmation based on consultation with TRPD. A summary of streamflow data availability for the selected stations is shown in Table 4. Streamflow records for these stations were provided by TRPD.

Table 4. Summary of streamflow and water quality data availability

Station ID	Description	Period of Record	Frequency	Calibration/ Confirmation
HAMEL	Elm Cr. at EC Golf Course	2000 - 2012	Daily	Calibration
EC77	Elm Cr. at 77th Ave.	2007 - 2012	Daily	Confirmation
RCSL	S. Fork Rush Cr. at Shannon Lane	2009 - 2012	Daily	Calibration
RCTH	Rush Cr. at Trail Haven Rd.	2009 - 2012	Daily	Calibration
RT	Rush Cr. at Territorial Rd.	2007 - 2012	Daily	Confirmation
DC	Diamond Cr. near mouth	2007 - 2012	Daily	Calibration
USGS	Elm Cr. - USGS gauge	2001 - 2012	Daily	Confirmation

Model Calibration and Confirmation Approach

The calibration process followed a logical order according to model parameters (or coefficients) that depend on each other and taking into account which model parameters are most sensitive and uncertain. The hydrology calibration was conducted first, and model performance was evaluated at a range of timescales (e.g., annual, monthly, and daily). Next, total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) were calibrated in terms of annual landscape unit area loading rates.

During calibration, model predictions were compared with site-specific streamflow measurements or literature unit area loadings (UALs) in the case of sediment and nutrients. The goodness of fit was evaluated using both statistical and visual techniques. Next, a subset of model parameters was adjusted within an acceptable range using best professional judgment. After the parameter adjustments were made, the model was re-run, and results were reviewed to determine if the model fit to data had improved. The process continued until it was determined that the best possible calibration had been reached, given available data and model limitations.

For hydrology, model calibration and confirmation was performed for the 2000 – 2012 period based on observed streamflow data from seven monitoring stations. Data from four monitoring sites, including HAMEL, RCSL, RCTH and DC, were used for calibration. Following calibration, model confirmation was performed by running the model without changing any parameters and comparing the results to available data from a second set of monitoring stations. Data from three monitoring sites, including EC77, RT, and the USGS Elm Creek station were utilized for model confirmation.

For sediment and nutrients the calibration targets are the annual average unit area loading rates (in lbs/ac/yr) established in the literature for various land use types. Model calibration was achieved by attaining reasonable agreement of the simulated UALs with the ranges available from literature.

Visual Evaluation and Statistical Metrics

For the hydrology calibration, model performance was evaluated using both visual and statistical comparisons of simulated and observed data. Graphics developed to visually assess model performance included annual bar charts, annual/monthly/daily time series plots, and daily scatter plots. The statistical metrics included the coefficient of determination (r^2), the Nash-Sutcliffe model efficiency coefficient (NSE) and percent bias (PBIAS).

The coefficient of determination (r^2) was used to evaluate the goodness of fit of the model to the observed data. An r^2 value of one (1) indicates a perfect correlation and a value of zero (0) indicates no correlation between model predictions (S) and observations (O):

$$r^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}} \right)^2$$

NSE indicates how well observed versus simulated data fits a 1:1 line. A NSE value of one (1) indicates a perfect prediction. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicate that the mean observed value is a better predictor than the simulated values, which indicates unacceptable performance (Moriasi et al. 2007). The NSE is calculated using the following equation:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

where O is observed and S is a paired simulated value.

Percent bias (PBIAS) measures the average tendency of the simulated results to be larger or smaller than the observed data (Gupta et al. 1999, Moriasi et al. 2007). The optimal value of PBIAS is zero (0) with low values indicating an unbiased model simulation. Positive values indicate that the model has an underestimation bias, and negative values indicate that the model has an overestimation bias (Gupta et al. 1999, Moriasi et al. 2007).

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(O_i - S_i) * (100)}{\sum_{i=1}^{n}(O_i)} \right]$$

where O is observed and S is simulated.

Statistical metrics were not established for pollutant loads (TSS, phosphorus and nitrogen). Instead, visual comparisons of model-simulated landscape UAL rates and literature values were performed to evaluate model performance.

Model Performance Targets

The model performance targets established for the ECWSWAT model hydrology calibration are summarized in Table 5. The prescribed model calibration tolerances or targets adhere to the generally accepted target recommendations (Donigian 2000 and 2002, Moriasi et al. 2007, Parajuli et al. 2009, Duda et al. 2012). The model performance target ranges apply to annual or monthly mean values. Typically, the statistical performance for daily predictions is expected to fall below the statistical performance ratings specified for monthly and annual time scales. If the daily statistics do not meet model performance targets specified for the monthly and annual time scales, it does not mean that the model does not have an acceptable level of performance and cannot be used at daily time scales. Instead, the wider range in the daily statistics reflects the increased difficulties in simulating the short-term timing of streamflow and water quality constituents, given the uncertainties in the model inputs in regard to the coverage, resolution, and accuracy of available data (e.g., precipitation). Therefore, the daily statistics are provided for informational purposes and are not formally evaluated against the model performance metrics and targets relevant to the monthly and annual time scales.

Table 5. Targets established for the ECWSWAT model calibration on an annual and monthly basis.

Parameters	Statistical Metric		
	r2	NSE	PBIAS (%)
Hydrology	0.50 to <0.90 *'Very Good'* 0.25 to 0.49 *'Satisfactory'* <0.25 *'Unsatisfactory'*	0.50 to <0.90 *'Very Good'* 0.25 to 0.49 *'Satisfactory'* <0.25 *'Unsatisfactory'*	PBIAS < ±15 *'Very Good'* ±15 ≤ PBIAS < ±25 *'Satisfactory'* PBIAS ≥ ±25 *'Unsatisfactory'*

Calibration and Confirmation Results

Hydrology

The first step in the hydrology calibration was the evaluation of the water budget to achieve a reasonable balance between evapotranspiration, surface runoff, lateral flow, tile flow, groundwater flow and seepage to deep aquifers. Achieving a proper balance between these hydrologic processes has important implications for sediment and nutrient transport. For Minnesota watersheds, evapotranspiration represents approximately 70% of the annual precipitation with the majority of the remaining fraction accounting for streamflow (Fairbairn 2011, Folle 2010). The water budget simulated by the model for the Elm Creek watershed is depicted in Figure 3.

The annual average precipitation for the watershed is 30.5 inches, based on climate dataset used in the ECWSWAT model. Evapotranspiration represents the largest component of the water balance, accounting for 64% of the precipitation input to the land surface. Water yield, the fraction of the water budget that constitutes streamflow, accounts for 22% of the precipitation input. About 14% of the precipitation input is attributed to seepage to deep aquifers.

The SWAT model simulates wetland influence on the hydrologic pathways. A portion of the surface, lateral, and tile flow originating within a subbasin are routed through the wetlands based on the wetland drainage area fraction (i.e., fraction of subbasin area draining through the wetland). These flow components, after being routed through the wetland, collectively become wetland outflow. Groundwater flow generated in a subbasin directly enters the stream network without any interaction with the wetland represented in that subbasin. The water yield components for the Elm Creek watershed are thus represented by a surface runoff flow, a subsurface flow (which includes tile flow, lateral flow and groundwater flow), and total wetland outflow. Approximately 89% of the watershed area drains through the wetlands represented in the ECWSWAT model. Therefore, wetland outflow represents a significant component of the overall water yield. Based on model simulation results, direct surface runoff contributes 6.4% of the total annual water yield. Lateral flow (i.e., flow through the unsaturated zone not passing through a wetland) contributes 0.6% of the water yield, and direct tile flow contributes 0.3% of the annual water yield. Wetland outflow (all of which entered the wetlands via surface, lateral, and/or tile flow) makes up 54% of the annual average water yield.

Roughly 39% of the annual streamflow in the Elm Creek watershed is sustained by groundwater flow (i.e., return flow from shallow aquifer). According to Delin and Falteisek (2007), the annual rate of recharge to unconfined aquifers for watersheds in southeastern Minnesota typically ranges from 6 – 8 inches. This estimate is consistent with the 6.9 inches of shallow groundwater flow and seepage to deep aquifers estimated for the Elm Creek watershed by the calibrated SWAT model.

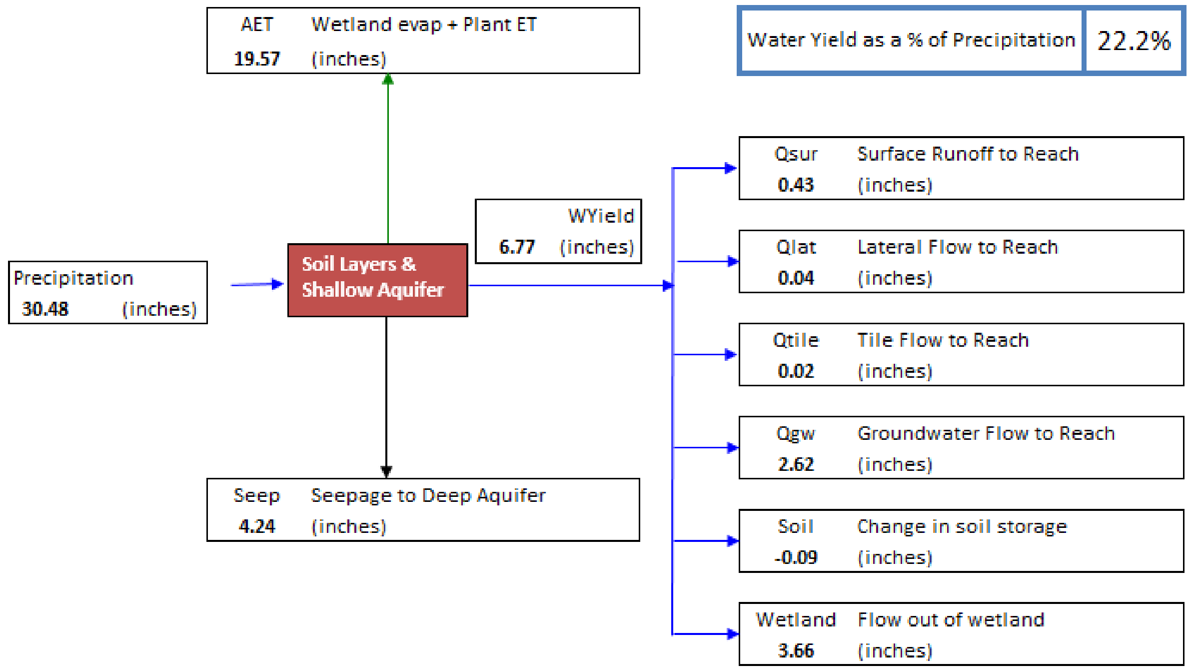


Figure 3. Elm Creek watershed SWAT model simulated annual average water balance (2000-2012)[2]

The next step in the hydrology calibration included an assessment of model performance relative to annual, monthly and daily streamflow observations. Model outputs were compared to streamflow records for several gaging stations throughout the watershed. Four stations served as calibration sites, including HAMEL, RCSL, RCTH and DC. Three additional sites, including EC77, RT and USGS were used to confirm model performance. The most complete data record was available for the USGS station (Elm Creek near Champlin, MN). At other sites there were noticeable data gaps in the observed streamflow throughout the 2000-2012 simulation periods, particularly during winter months. Therefore, streamflow data from the USGS gage at Elm Creek were primarily used to assess model performance with respect to winter/spring hydrology. For the purpose of monthly comparisons, monthly average streamflow was estimated using only months that had 70% or greater daily data coverage. For the purpose of annual comparisons, data gaps were first filled by using a “drainage area ratio” approach to scale daily observed flow at the USGS gage to other stations and then annual average streamflow was estimated.

Model performance was evaluated using visual comparisons of observed and simulated streamflow at annual, monthly, and daily time scales (Figures 4 – 12). The simulation represented a range of hydrologic conditions: a wet year (2002); dry years (2000, 2003, and 2005-2009) and average years (2001, 2004,

[2] 89% of the Elm Creek watershed is simulated as draining through wetlands. In Figure 3, Q_{sur}, Q_{lat}, Q_{tile}, and Q_{gw} are hydrologic contributions from subbasins that enter directly into the stream network without being intercepted by wetlands.

and 2010-2012)[3]. Overall, the model was able to reasonably reproduce the range of hydrologic conditions observed in the watershed including annual, monthly, and daily average streamflows. Calibration stations HAMEL (upstream station) and DC (downstream station) are reviewed below as well as confirmation station USGS (Figures 4 – 12). Graphical results for other calibration and confirmation stations can be found in Appendix C.

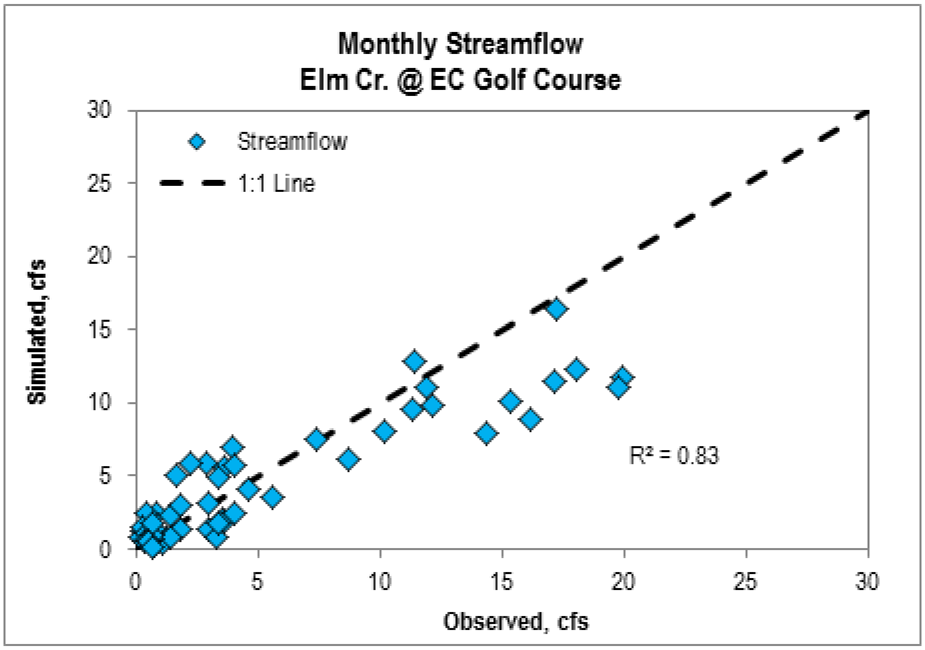


Figure 4. A 1:1 plot of the monthly simulated and observed streamflow at calibration site HAMEL (Elm Creek at the Elm Creek Golf Course) for years 2000-2012.

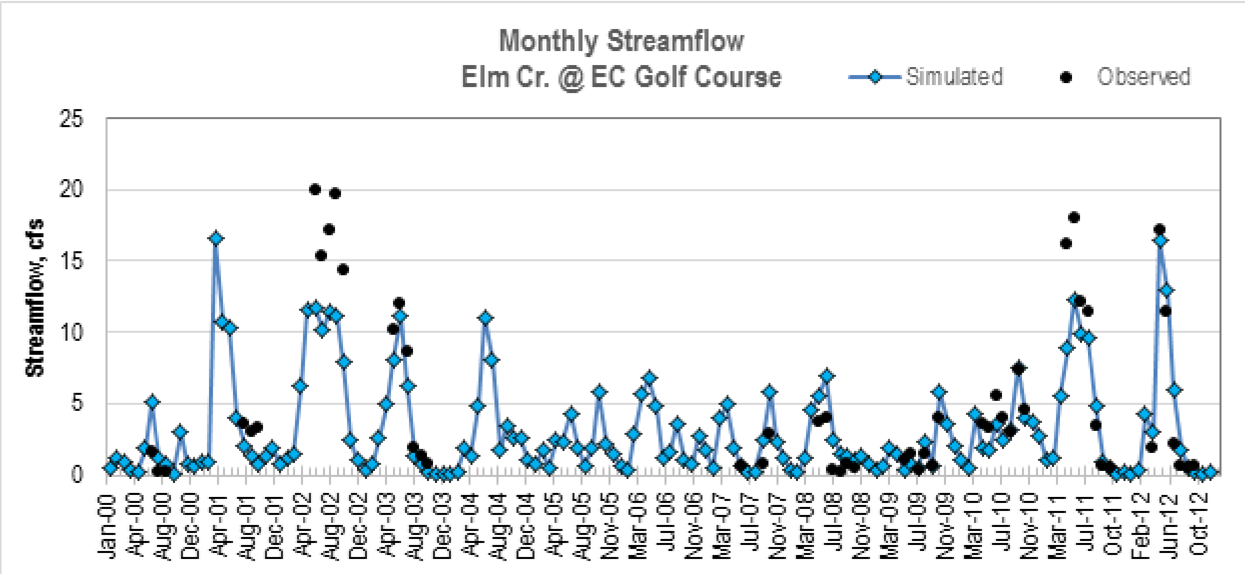


Figure 5. Monthly average simulated and observed streamflow at calibration site HAMEL (Elm Creek at the Elm Creek Golf Course) from 2000-2012.

[3] "Wet" and "dry" are defined here as 110% and 90%, respectively, of the 30 year normal annual precipitation as determined by the National Climatic Data Center for the Minneapolis St. Paul International Airport. Average years are those which fall in the range between "wet" and "dry".

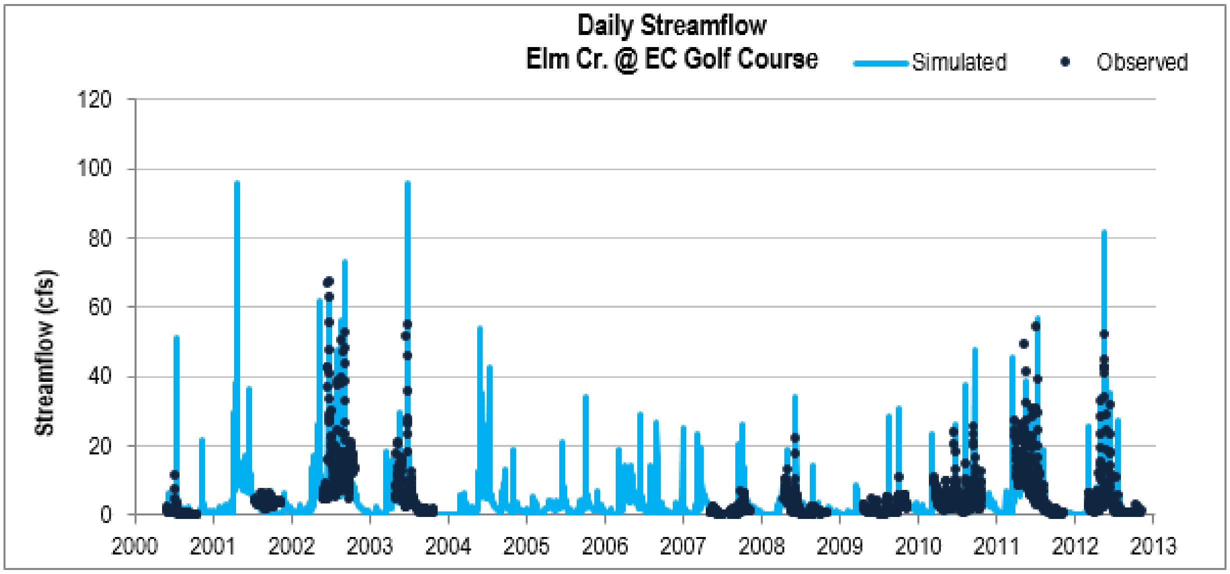


Figure 6. Daily simulated and observed streamflow at calibration site HAMEL (Elm Creek at the Elm Creek Golf Course) from 2000-2012.

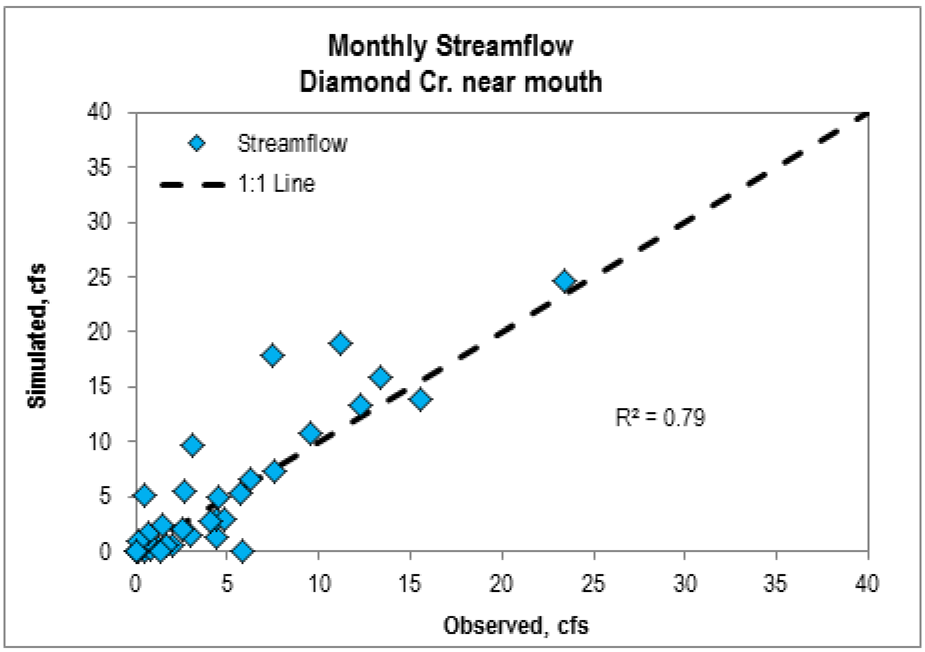


Figure 7. A 1:1 plot of the monthly simulated and observed streamflow at calibration site DC (Diamond Creek near mouth) for years 2007-2012.

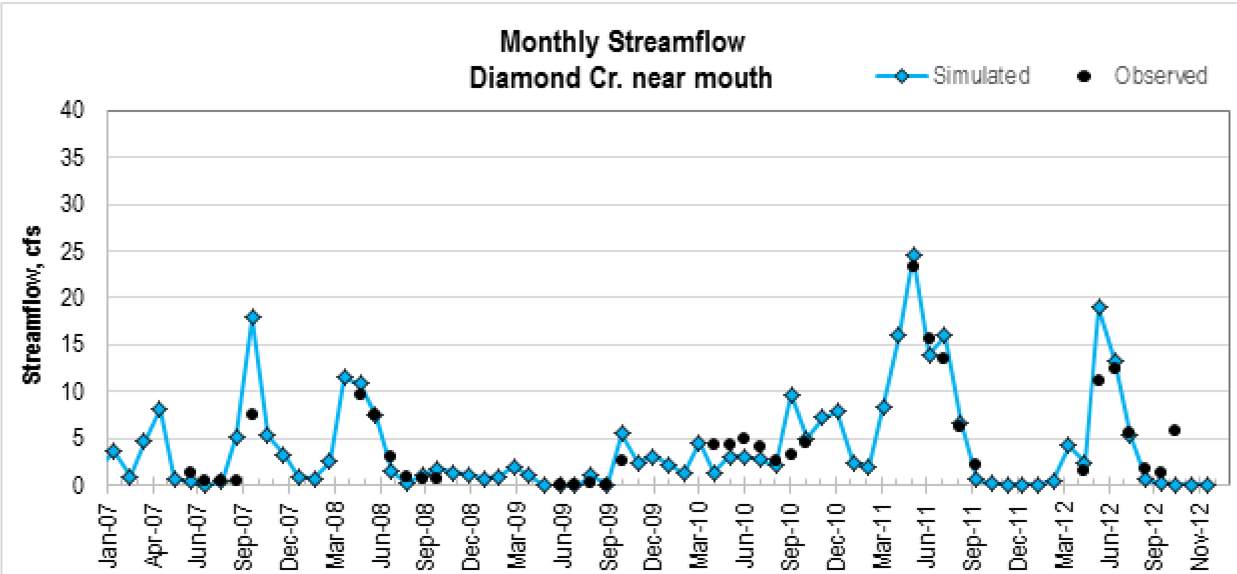


Figure 8. Monthly average simulated and observed streamflow at calibration site DC (Diamond Creek near mouth) for years 2007-2012.

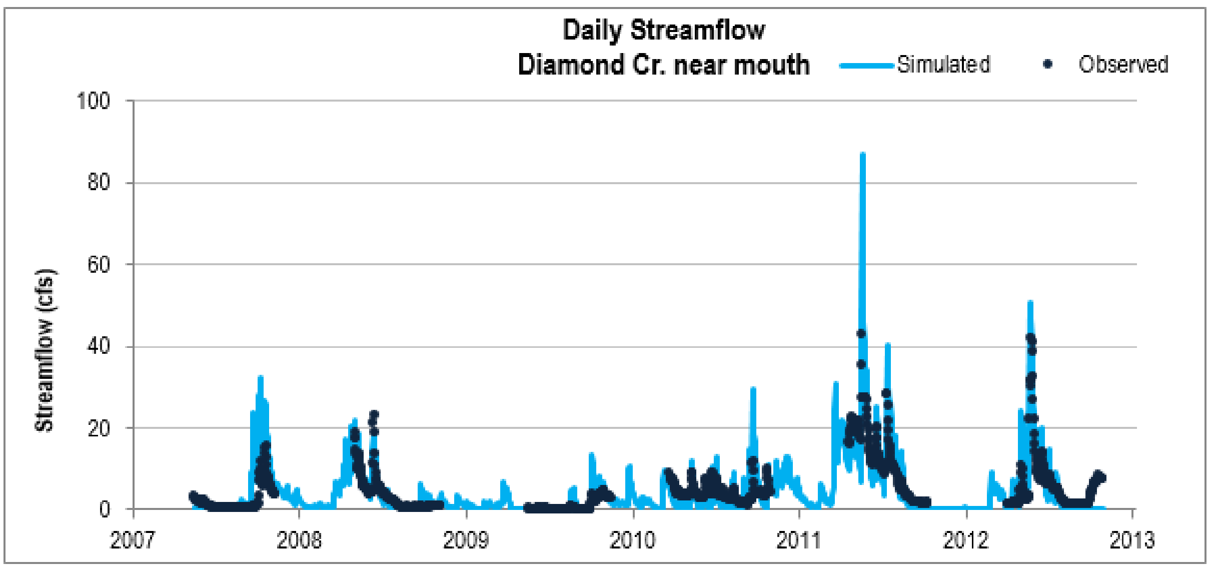


Figure 9. Daily simulated and observed streamflow at calibration site DC (Diamond Creek near mouth) for years 2007-2012.

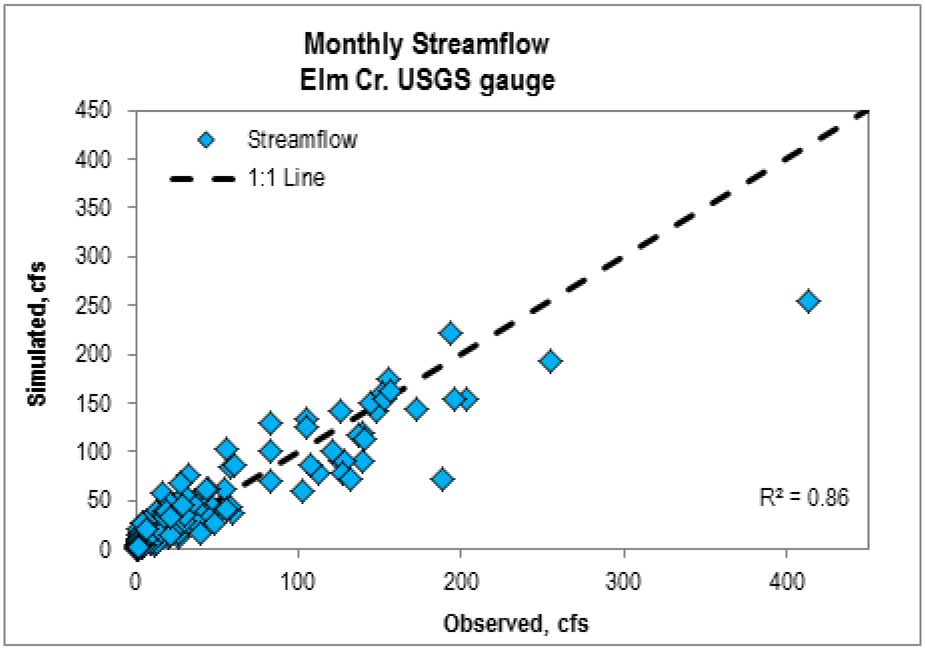


Figure 10. A 1:1 plot of the monthly simulated and observed streamflow at confirmation site USGS Elm Creek (USGS gage 05287890) for years 2000-2012.

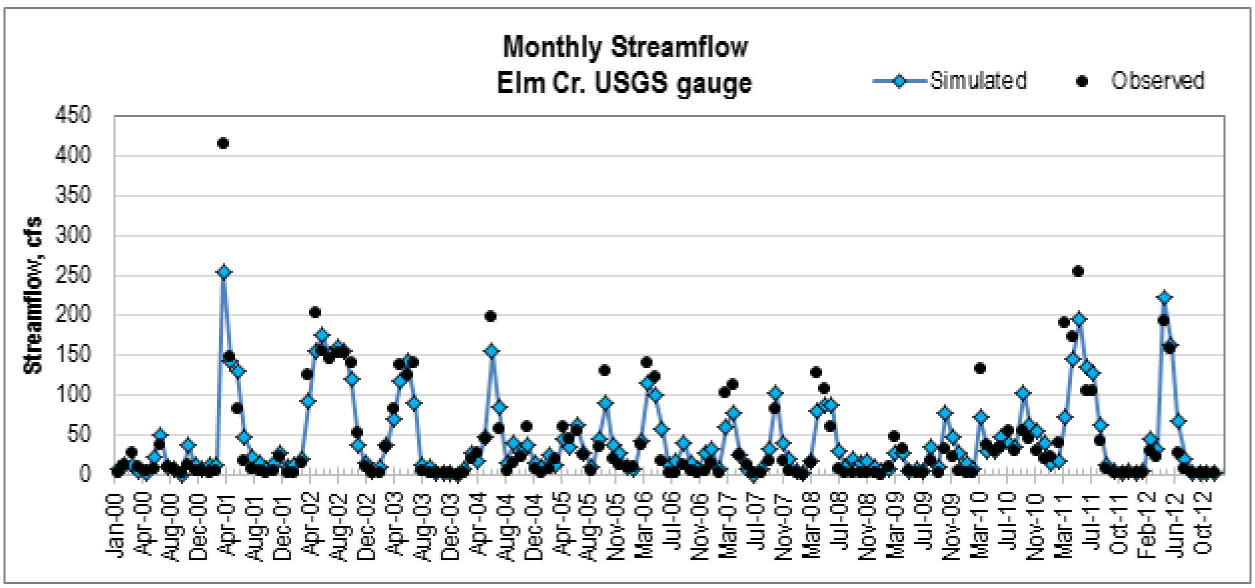


Figure 11. Monthly average simulated and observed streamflow at confirmation site USGS Elm Creek (USGS gage 05287890) for years 2000-2012.

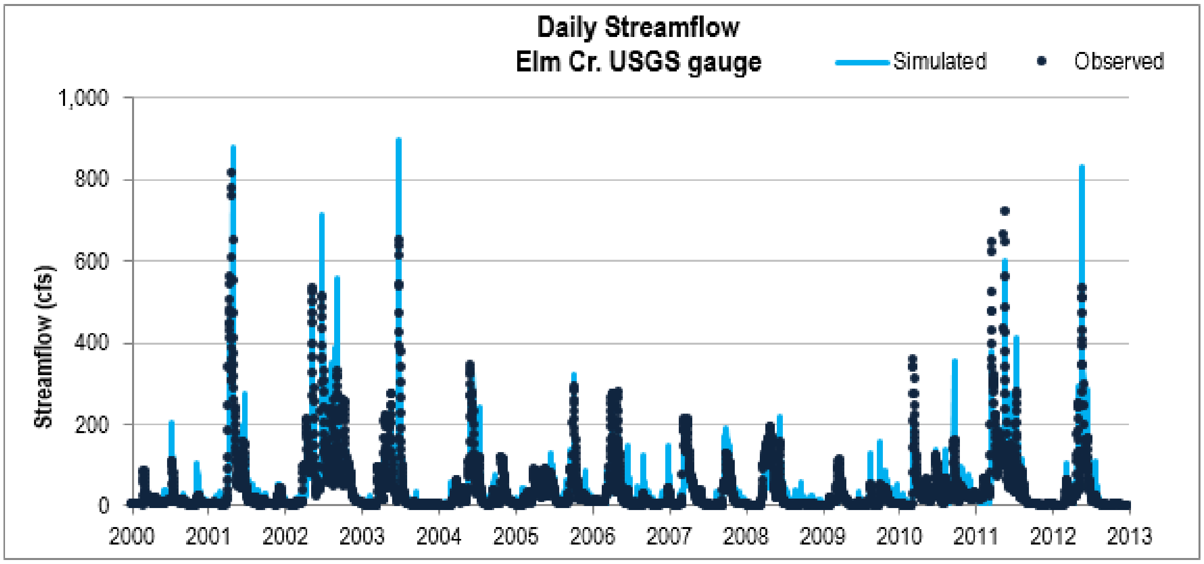


Figure 12 Daily simulated and observed streamflow at confirmation site USGS Elm Creek (USGS gage 05287890) for years 2000-2012.

The statistical targets and model results for the hydrology calibration are shown in Table 6. Overall, the calibration of streamflow resulted in a "very good" model performance based on statistical and visual comparison of observed and simulated streamflow (Table 6, Figures 4-12). A brief summary of the model performance is provided below:

- The annual and monthly r^2 values are greater than 0.57 ("very good" performance);
- The annual NSE values are above 0.85 ("very good" performance) for all calibration stations and above 0.86 ("very good" performance) for all confirmation stations;
- Monthly NSE values at all calibration and confirmation stations are greater than 0.50 and meet the "very good" target performance standards; and
- At the annual and monthly time scales, the PBIAS ranges from ±37.45% to ±2.48% with 8 values rated as "very good" and 5 values rated as "satisfactory". Monthly PBIAS for station RCTH rated as "unsatisfactory".

The relatively high monthly PBIAS value for station RCTH is a consequence of the model not reproducing large flow events that occurred between May 22nd, 2011 and May 24th, 2011. The model under-predicted this flow event at all Rush Creek stations, and this model behavior contributed significantly to the "unsatisfactory" PBIAS metric. The precipitation inputs to the Rush Creek sub basins were represented by Medina, Rockfork and Anoka stations. The total rainfall amount recorded over the two day period of May 21st to May 22nd at three stations varied between 71 mm and 107 mm. It is possible that the high streamflow response during May 21 – 22, 2011 observed in Rush Creek tributaries was caused by a strong local rainfall event not captured by the precipitation stations represented in the model.

The model also under predicted streamflow at HAMEL during 2002. Peak streamflows observed at HAMEL were typically sustained for few days and were characterized by an extended recession to the baseflow. ECWSWAT was able to predict the event magnitude reasonably well, but the sustained peak flow response was not captured by the model. Possible reasons for this discrepancy include under-representation of precipitation used in the model for 2002 and/or potential external groundwater influence to the HAMEL subbasins.

Table 6. Calibration and confirmation statistics for the streamflow model performance evaluation

		Calibration				Confirmation		
Time Interval	Statistic	HAMEL	RCTH	RCSL	DC	USGS	EC77	RT
Annual	*Coeff. of Determination (R^2)*	0.94	0.75	0.90	0.95	0.96	0.87	0.75
	Nash-Sutcliffe Efficiency (NSE)	0.91	0.85	0.93	0.97	0.98	0.91	0.86
	Percent Bias (PBIAS)	16.13	-18.35	12.76	2.48	-3.36	7.64	20.95
Monthly	*Coeff. of Determination (R^2)*	0.83	0.57	0.87	0.79	0.86	0.85	0.74
	Nash-Sutcliffe Efficiency (NSE)	0.77	0.53	0.86	0.65	0.84	0.84	0.58
	Percent Bias (PBIAS)	15.36	-37.45	6.80	-14.56	-3.38	2.97	20.81
Daily	*Coeff. of Determination (R^2)*	0.41	0.32	0.45	0.66	0.63	0.17	0.25
	Nash-Sutcliffe Efficiency (NSE)	0.37	0.31	0.43	0.36	0.63	-0.16	0.21
	Percent Bias (PBIAS)	14.84	-33.02	14.92	-12.12	-3.35	2.34	19.21

In summary, the hydrology calibration and confirmation of the Elm Creek watershed resulted in achieving a large majority of the model performance targets. The model is able to simulate watershed hydrology and streamflow with a reasonable level of accuracy and therefore provides a suitable foundation for the simulation of land management scenarios to estimate the potential benefits of best management practices (BMPs) and the potential impacts of land development in the Elm Creek watershed. The final hydrology model calibration parameters are provided in Appendix B.

Sediment

Soil erosion is a function of climate, soils, land use/land cover, and land management practices. Sediment load yields are computed at the HRU level within the SWAT model. The Modified Universal Soil Loss Equation (MUSLE) is used to calculate upland sediment yields (Williams 1975, Williams 1995, Neitsch et al. 2011). As with the hydrologic components, erosion loads are aggregated at the subbasin level, routed through the wetlands (if necessary), and then added to the channel (reach) system. In SWAT, wetlands settle out sediment as a function of a user defined settling rate coefficient (also used for reservoir sediment settling) and particle size. Once in the reach, sediment routing is simulated using the simplified version of the Bagnold approach (Bagnold 1977) where sediment transport is a function of peak channel velocity (Neitsch et al. 2011).

The main objective of the sediment calibration was to achieve an appropriate representation of sediment contributions from upland sources. Upland sediment loads generally expected from various land use types (i.e., watershed UALs for each land use type) were obtained from literature (CH2M Hill and AquaTerra Consultants 2002). Model parameters were adjusted to achieve similarity between the simulated and literature reported UALs for each land use type. It is important to note that the literature-based and simulated UALs discussed in this section reflect sediment loadings from the landscape prior to being routed through the wetlands.

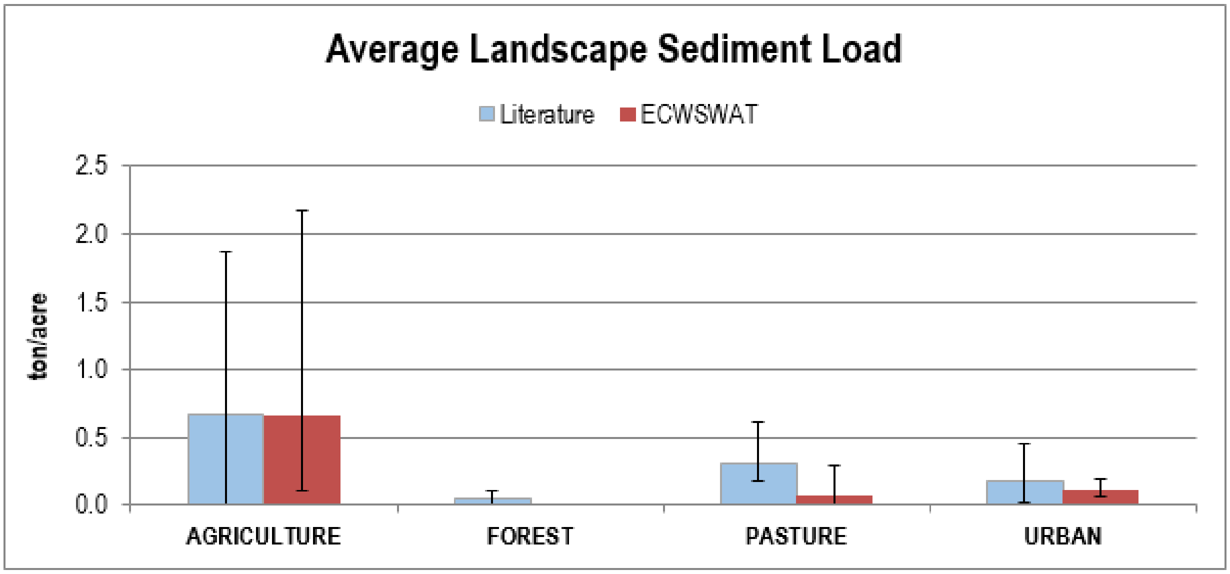


Figure 13 Average annual simulated landscape sediment loading in the Elm Creek SWAT model as compared to literature values. Whiskers represent maximum/minimum values to quantify the literature and simulated ranges. Literature UALs were compiled from CH2M Hill and AquaTerra Consultants (2002)[4].

Loads from agricultural HRUs (land areas characterized by corn and soy rotations) compared well with the literature average values (Figure 13). This was an especially important target to meet, as agricultural land areas make up roughly 27% of the modeled watershed area. Forested land areas tended to only export appreciable sediment amounts during years of high precipitation. The average annual sediment loads for this land type were somewhat lower than literature values. This was deemed acceptable as forest area accounted for approximately 5% of the total area and was not modeled as having any logging or fire operations which could increase sediment yields. Pastured HRUs tended to generate lower sediment yield than represented by literature-based values. This might be explained by the inclusion of degraded pasture areas in the literature review which could be expected to have elevated sediment export. Pastured areas in the Elm Creek SWAT model were simulated as alfalfa areas under haying operation and were expected to transport much less sediment to the reaches than agricultural areas. The sediment UALs from the urban HRUs compared well with the literature values.

A summary comparison of model-predicted UAL values and UALs reported in literature sources is shown in Table 7. Overall, the model-predicted UALs compared reasonably well with the literature values, particularly for the land use (agriculture) that accounts for the largest percentage of land area in the watershed. The consistency between SWAT-predicted and literature-based UALs suggest that the model is able to simulate landscape sediment loading and delivery with a reasonable level of accuracy.

[4] All TSS, TN, and TP "URBAN" literature values, referenced in the figures and tables, are average of Urban-Low Density & Urban-Medium Density land uses, as these two land uses make up nearly 97% of the urban land areas represented in the ECWSWAT model.

Table 7 Comparison of simulated and literature-based unit area loads for the Elm Creek watershed. Literature UALs were compiled from (CH2M Hill and AquaTerra Consultants 2002).

	Sediment (tons/acre/yr)		
Land Use Type	Literature Range	Literature Average	Elm Creek SWAT
Agriculture	0.009 - 1.87	0.67	0.66
Urban	0.04 - 0.45	0.18	0.11
Forest	0.008 - 0.11	0.04	0.003
Pasture	0.18 - 0.61	0.31	0.06

After establishing reasonable agreement of model simulation and literature reported UALs, in-stream sediment transport was simulated. Model parameters related to sediment settling and re-suspension were adjusted in order to bring simulated in-stream TSS concentrations within the range of observed values. This process continued until it was determined that the best possible results had been achieved, given the available data and model limitations.

A large proportion of the sediment mobilized from the landscape settled in the reservoir systems represented in the model. The stream channels in the Elm Creek watershed are a small net source of sediments. Over the 2000-2012 simulation period, the average sediment loading rate at the watershed outlet is 0.017 tons/acre/year. This loading rate is consistent with 0.010 – 0.025 tons/acre/year reported for neighboring Bassett Creek (MCES, 2010). The ECWSWAT simulated watershed delivery ratio is 29% (i.e., of total sediment mobilized within the watershed 29% is delivered to the outlet).

Table 8. Simulated annual average landscape sediment delivery to the watershed outlet for the Elm Creek watershed (2000-2012).

Subbasin[5] Yield (tons/year)	Net Settling in Reservoirs (tons/year)	Net Channel Erosion (tons/year)	Sediment Yield at outlet (tons/year)
3,505	(2,583)	133	1,008

The total annual average sediment load (2000-2012) simulated by the SWAT model at the outlet of the watershed is 1,008 tons/year. The total landscape sediment yield (3,505 tons/year) and the contributions by land use types simulated by the SWAT model are shown in Figure 14. Soil erosion from cropland areas contributes the majority of the sediment originating from the upland landscapes, which is expected given that cropland is a dominant land use in the watershed and characterized by the highest UAL rate.

[5] Subbasin yield represents sediment loading after transport through the wetlands.

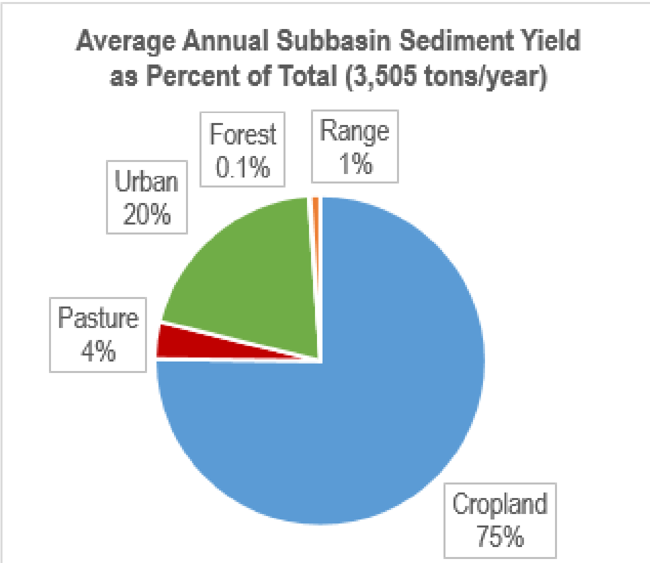


Figure 14. Average annual simulated sediment load (2000-2012) by land use type, as estimated by the SWAT model for the Elm Creek Watershed.

A comparison of simulated and observed TSS measurements (Figures 15 and 16) shows that the Elm Creek SWAT model is predicting in-stream TSS concentrations within acceptable ranges.

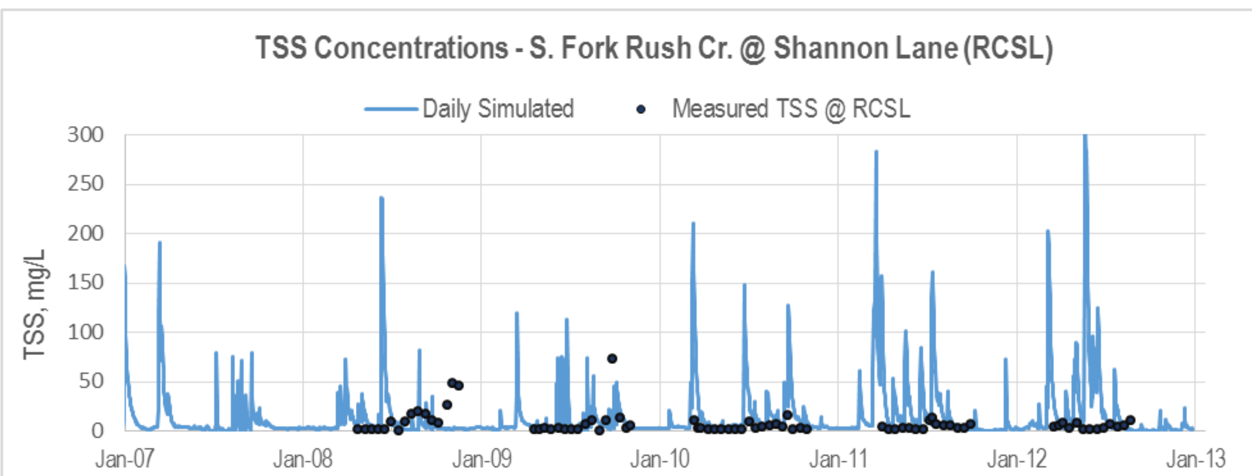


Figure 15. Simulated and observed TSS concentrations at station RCSL (S. Fork Rush Creek @ Shannon Lane). Simulated values are plotted as five day moving averages.

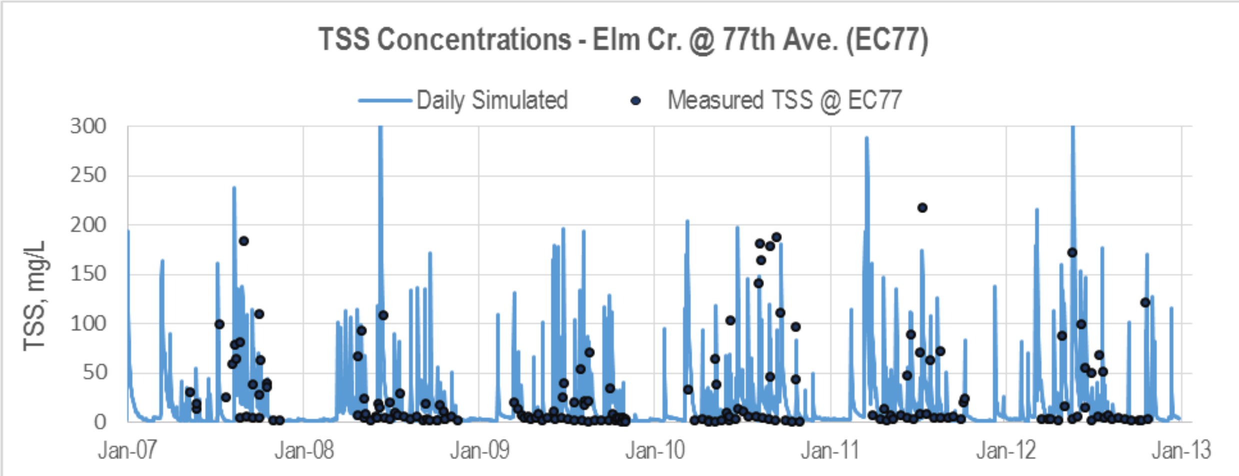


Figure 16. Simulated and observed TSS concentrations at station EC77 (Elm Creek @ 77th Ave.). Simulated values are plotted as five day moving averages.

Nitrogen

Upland nitrogen cycling and transport is an HRU level process in SWAT. The main components of the nitrogen cycle represented in SWAT include nitrogen storage in the soil matrix, nitrogen added in the form of manure or mineral fertilizer, and nitrogen stored in live plant biomass and residue. SWAT model algorithms simulate the mineralization, decomposition, and immobilization processes that control the transformations of soil nitrogen (Neitsch et al. 2011). Nitrogen processes simulated by SWAT include crop uptake, transport in surface runoff in both the solution phase and on eroded sediment, percolation below the root zone, lateral subsurface flow including tile drains, and volatilization to the atmosphere (Neitsch et al. 2011). The cycling and transport of nitrogen in SWAT is determined by the simulated hydrology, plant growth, and erosion processes. Nitrogen loads generated at the HRU level are aggregated to the subbasin level, routed through connected wetlands, and then added into the channel associated with the subbasin. Nutrient (phosphorus and nitrogen) routing includes the fate and transport of nutrients based on instream kinetics adapted from the QUAL2E model.

The calibration approach for total nitrogen is similar to that described for sediment. Upland nitrogen yields typically expected from various land use types (i.e., UALs for each major land use type) were obtained from literature. These literature average UAL values served as the calibration targets for the landscape loadings of TN simulated by the SWAT model.

Landscape unit area loadings of TN by land use type generally compared well with the literature values (Figure 17, Table 9). Consistent with the literature values, the TN loading rates were the highest from the agriculture areas and lowest from the forest landscape. After agriculture areas, TN loadings were highest for the pasture areas that were modeled as receiving manure treatment. The SWAT-predicted UALs of TN for the urban areas were also within the range of literature average values. Overall croplands and pasture contribute 62% and 22%, respectively, of the TN delivered from upland to the main channel (Figure 18).

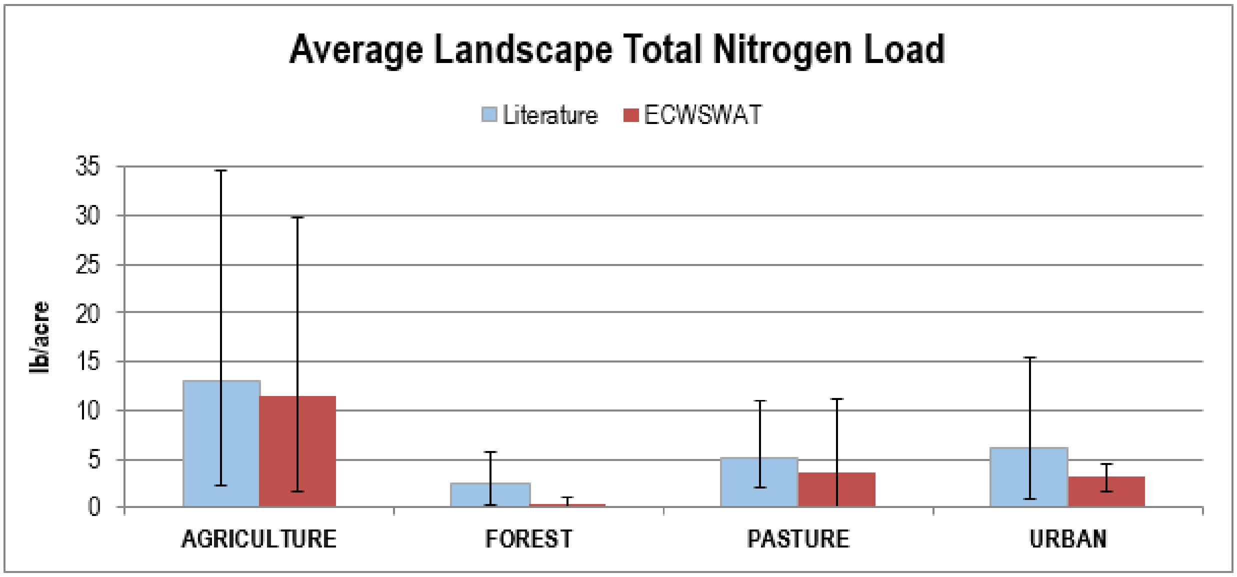


Figure 17. Average annual simulated landscape sediment loading in the Elm Creek SWAT model as compared to literature values. Whiskers represent maximum/minimum values to quantify the literature and simulated ranges. Literature UALs were compiled from CH2M Hill and AquaTerra Consultants (2002).

Table 9. Total nitrogen UALs from the calibrated Elm Creek SWAT model (2000-2012). Literature UALs were compiled from (CH2M Hill and AquaTerra Consultants, 2002).

	TN (lbs/acre/yr)		
Land Use Type	Literature Range	Literature Average	Elm Creek SWAT
Agriculture	2.23 - 34.6	12.9	11.4
Urban	0.78 - 15.4	6.2	3.1
Forest	0.35 - 5.7	2.5	0.4
Pasture	2.1 - 11.0	5.2	3.7

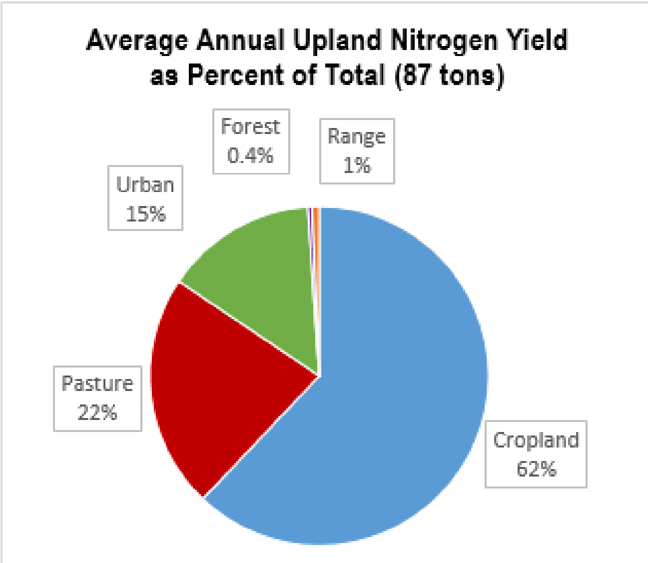


Figure 18. Average annual simulated nitrogen load (2000-2012) by land use type, as estimated by the SWAT model for the Elm Creek Watershed.

Following calibration of the landscape TN loading, wetland processes were activated in the model. Model simulations suggest that the wetlands were a net sink for nitrogen, removing 21% of the total nitrogen originating from the landscape and entering the wetlands. Finally, in-stream and reservoir parameters were adjusted to achieve a reasonable agreement between simulated and observed in-stream TN concentrations (Figures 19 and 20). Parameters that were modified during this calibration process are provided in Appendix B.

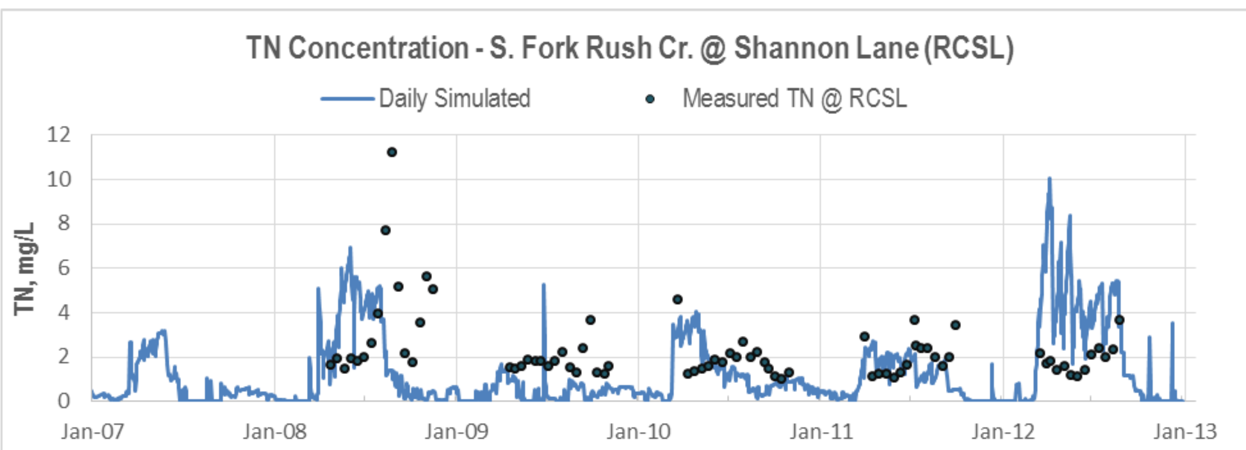


Figure 19. Simulated and observed TN concentrations at station RCSL (S. Fork Rush Creek @ Shannon Lane). Simulated values are plotted as five day moving averages.

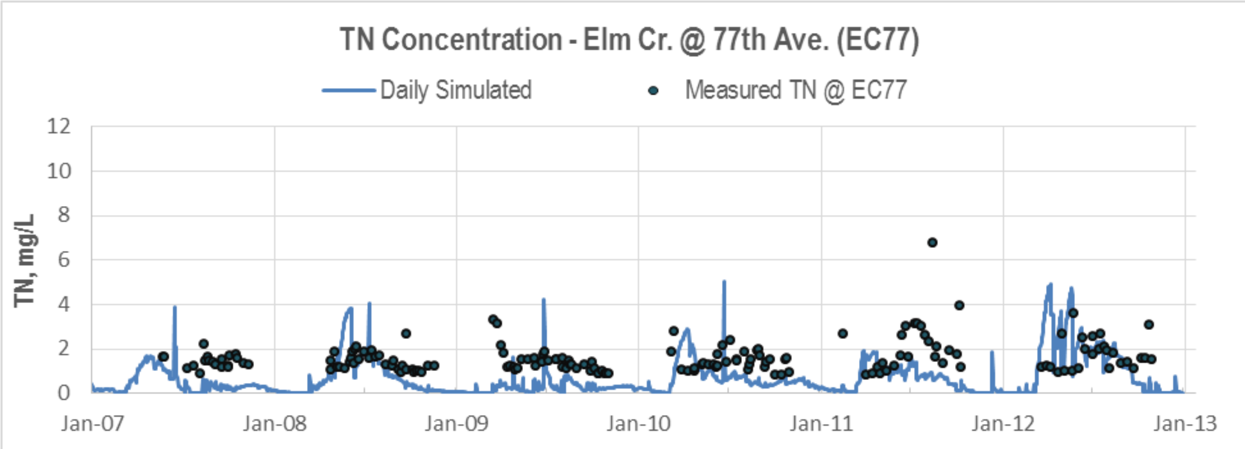


Figure 20. Simulated and observed TN concentrations at station EC77 (Elm Creek @ 77th Ave.). Simulated values are plotted as five day moving averages.

The model-simulated annual average (2000 – 2012) TN yield for the Elm Creek watershed is 1.95 lbs/acre/year at the outlet. This is comparable to the TN outlet yield of the Mississippi River – Twin Cities watershed which is between 3.3 and 5.0 lbs/acre/year (MPCA 2013). Annual TN loading simulated at the USGS gage varied between 7.5 and 137.4 tons per year (Figure 21). Simulated results suggest that the largest component of this load comes from the north and south branches of the Rush Creek, which drains the rural portion of the watershed that is characterized by the highest levels of agricultural activity.

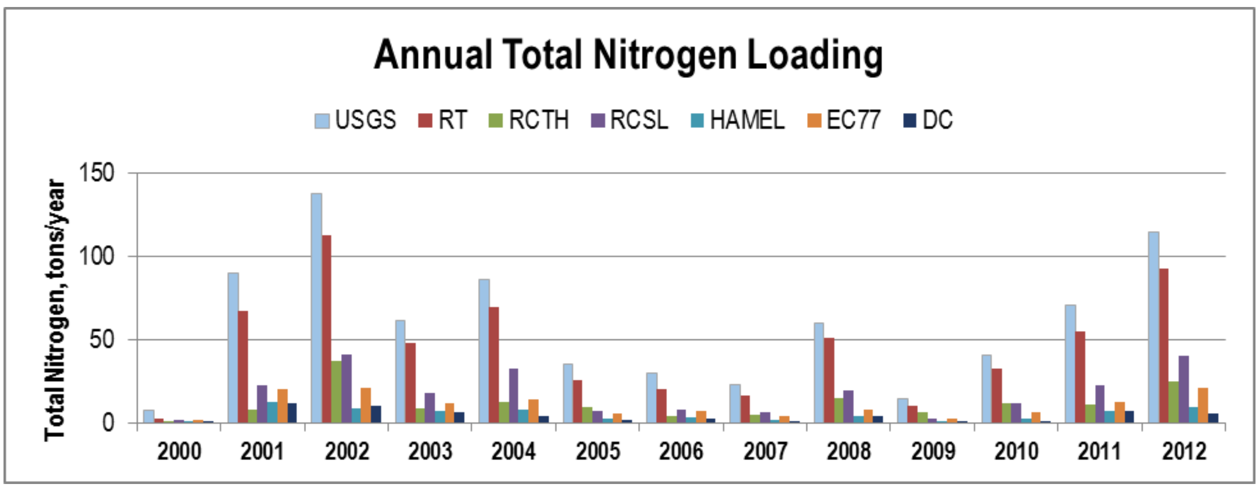


Figure 21. Simulated annual total nitrogen loads at select gages for years 2000 – 2012 in the Elm Creek watershed.

Monthly average TN loads are summarized in Figure 22. The average monthly TN load peaks in June. When averaged across all stations, roughly 84% of the annual nitrogen load occurs during the five months between March and July, during periods of spring runoff and early summer storms. A large majority of the model-simulated TN is in the form of nitrate (95% on average). Nitrate represents more than 75% of the TN loads for many of the major river basins in Minnesota (MPCA 2013). The hydrology of the Elm Creek Watershed results in a particularly high contribution of nitrate to the overall TN load because particulate organic forms of nitrogen have a high probability of being deposited as they are routed through the various wetland complexes and reservoirs present in the watershed.

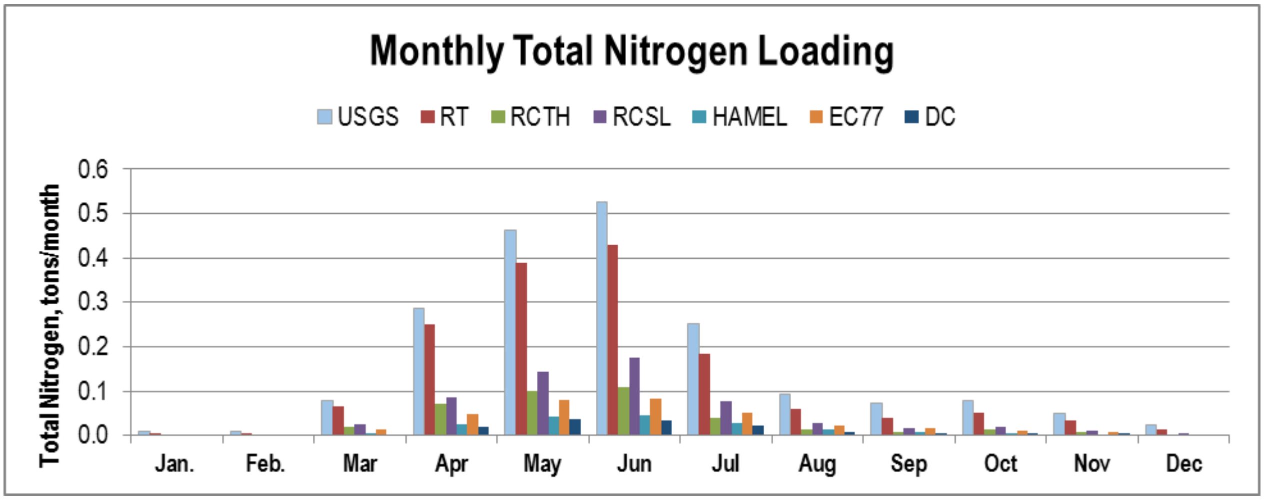


Figure 22. Simulated average monthly total nitrogen loading by station for the Elm Creek watershed (2000 – 2012).

Phosphorus

Upland phosphorus cycling and transport is an HRU level process in SWAT. The main components of the phosphorus cycle represented in SWAT include phosphorus stored in the soil matrix, phosphorus added in the form of manure or mineral fertilizer, phosphorus stored in live plant biomass and residue, and sediment-associated phosphorus buildup on impervious surfaces (Neitsch et al. 2011). SWAT model algorithms simulate the mineralization, decomposition, and immobilization processes that control the transformations of soil phosphorus. Other soil phosphorus processes simulated by SWAT include inorganic phosphorus sorption-desorption, leaching to groundwater, and surface runoff transport of soluble and sediment-bound phosphorus (both mineral and organic forms) (Neitsch et al. 2011). The cycling and transport of phosphorus in SWAT is determined by simulated hydrology, plant growth, and erosion processes. Phosphorus loads generated at the HRU level are aggregated to the subbasin level, routed through connected wetlands, and then added into the channel associated with the subbasin. Phosphorus fate and transport in the channel are computed based on instream kinetics adapted from the QUAL2E model.

The calibration approach for TP was similar to that described for sediment and TN – i.e., model-simulated upland UALs of TP for various land use types were evaluated to achieve consistency with the corresponding literature values. Model-predicted UALs for various land use types compared reasonably well with the literature values (Figure 23, Table 10). Croplands constitute the most significant source of TP in surface waters and generate higher phosphorus yields than other land types/uses in the watershed. Forested landscape is the least significant source of TP to the surface waters. Model-predicted TP yield from urban landscape tended to be close to the minimum values reported in the literature for this land use. The relatively low TP yield from the urban areas can be attributed to the specification of P-free fertilizer input in the model for urban HRUs. Minnesota began regulating the use of P-containing fertilizer on lawns and turf beginning in 2004. In recent years the use of lawn fertilizers without a phosphorus component has become a common practice. It is likely that the literature reported UALs reflect conditions before the legislative decisions regarding P-free lawn fertilizer came into effect.

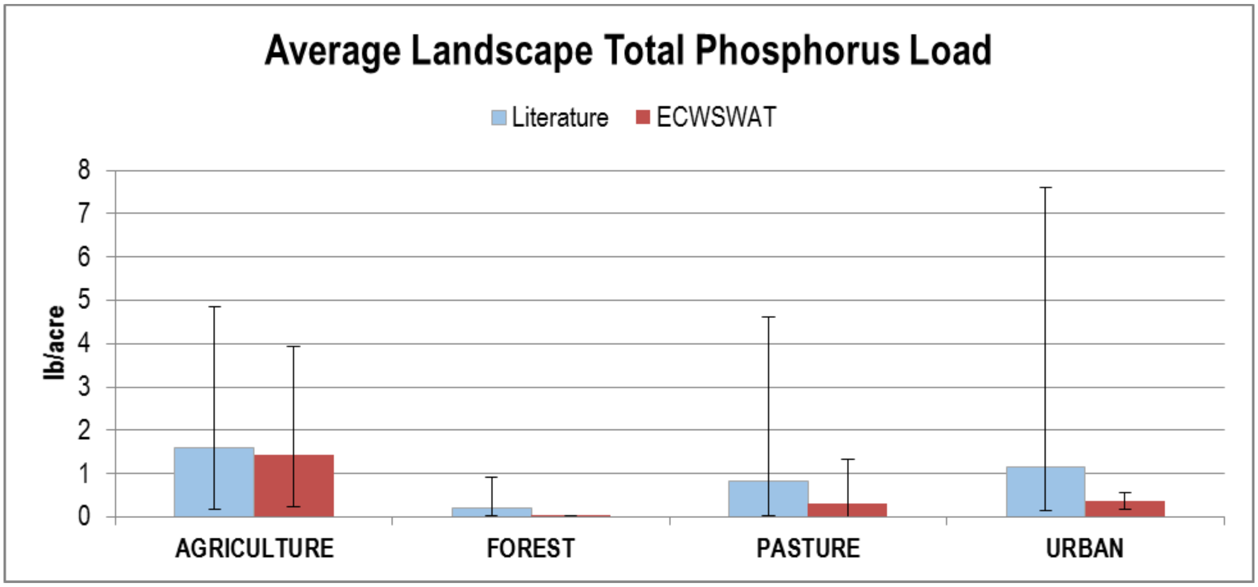


Figure 23. Average annual simulated landscape total phosphorus loading in the Elm Creek SWAT model as compared to literature values. Whiskers represent maximum/minimum values to quantify the literature and simulated ranges. Literature UALs were compiled from (CH2M Hill and AquaTerra Consultants 2002).

Table 10. Total phosphorus UALs from the calibrated Elm Creek SWAT model (2000 – 2012). Literature UALs were compiled from CH2M Hill and AquaTerra Consultants (2002).

	TP (lbs/acre/yr)		
Land Use Type	Literature Range	Literature Average	Elm Creek SWAT
Agriculture	0.2 - 4.9	1.6	1.4
Urban	0.15 - 7.6	1.2	0.4
Forest	0.01 - 0.9	0.2	0.01
Pasture	0.04 - 4.6	0.8	0.3

Among the various land use types, croplands export the most TP to surface waters in the Elm Creek watershed (Figure 24). A total of 56% of landscape TP comes from agricultural land areas. Pastured land areas contribute about 10% of total phosphorus landscape yields, while urban areas contribute 31% of TP. Forested and range areas contribute little phosphorus compared to the overall totals.

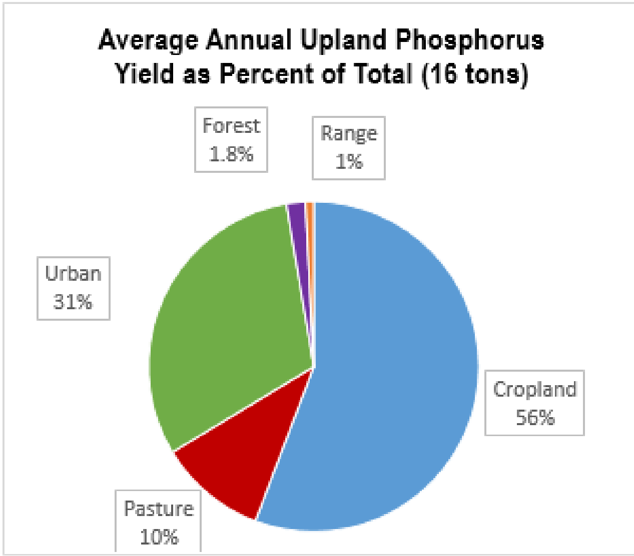


Figure 24. Average annual simulated phosphorus load (2000 – 2012) by land use types, estimated by SWAT model for the Elm Creek watershed.

The major forms of TP simulated by the SWAT model from upland landscape include soluble reactive phosphorus (SRP), particulate inorganic phosphorus and organic phosphorus. Prior to routing through the wetlands, model-simulated organic phosphorus constitutes approximately 80% of the TP. Particulate inorganic phosphorus, the form of inorganic phosphorus attached to sediment, accounts for 8% of TP. SRP represents the remaining 12% of TP.

Following calibration of the landscape TP loading wetlands, reservoirs and in-stream processes were activated in the model. Relevant model parameters were adjusted to achieve a reasonable agreement between simulated and observed in-stream TP concentrations. Modifications to the wetland parameters included specifying a SRP release rate during summer months (May through August). Wetlands behaved as a net source of SRP and a net sink for organic phosphorus. Parameters that were modified during this calibration process are provided in Appendix B. A comparison of the predicted and observed TP concentrations for the RCSL and EC77 monitoring stations are shown in Figures 25 and 26. The SWAT predicted in-stream TP concentrations are within the range of observed values, suggesting that the representation of TP delivery and transport in the model is reasonable for the Elm Creek Watershed.

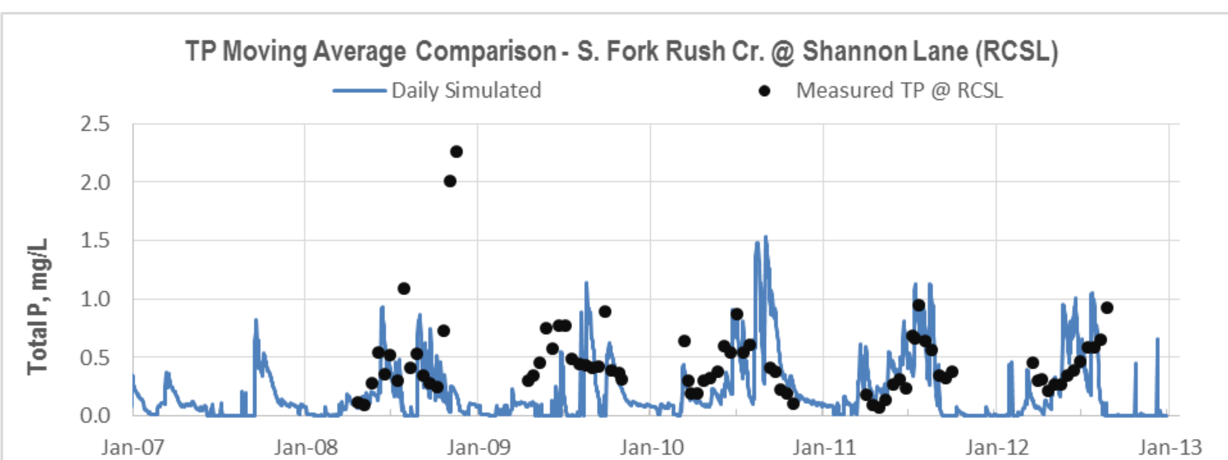


Figure 25. Simulated and observed TP concentrations at station RCSL (S. Fork Rush Creek @ Shannon Lane). Simulated values are plotted as five day moving averages.

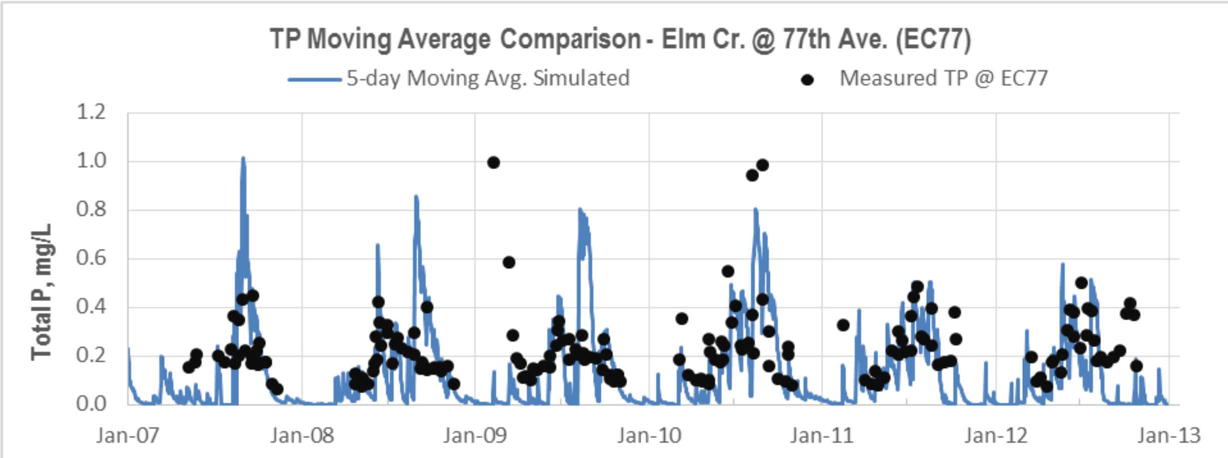


Figure 26. Simulated and observed TP concentrations at station EC77 (Elm Creek @ 77th Ave.). Simulated values are plotted as five day moving averages.

The simulated average annual TP yield at the watershed outlet for the simulation period (2000 - 2012) was 0.42 lbs/acre/year. This compares well with the range of 0.21 to 0.5 lbs/acre/year reported for the neighboring Bassett Creek watershed (MCES 2010). Annual TP loadings at the USGS gauge varied between 2 and 43 tons per year (Figure 27). Model results suggest that Rush Creek is a significant source of TP loads, with roughly equal amounts coming from the north and south branches.

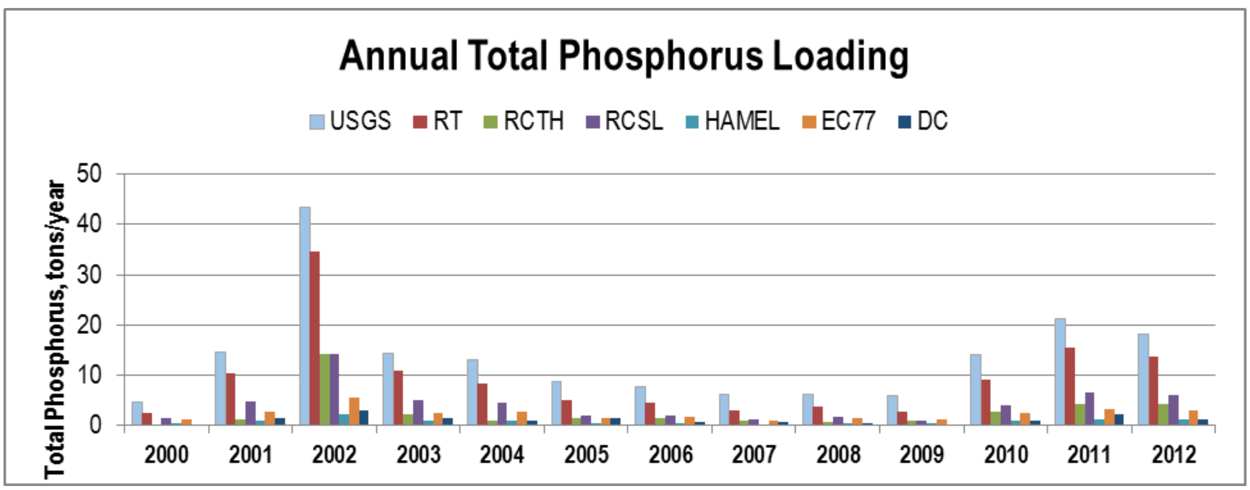


Figure 27. Simulated annual total phosphorus loads at select gages for years 2000 – 2012 in the Elm Creek watershed.

Model-simulated monthly average TP loads are summarized in Figure 28. TP loadings typically tend to peak in June. Roughly 66% of the total annual TP load occurs during the five months from March to July, likely due to large spring runoff events. A large majority of the model simulated in-stream TP loads are in the form of soluble reactive phosphorus (70% on average). Wetlands in the ECWSWAT model served as a net sink of organic P but a net source of SRP. Because wetlands were modeled as a net source of SRP, the proportion of SRP in TP is significantly higher in the in-stream loading (70%) relative to the landscape loading (12%). The model-simulated SRP proportion of TP in stream reaches is generally consistent with the measured data as SRP tends to comprise 57% of measured TP at station EC77 and 70% of measured TP at station RCSL.

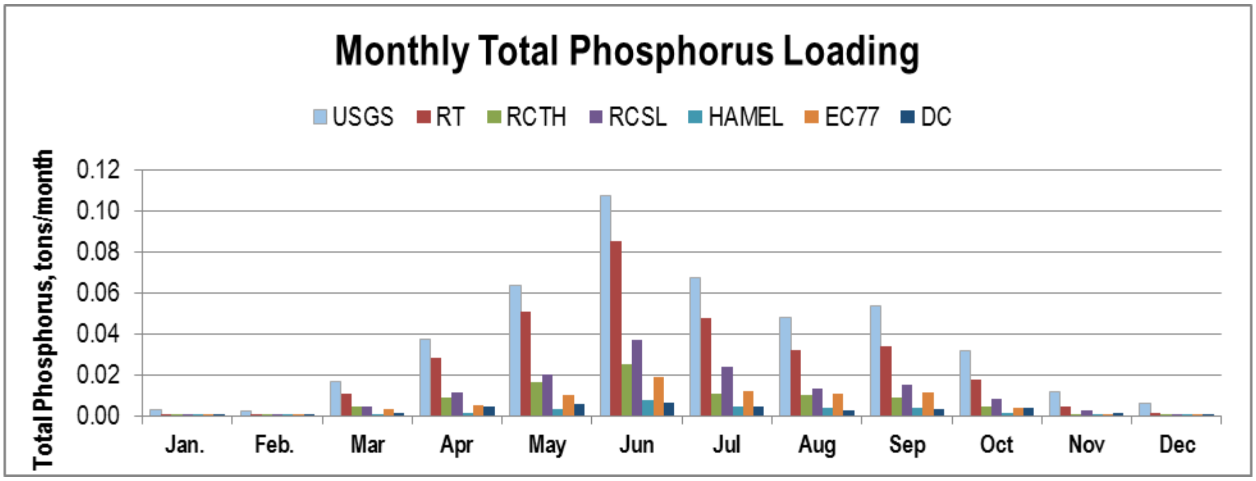


Figure 28. Simulated average monthly total phosphorus loading by station for the Elm Creek watershed (2000 – 2012).

Summary

This memorandum describes the development and calibration of a SWAT model for the Elm Creek Watershed. The ECWSWAT model was calibrated for hydrology, sediment, TP and TN. The hydrology calibration was performed using available streamflow monitored at several locations within the watershed. For sediments and nutrients the model calibration was performed with the primary objective of quantifying landscape loadings to the stream network. Sediment (as TSS) and nutrient calibrations were performed by comparing landscape loading of constituents to the available literature UALs associated with the various land use categories. As an additional check, SWAT-predicted in-stream concentrations of TSS, TP, and TN were compared to observed concentrations at various monitoring locations to ensure that the model reasonably represents wetland, channel, and reservoir source/sink and transport processes.

The model simulation of hydrology is in very good agreement with the observed streamflow conditions at eight monitoring locations within the watershed. The calibrated model also performed reasonably well in predicting loading rates of TSS, TN and TP expected from the various land use categories. Model simulations suggest that croplands are a significant contributor of TSS, TP and TN in the Elm Creek Watershed. Once the model predictions of landscape loadings were constrained, wetland and in-stream processes were activated and used to simulate delivery to reach outlets and the watershed outlet. The Elm Creek watershed had an estimated annual average (2000 – 2012) loading at the outlet of 0.017 tons/acre for TSS, 1.95 lbs TN/acre and 0.42 lbs TP/acre.

Limitations of the model calibrations are noted as follows. The primary focus of the sediment and nutrient calibration was to characterize the load contributions from the upland landscape. The ECWSWAT model performed reasonably well in predicting constituent loadings from the landscape. However, the sediment and nutrient calibrations were not constrained by observed data, but rather based on comparisons of model-predicted yields with available literature values. The literature UALs were compiled from various modeling studies representing a wide range of conditions. Therefore, the model-predicted landscape sediment and nutrient yields have some inherent uncertainty. The complex hydrologic interactions within the Elm Creek Watershed were represented in the ECWSWAT model using wetlands, reservoir and stream network features. In-stream processes were simulated and model-predicted constituent concentrations (TSS, TN, and TP) were compared with observed data as a cursory check. Model-predicted constituent concentrations were within the range of observed values.

Overall, the ECWSWAT model was able to simulate the hydrology and transport of pollutants under the land use systems, climate, hydrologic and physiographic settings of the Elm Creek Watershed. The model was able to reproduce temporal (i.e., annual, monthly and daily) variations in streamflow and unit area loadings of sediment and nutrient from landscape. Thus the performance of the ECWSWAT provides confidence that the model can be used to inform landscape loadings to lakes within the watershed and linked with other in-stream or lake models.

Some limitations with SWAT associated with process representations of wetlands, reservoirs and in-stream transport should be considered when applying the model or using the results to inform watershed management. SWAT provides a relatively simplified framework for wetland, reservoir and in-stream representation, and some of the important processes controlling sediment and nutrients delivery are not represented.

References

Bagnold, R.A. 1977. Bedload transport in natural rivers. Water Resources Research, Vol. 13, pp. 303-312.

Bierman, P., Rosen, C., Venterea, R., and Lamb J. 2011. Survey of Nitrogen Fertilizer Use on Corn in Minnesota. Department of Soil, Water and Climate, University of Minnesota, and USDA Agricultural Research Service. http://www.mda.state.mn.us/protecting/cleanwaterfund/~/media/C0D97703C7A84E74936431110A5FE897.ashx

CH2M Hill and AquaTerra Consultants. 2002. BASINS Training California Water Board. Technical Memorandum. Prepared for California State Water Resources Control Board. Prepared by CH2M Hill and AquaTerra Consultants. September 30, 2002.

Delin, G. N., and J. D. Falteisek. 2007. Ground-water recharge in Minnesota. USGS Fact Sheet 2007-3002.

Donigian, A.S. 2000. HSPF Training Workshop Handbook and CD. Lecture #19. Calibration and Verification Issues, Slide #L19-22. EPA Headquarters, Washington Information Center, 10-14 January, 2000. Presented and prepared for U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, D.C.

Donigian, A.S. 2002. Watershed Model Calibration and Validation: The HSPF Experience. Water Environment Federation (WEF) National TMDL Science and Policy 2002, November 13-16, 2002. Phoenix, AZ. WEF Specialty Conference Proceedings on CD-ROM.

Duda, P.B., Hummel, P.R., Donigian, A.S. and J.C. Imhoff. 2012. BASINS/HSPF: Model Use, Calibration, and Validation. American Society of Agricultural and Biological Engineers, Vol. 55, No. 4, pp. 523-1547.

ECWMC, 2003.Elm Creek Watershed Management Plan. Prepared by WSB & Associates, Inc. WSB Project No. 1334-00. Elm Creek Watershed Management Commission. April 2003. http://elmcreekwatershed.org/pages/ManagementPlan/

Fairbairn, 2011. Minnesota Water Supply and Availability. Minnesota Water Sustainability Framework. University of Minnesota Water Resources Center. January, 2011.

Folle, S.M. 2010. SWAT modeling of sediment, nutrient and pesticides in the Le Sueur River watershed, South-Central Minnesota. Ph.D. Dissertation. January, 2010.

LimnoTech, 2014. Little Cannon River Watershed SWAT modeling. Task 1 – Complete the construction, construction, calibration and confirmation of the SWAT model. Memorandum prepared for the Minnesota Pollution Control Agency. June 20, 2014. LimnTech, Ann Arbor.

MCES, 2010. Annual Stream Water Quality Assessment Report. Metropolitan Council Environmental Services. http://www.metrocouncil.org/getattachment/8a9cc8ee-587d-4697-aa30-60d4a0353cd3/.aspx

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and T.L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the American Society of Agricultural and Biological Engineers (ASABE), Vol. 50, No. 3, pp. 885-900.MPCA, 2011. Cannon River Watershed Management Strategy 2011 – 2015. Chapter 11: Lower Cannon River Lobe Management and Monitoring Strategy. June 30, 2011. Minnesota Pollution Control Agency, St. Paul, MN.

MPCA, 2013. Nitrogen in Minnesota Surface Waters, Conditions, Trends, Sources, and Reductions. Minnesota Pollution Control Agency, St. Paul, MN.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and J.R. Williams. 2011. Soil and Water Assessment Tool, Theoretical Documentation, Version 2009. Grassland, Soil and Water Research Laboratory, Agricultural Research Services, TX and Blackland Research Center, Agricultural Experiment Station, TX. September 2011.

Parajuli, P.B., Nelson, N.O., Frees, L.D. and K.R. Mankin. 2009, Comparison of AnnAGNPS and SWAT model simulation results in USDA-CEAP agricultural watersheds in south-central Kansas. Hydrological Processes. Vol. 23, pp. 748- 763.

TetraTech, 2013. Root River Model Calibration. Prepared for USEPA Region 5 and Minnesota Pollution Control Agency, Rochester. April 10, 2013. TetraTech, Research Triangle Park, NC 27709.

Williams, J.R. 1995. Chapter 25: The EPIC model. p. 909-1000. In V.P. Singh (ed). Computer models of watershed hydrology. Water Resources Publications, Highlands Ranch, CO.

Williams, J.R. 1975. Sediment routing for agricultural watersheds. Water Resources Bulletin, Vol. 11, No. 5, pp. 965-974.

Appendix A
SWAT Wetland Configuration

Table A-1. Summary of information used to represent wetlands in each subbasin in the ECWSWAT model.

Subbasin	Municipality	Subbasin Category	Subbasin Area (acre)	Wetland Area (acre)	Drainage Area Fraction[6]
1	Maple Grove/Plymouth	Urban	1003	147	0.50
2	Plymouth	Urban	63	0	0.00
3	Corcoran/Maple Grove	Rural	273	84	1.00
4	Corcoran/Maple Grove	Rural	554	62.3	0.90
5	Rogers	Rural	827	54.7	1.00
6	Rogers	Rural	335	79.5	1.00
7	Dayton	Rural	1053	184.5	1.00
8	Dayton	Rural	22	1.2	1.00
9	Dayton	Rural	493	19	1.00
10	Dayton	Rural	83	0	1.00
11	Maple Grove	Rural	350	118.3	1.00
12	Maple Grove	Urban	328	40.5	0.87
13	Maple Grove	Urban	44	21.5	0.33
14	Maple Grove	Urban	547	59.5	0.91
15	Maple Grove	Urban	2204	156.1	0.83
16	Maple Grove	Rural	165	34	1.00
17	Maple Grove/Plymouth	Urban	1113	15.4	0.53
18	Maple Grove	Urban	283	9.1	0.71
19	Maple Grove/Plymouth/Medina/Corcoran	Urban	849	8.9	0.13
20	Plymouth/Medina	Urban	1687	136.3	0.60
21	Maple Grove	Urban	723	142.5	0.68
22	Maple Grove	Urban	921	24.9	0.22
23	Plymouth/Maple Grove	Urban	1622	145.9	0.57
24	Maple Grove	Urban	128	13.2	0.80
25	Dayton/Rogers	Rural	693	145.6	1.00

[6] Drainage area fraction represents fraction of SWAT subbbasin area draining through the wetlands. For SWMP ponds, drainage area information was provided by TRPD. When representing in-channel NWI wetlands, it was assumed that the entire subbasin drains through the wetland (i.e., Drainage area fraction = 1).

Subbasin	Municipality	Subbasin Category	Subbasin Area (acre)	Wetland Area (acre)	Drainage Area Fraction[6]
26	Dayton	Rural	722	152.5	1.00
27	Dayton/Champlin/Maple Grove	Urban/Rural	227	14	0.45
28	Rogers/Dayton	Urban/Rural	2077	545.5	1.00
29	Medina	Rural	720	57.3	1.00
30	Medina	Rural	1693	69.3	1.00
31	Medina	Rural	1858	337.8	1.00
32	Dayton	Rural	368	109.2	1.00
33	Dayton/Champlin	Urban/Rural	1542	391	1.00
34	Corcoran	Rural	1913	152.3	1.00
35	Maple Grove/Dayton	Rural	133	48.7	0.60
36	Maple Grove	Urban	21	2.5	0.56
37	Maple Grove	Urban	187	10.3	0.87
38	Corcoran/Medina	Rural	1025	123.4	1.00
39	Maple Grove	Urban	329	6.3	0.77
40	Champlin	Urban	834	30.6	0.69
41	Maple Grove	Rural	25	5.1	1.00
42	Maple Grove/Dayton	Urban	943	49.6	0.59
43	Dayton	Rural	209	32	1.00
44	Dayton	Rural	634	23.5	0.50
45	Maple Grove/Dayton	Rural	647	47.6	1.00
46	Roger/Dayton/Maple Grove/Corcoran	Rural	2040	166.3	1.00
47	Maple Grove/Dayton	Rural	170	4.8	1.00
48	Rogers/Corcoran	Rural	1482	99	1.00
49	Rogers	Rural	1900	146.8	1.00
50	Corcoran	Rural	2554	129.2	1.00
51	Corcoran/Rogers	Rural	879	58	1.00
52	Corcoran/Maple Grove	Urban/Rural	1242	160.7	0.87
53	Corcoran	Rural	482	77.9	1.00
54	Corcoran/Medina	Rural	2910	421.7	1.00
55	Corcoran	Rural	232	50	1.00
56	Corcoran	Rural	1423	75.5	1.00
57	Corcoran	Rural	1364	235.6	1.00
58	Corcoran/Medina	Rural	1567	227.6	1.00
59	Corcoran	Rural	75	22.2	1.00
60	Corcoran/Rogers	Rural	520	147.7	1.00
61	Corcoran	Rural	1293	68	1.00
62	Corcoran/Greenfield	Rural	3524	253.1	1.00
63	Maple Grove	Urban	14	6.4	0.54

Subbasin	Municipality	Subbasin Category	Subbasin Area (acre)	Wetland Area (acre)	Drainage Area Fraction[6]
64	Maple Grove/Dayton	Urban	2063	136.4	0.34
65	Maple Grove/Corcoran	Urban/Rural	1638	217.4	1.00
66	Corcoran	Rural	183	57.2	1.00
67	Dayton	Rural	817	118.4	1.00
68	Maple Grove	Urban	70	12.4	0.82
69	Champlin/Maple Grove	Rural	328	42.7	1.00
70	Maple Grove	Urban	234	38.4	0.79
71	Maple Grove	Urban	348	8	0.37
72	Dayton	Rural	1320	35.9	1.00
73	Dayton	Rural	92	7	1.00
74	Dayton	Rural	118	45.8	1.00
75	Maple Grove	Urban	1233	187.4	0.85
76	Champlin	Urban	754	49.3	0.74
77	Champlin	Urban	258	6.9	0.97

Appendix B
Model Calibration Parameterization

Table B-1. Elm Creek watershed SWAT model hydrology parameters – summary of calibrated values.

Parameter Name	Description	Initial Value(s)	Calibrated Value(s)
IPET.bsn	Potential evapotranspiration method	1	0
SURLAG.bsn	Surface runoff lag coefficient	4	0.8
DEPIMP_BSN.bsn	Depth to impervious layer – basin wide (mm)	0	6000
SMFMX.bsn	Melt factor on June 21st (mm H_2O/°C-day)	4.5	3
SMTMP.bsn	Snow melt base temperature (°C)	0.5	2.3
TIMP.bsn	Snow pack temperature lag factor	1	0.3
IRTE.bsn	Channel water routing method	0	0
WET_MXVOL.pnd	Volume of water stored in wetlands when filled to maximum water level (10^4 m^3 H_2O)	WET_NVOL	WET_NVOL * 1.20
GW_REVAP.gw	Groundwater "revap" coefficient	0.02	0.1
ALPHA_BF.gw	Baseflow alpha factor (days)	0.048	0.1
GW_DELAY.gw	Groundwater delay time (days) for aquifer recharge	31	30
RCHRG_DP.gw	Deep aquifer percolation fraction	0.05	0.4
ESCO.hru	Soil evaporation compensation factor	0.95	All urban HRUs = 0.75
DEP_IMP.hru	Depth to impervious layer (mm)	0	Drained HRUs = 1200
CNOP.mgt2	Operation specific SCS runoff curve number for moisture condition II	*varies* (30-94)	Original * 0.70[7]
DDRAIN.mgt1	Depth to the subsurface drain (mm)	0	Drained HRUs = 1000
TDRAIN.mgt1	Time to drain soil to field capacity (hours)	0	Drained HRUs = 24
GDRAIN.mgt1	Drain tile lag time (hours)	0	Drained HRUs = 96
NDTARGR.res	Number of days to reach target storage from current reservoir storage.	1	4

[7] Minimum values of 30 and 39 were set for forested and pastured HRUs, respectively. Urban CNOP values were not modified.

Table B-2. Elm Creek watershed SWAT model sediment parameters – summary of calibrated values.

Parameter Name	Description	Initial Value(s)	Calibrated Value(s)
ADJ_PKR	Peak rate adjustment factor for sediment routing in the subbasin	1	0.5
SPCON	Linear parameter for calculating sediment reentrained in channel sediment routing	0.0001	0.001
RES_STLR_CO.bsn	Reservoir settling coefficient	0.184	0.09
USLE_P	USLE equation support practice factor	1	0.6 in agricultural HRUs only
LAI_INIT.mgt	Initial leaf area index	0	0.75 for forest HRUs only
BIO_INIT.mgt	Initial dry weight biomass (kg/ha)	0	33,840 for forest HRUs only
USLE_C[8]	Minimum factor of USLE C factor for water erosion applicable to the land cover/plant	*Varies*	FRSD to .01, ALFA = 0.04, PAST = 0.02
MAT_YRS[9]	Number of years required for tree species to reach full development (years)	10	0
FIMP[10]	Fraction total impervious area in urban land type - both directed and indirectly connected	0.98	Urban-Transportation = 0.6
FCIMP[11]	Fraction directly connected impervious area in urban land type	0.95	Urban-Transportation = 0.44
WET_SED.pnd	Initial sediment concentration in wetland water (mg/L)	0	5
WET_NSED.pnd	Equilibrium sediment concentration in wetland water (mg/L)	0	Subbasins draining to RCSL, RT, & RCTH = 1.0, All others = 5.0
SECCIR.res	Water clarity coefficient for the reservoir	1	1
RES_NSED.res	Equilibrium sediment concentration in reservoir water (mg/L)	0	10
RES_D50.res	Median particle diameter of sediment (µm)	10	5
CH_COV1.rte	Channel erodibility factor or bank vegetation coefficient	0	0.08
CH_COV2.rte	Channel cover factor or bed vegetation coefficient	0	0.08

[8] This parameter located in file crop.dat
[9] This parameter located in file crop.dat
[10] This parameter located in file urban.dat
[11] This parameter located in file urban.dat

Table B-3. Elm Creek watershed SWAT model nutrient parameters– summary of calibrated values.

Parameter Name	Description	Initial Value(s)	Calibrated Value(s)
ISUBWQ.bsn	Subbasin water quality code	0	0
CDN.bsn	Denitrification exponential rate coefficient	1.4	0.9
SDNCO.bsn	Denitrification threshold water content	1.1	1
IWQ.bsn	In-stream water quality code	0	1
FIXCO.bsn	Nitrogen fixation coefficient	0.5	0.35
N_UPDIS.bsn	Nitrogen uptake distribution parameter	20	25
P_UPDIS.bsn	Phosphorus uptake distribution parameter	20	9
NPERCO.bsn	Nitrate percolation coefficient	0.2	0.5
PPERCO.bsn	Phosphorus percolation coefficient	10	17.5
PHOSKD.bsn	Phosphorus soil partitioning coefficient (m3/Mg)	175	95
PSP.bsn	Phosphorus availability index	0.4	0.6
RS2.swq	Benthic source rate for dissolved phosphorus in the reach at 20°C ($mg/m^2/day$)	0.05	0.01
RS3.swq	Benthic source rate for NH4-N in the reach at 20°C ($mg/m^2/day$)	0.5	0.01
RS5.swq	Organic phosphorus settling rate in the reach at 20°C (day^{-1})	0.05	0.04
BC3.swq	Rate constant for hydrolysis of organic N to NH4 in the reach at 20°C (day^{-1})	0.21	0.03
BC4.swq	Rate constant for mineralization of organic P to dissolved P in the reach at 20°C (day^{-1})	0.35	Subbasins draining to EC77 & HAMEL = 0.001, All others = 0.05
ERORGN.hru	Organic N enrichment ratio for loading with sediment	model calculated	3 for urban, 1.5 for croplands, 1.0 for pasture
ERORGP.hru	Organic P enrichment ratio for loading with sediment	model calculated	3 for urban & pasture, 2.3 for croplands
IPND1.pnd	Beginning month of mid-year nutrient settling season	1	5
IPND2.pnd	Ending month of mid-year nutrient settling season	1	8
PSETLW1.pnd	Phosphorus settling rate in wetlands for months IPND1 through IPND2 (m/year)	5	0.01
PSETLW2.pnd	Phosphorus settling rate in wetlands for months other than INPD1-IPND2 (m/year)	5	7
NSETLW1.pnd	Nitrogen settling rate in wetlands for months IPND1 through IPND2 (m/year)	4.7	Subbasins draining to RCSL & RT = 12.0, draining to RCTH = 15.0, All others = 2.0
NSETLW2.pnd	Nitrogen settling rate in wetlands for months other than INPD1-IPND2 (m/year)	4.7	Subbasins draining to RCSL & RT = 90.0, draining to RCTH = 95.0, All others = 10.0
PND_D50.pnd	Wetland source rate of soluble phosphorus for months IPND1 through IPND2 ($mg/m^2/day$) *Definition specific to this project*	0	Subbasins draining to EC77 & HAMEL = 8.0, All others = 12.0

Appendix C
Additional Calibration Figures

Annual Scatter Plots

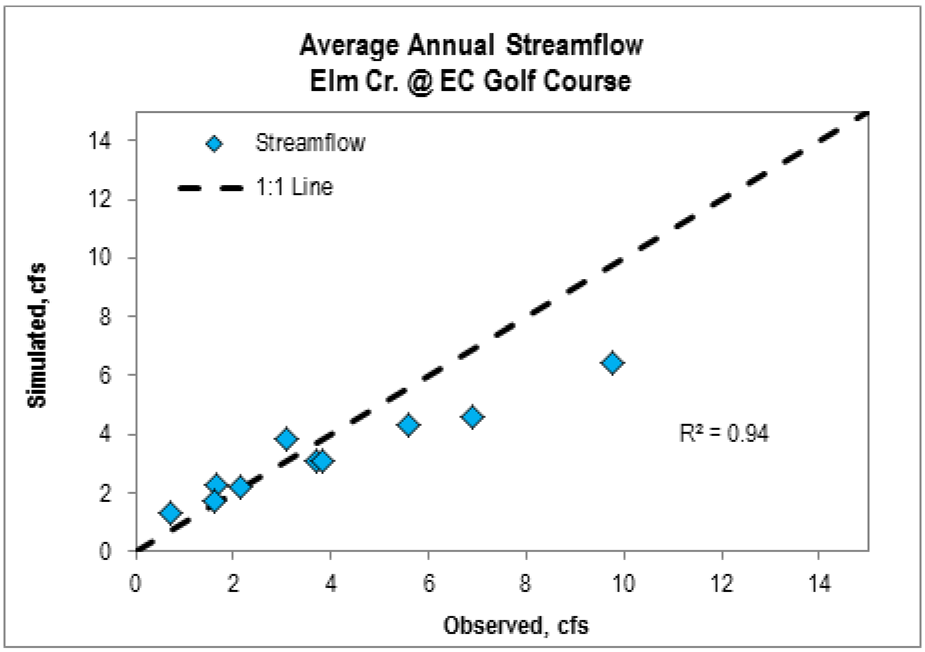


Figure C-1. A 1:1 plot of the annual simulated and observed streamflow at calibration site HAMEL (Elm Creek at the Elm Creek Golf Course) over select years from 2000-2012.

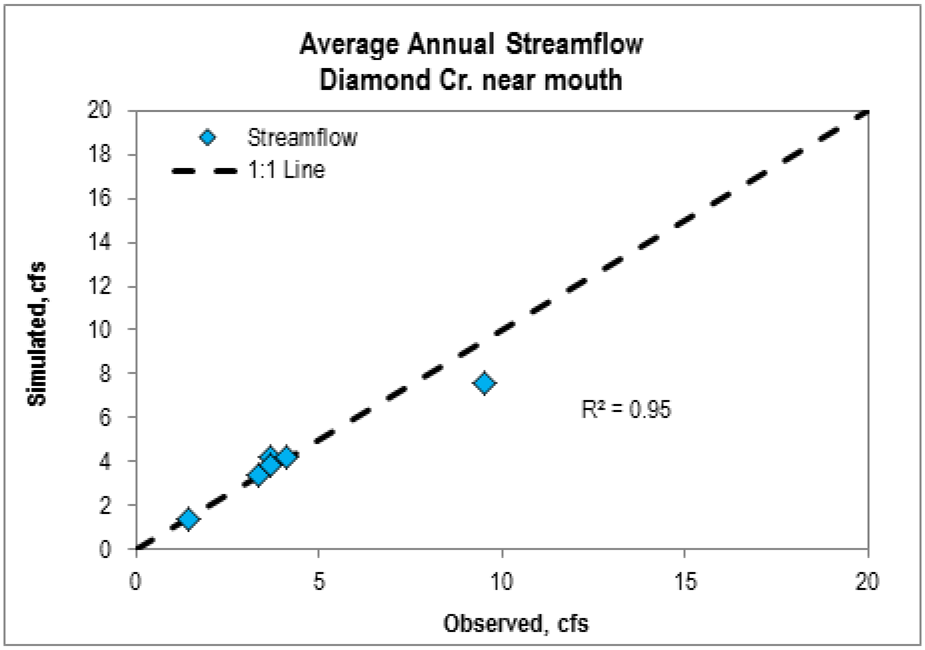


Figure C-2. A 1:1 plot of the annual simulated and observed streamflow at calibration site DC (Diamond Creek near mouth) for years 2007-2012.

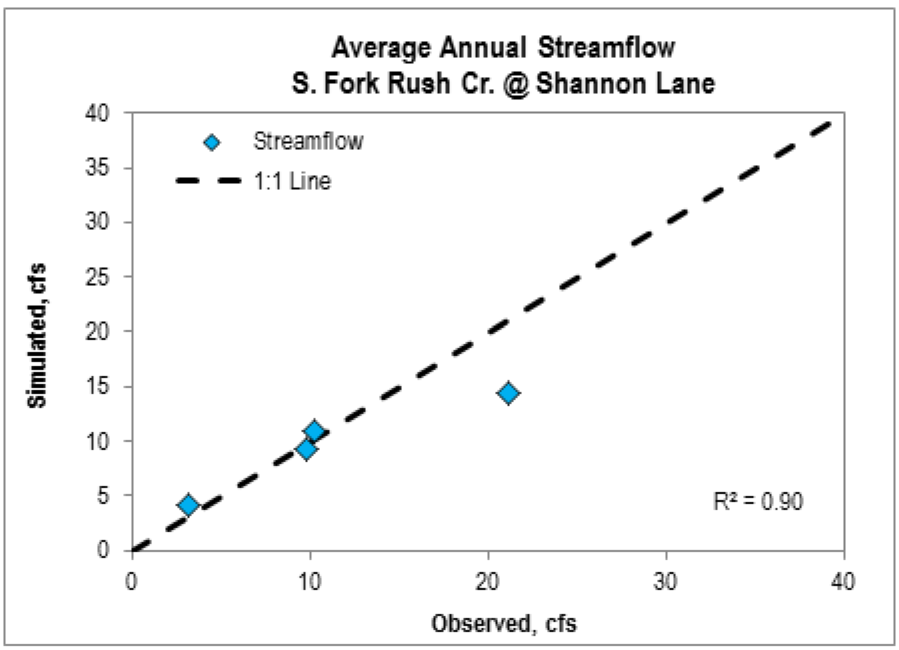


Figure C-3. A 1:1 plot of the annual simulated and observed streamflow at calibration site RCSL (S. Fork Rush Creek @ Shannon Lane) for years 2000-2012.

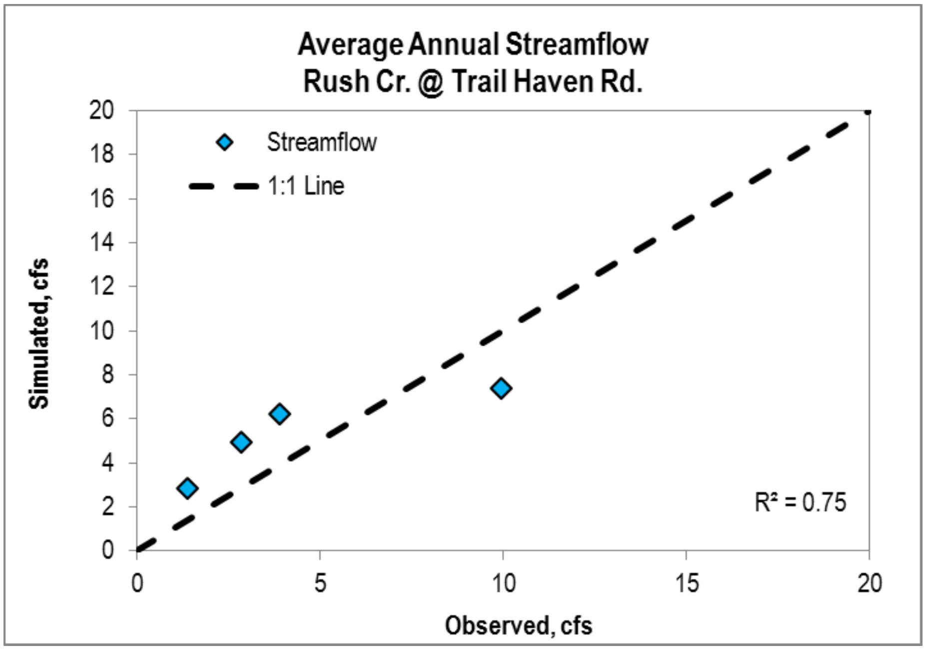


Figure C-4. A 1:1 plot of the annual simulated and observed streamflow at calibration site RCTH (Rush Creek @ Trail Haven Rd.) for years 2000 – 2012.

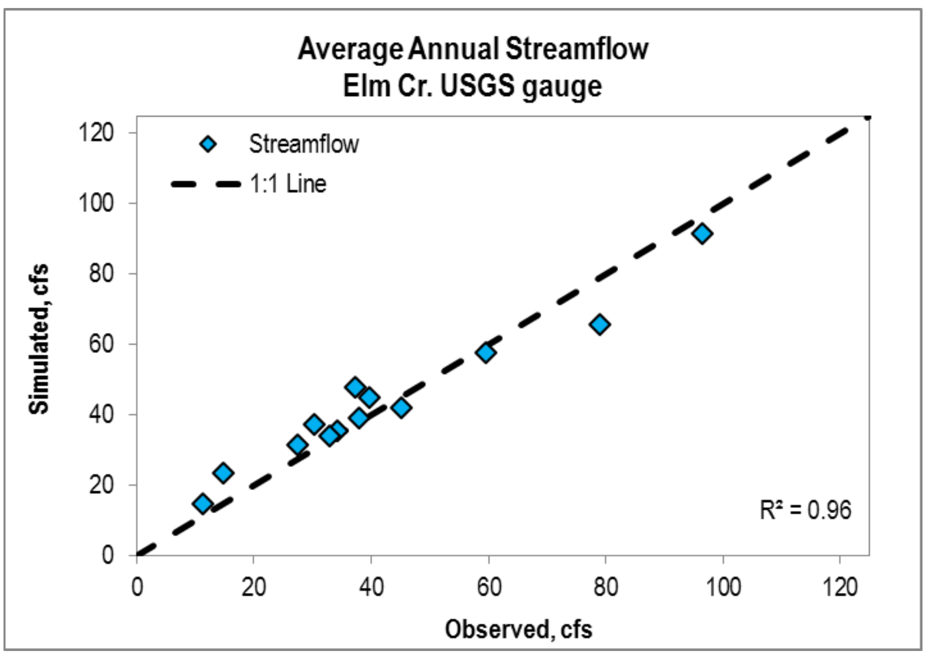


Figure C-5. A 1:1 plot of the annual simulated and observed streamflow at confirmation site USGS (Elm Creek USGS gauge) for years 2000-2012.

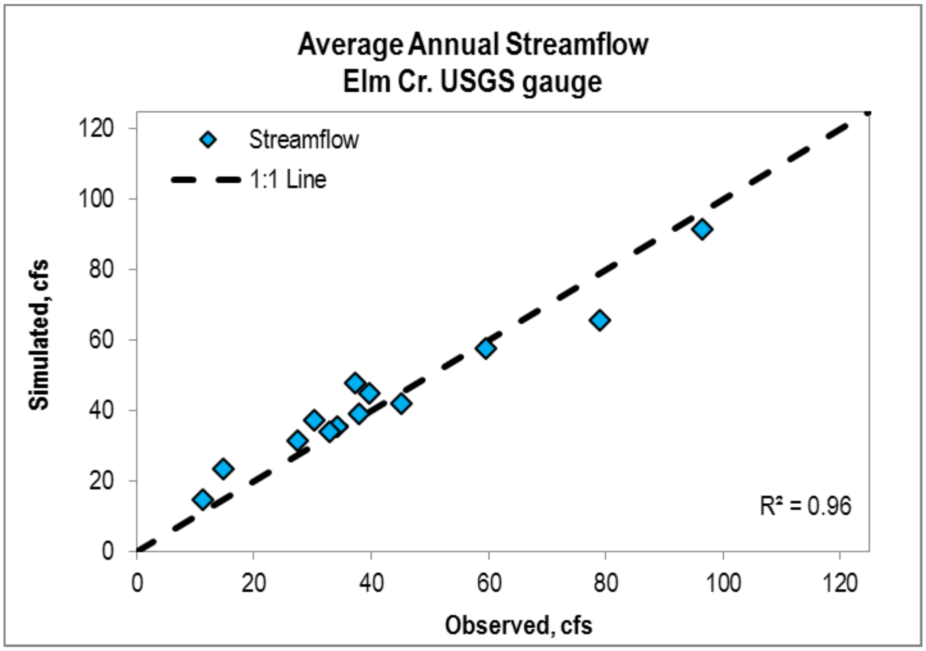


Figure C-6. A 1:1 plot of the annual simulated and observed streamflow at confirmation site EC77 (Elm Creek @ 77th Ave.) for years 2000-2012.

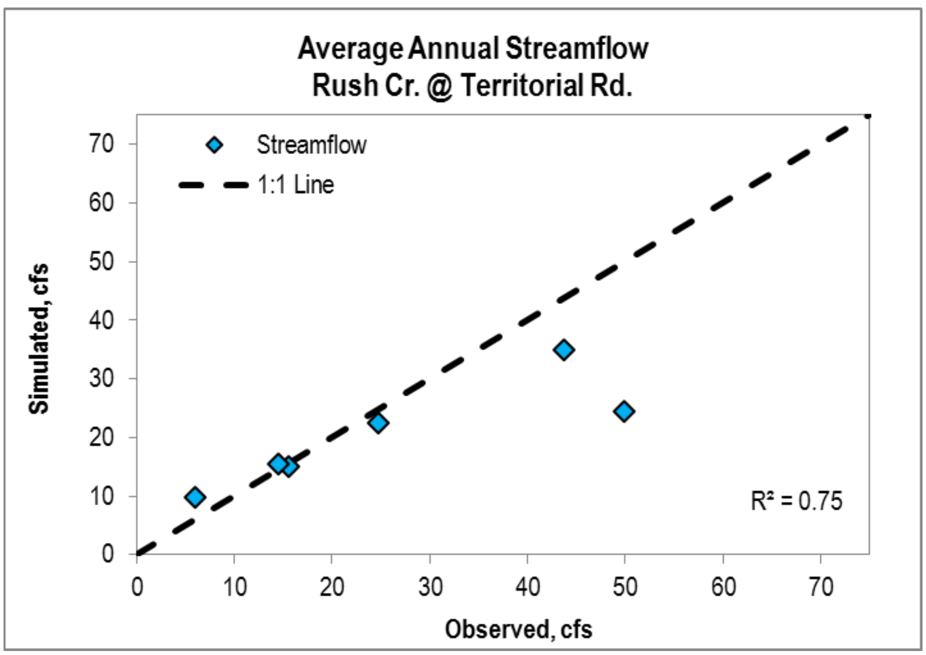


Figure C-7. A 1:1 plot of the annual simulated and observed streamflow at confirmation site RT (Rush Creek @ Territorial Rd.) for years 2000-2012.

Additional Monthly Scatter Plots

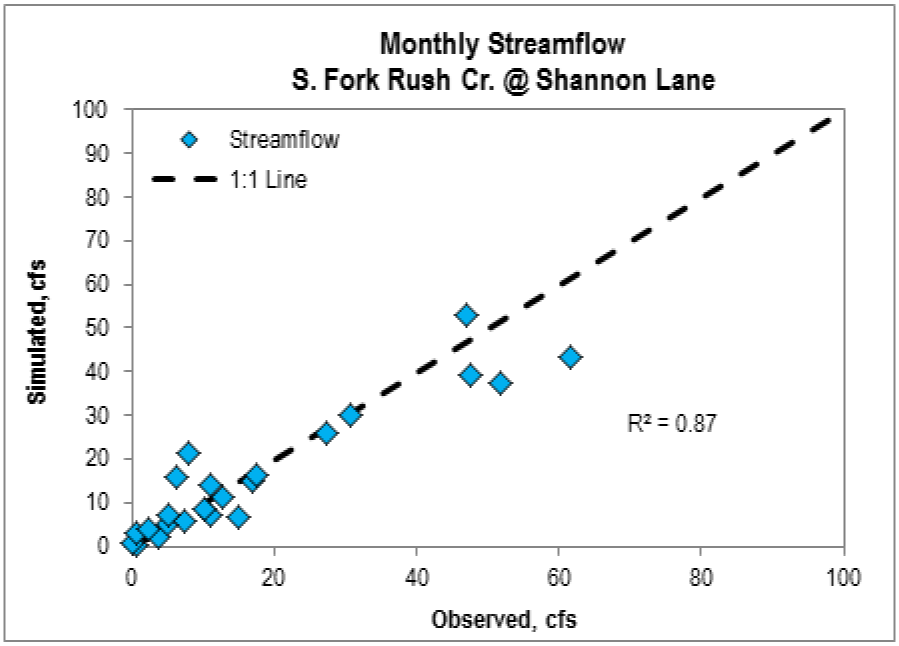


Figure C-8. A 1:1 plot of the monthly simulated and observed streamflow at calibration site RSCL (S. Fork Rush Creek @ Shannon Lane) for years 2000-2012.

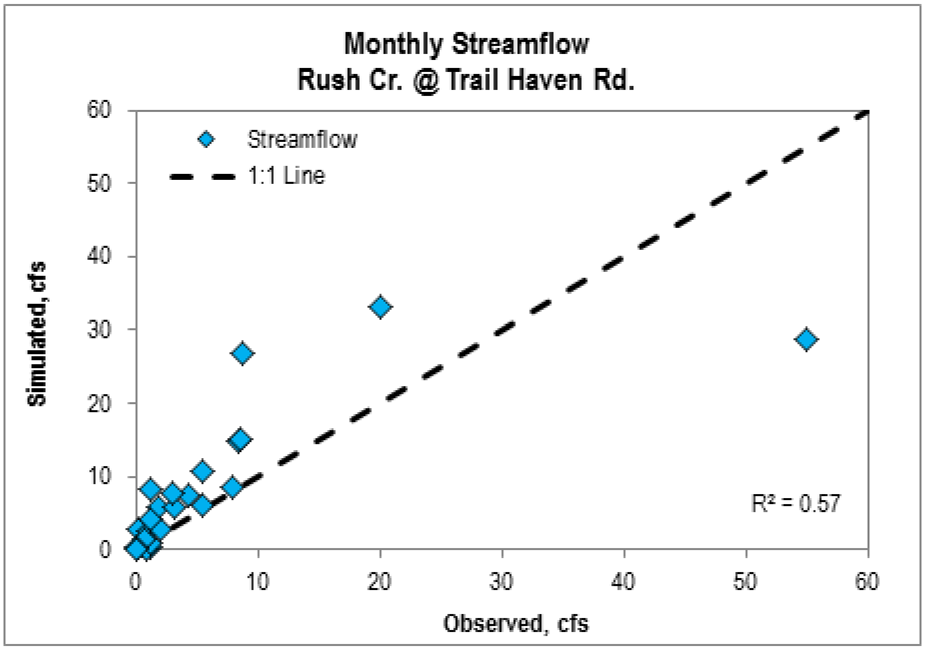


Figure C-9. A 1:1 plot of the monthly simulated and observed streamflow at calibration site RCTH (Rush Creek @ Trail Haven Rd.) for years 2000-2012.

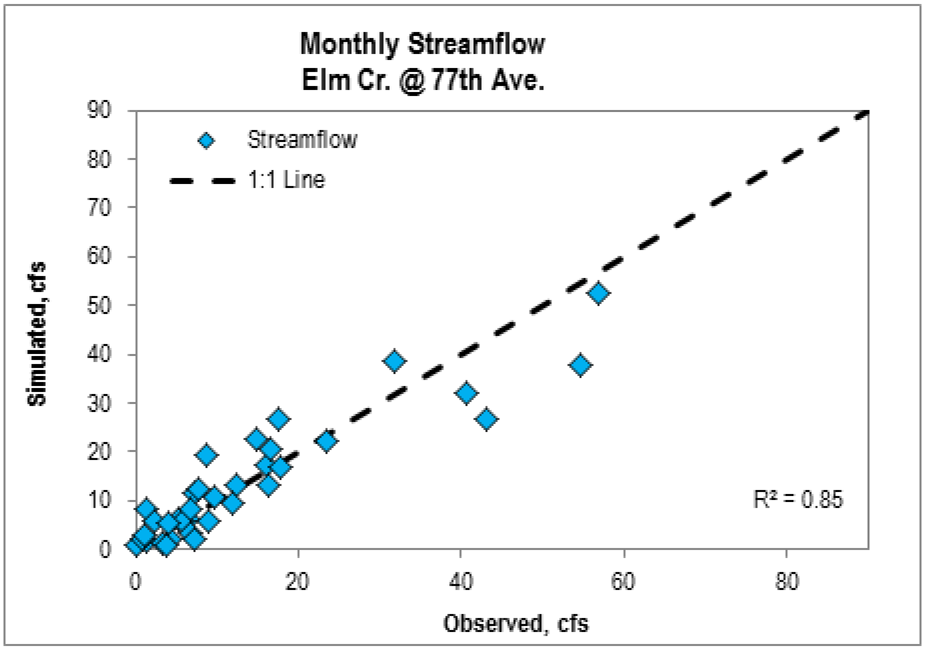


Figure C-10. A 1:1 plot of the monthly simulated and observed streamflow at confirmation site EC77 (Elm Creek @ 77th Ave.) for years 2000-2012.

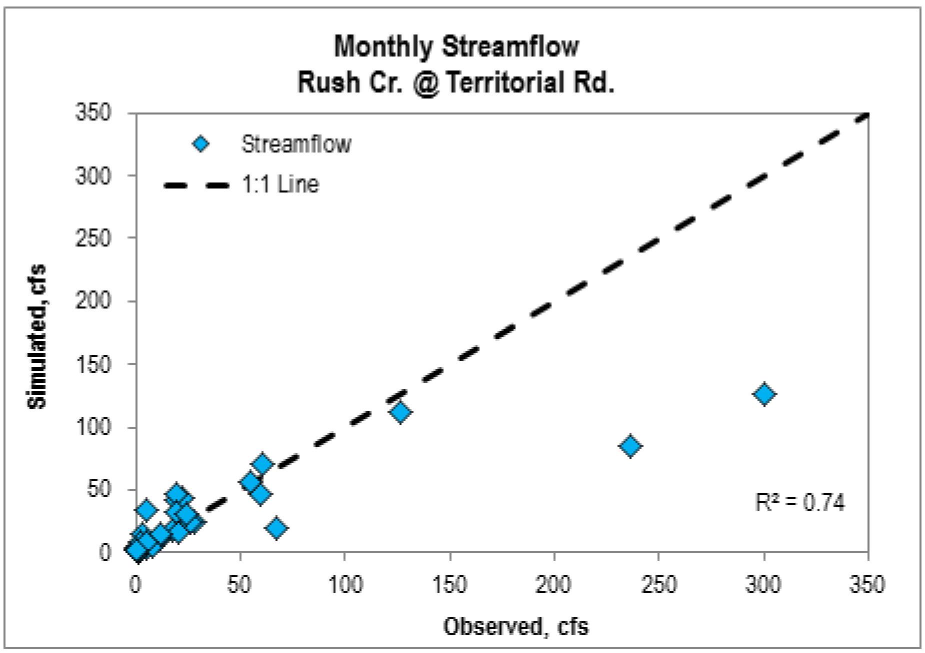


Figure C-11. A 1:1 plot of the monthly simulated and observed streamflow at confirmation site RT (Rush Creek @ Territorial Rd.) for years 2000-2012.

Additional Monthly Time Series Plots

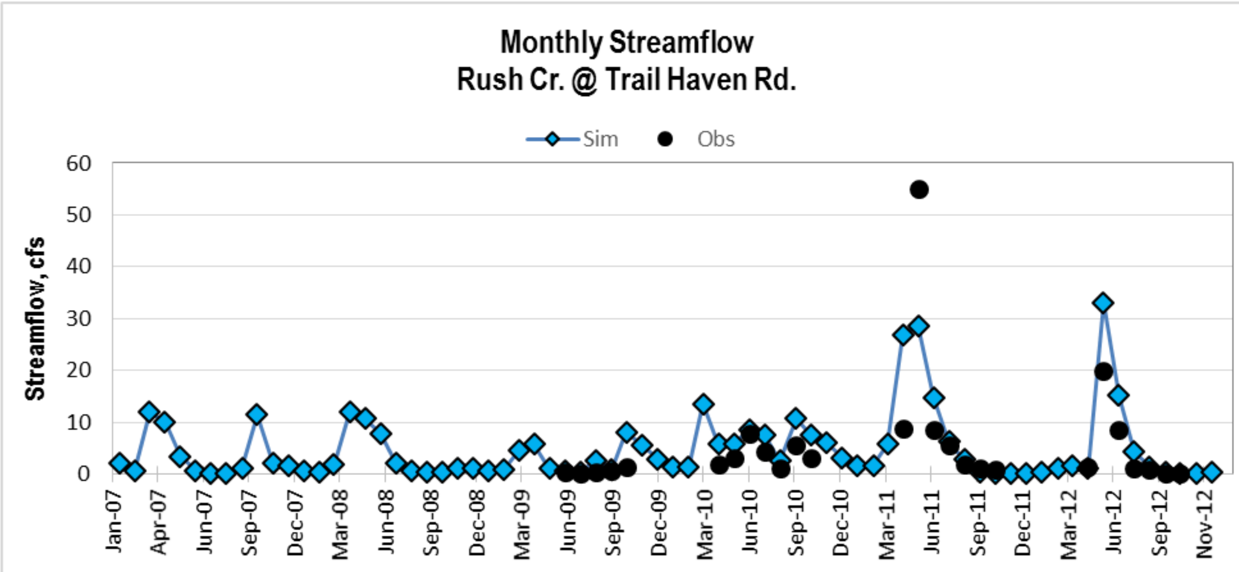


Figure C-12. Monthly average simulated and observed streamflow at calibration site RCTH (Rush Creek @ Trail Haven Rd.) for years 2007-2012.

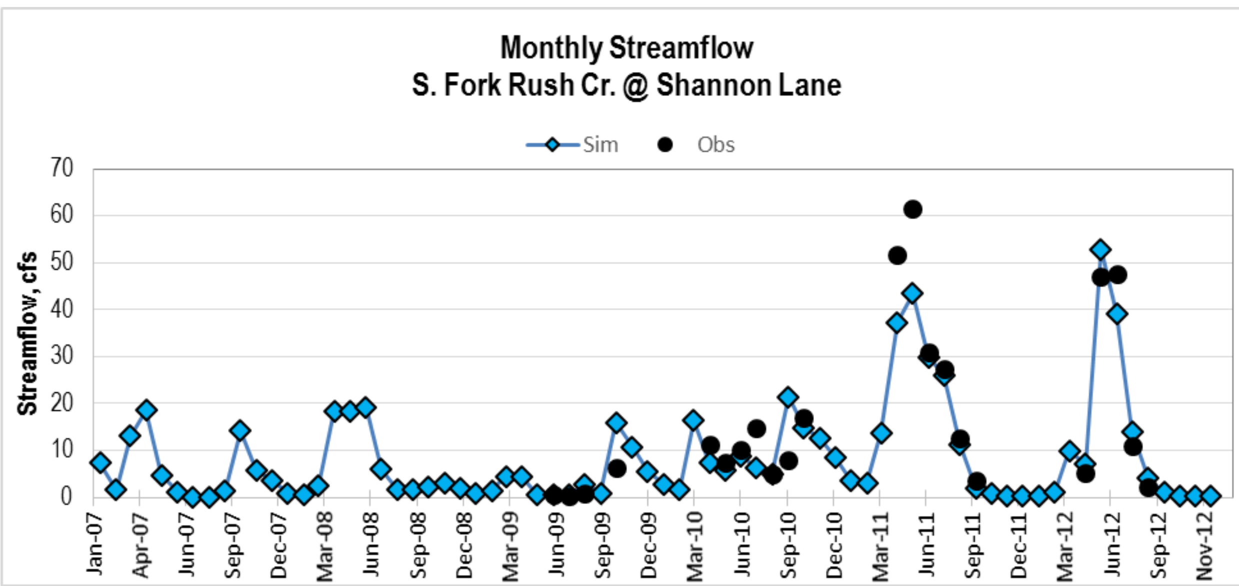


Figure C-13. Monthly average simulated and observed streamflow at calibration site RCSL (S. Fork Rush Creek @ Shannon Lane) for years 2007-2012.

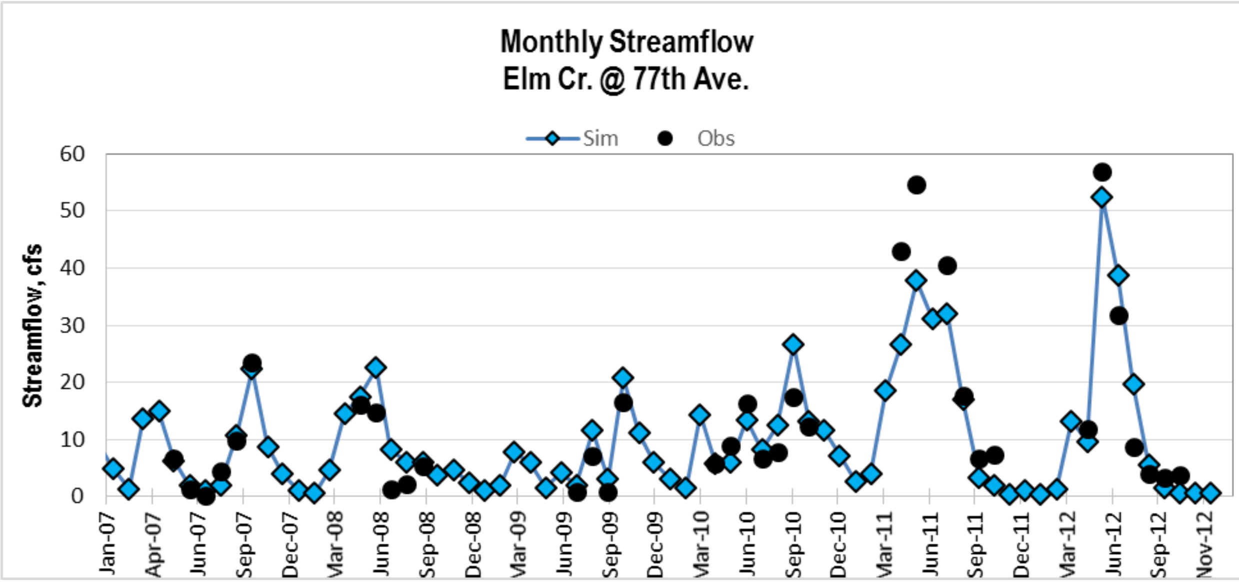


Figure C-14. Monthly average simulated and observed streamflow at confirmation site EC77 (Elm Creek @ 77th Ave.) for years 2007-2012.

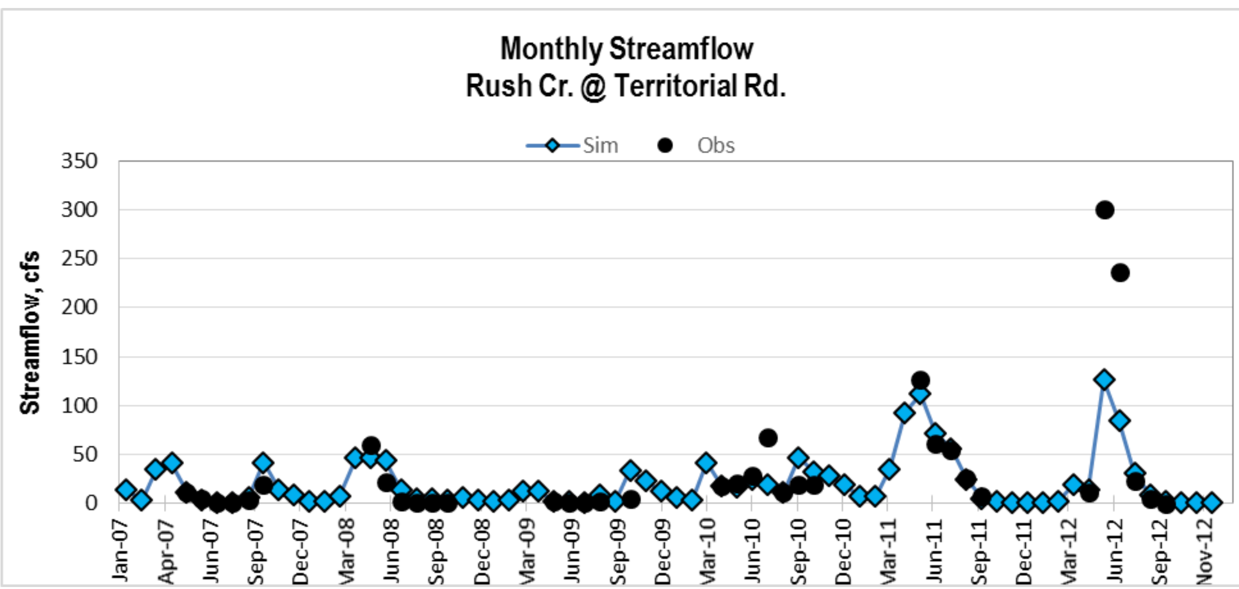


Figure C-15. Monthly average simulated and observed streamflow at confirmation site RT (Rush Creek @ Territorial Rd.) for years 2007-2012.

Additional Daily Time Series Plots

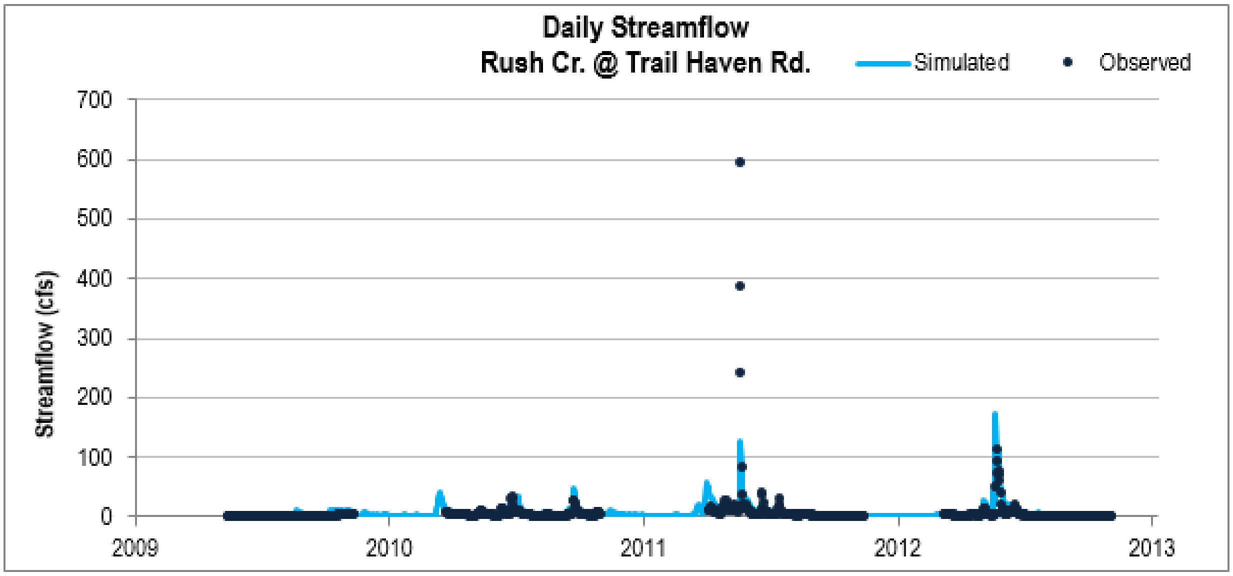


Figure C-16. Daily average simulated and observed streamflow at calibration site RCTH (Rush Creek @ Trail Haven Rd.) for years 2009-2012.

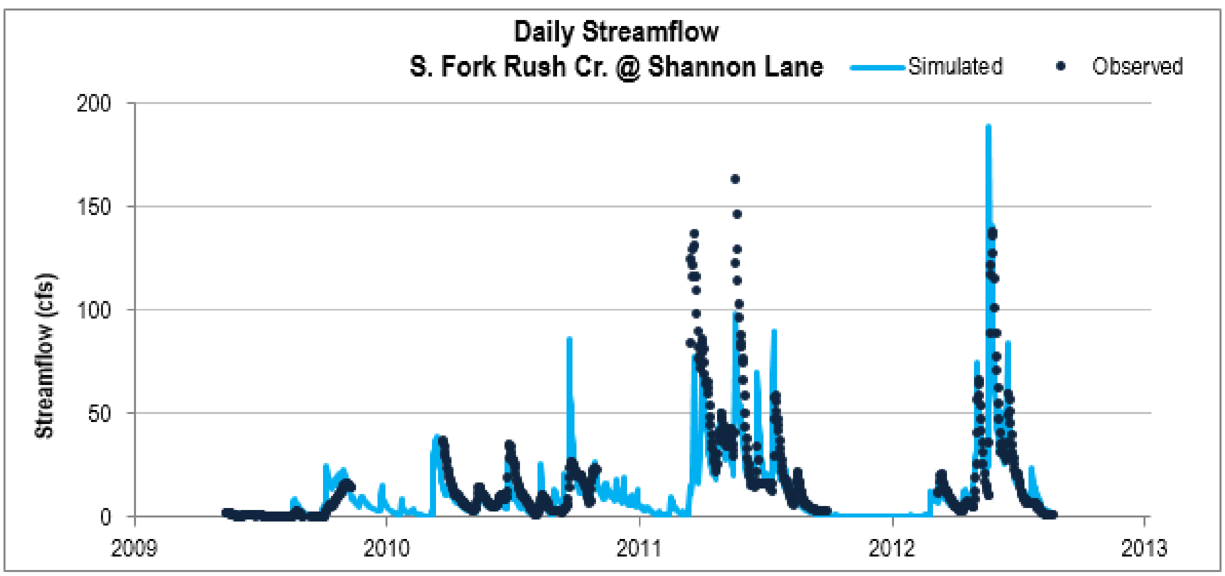


Figure C-17. Daily average simulated and observed streamflow at calibration site RCSL (S. Fork Rush Creek @ Shannon Lane) for years 2009-2012.

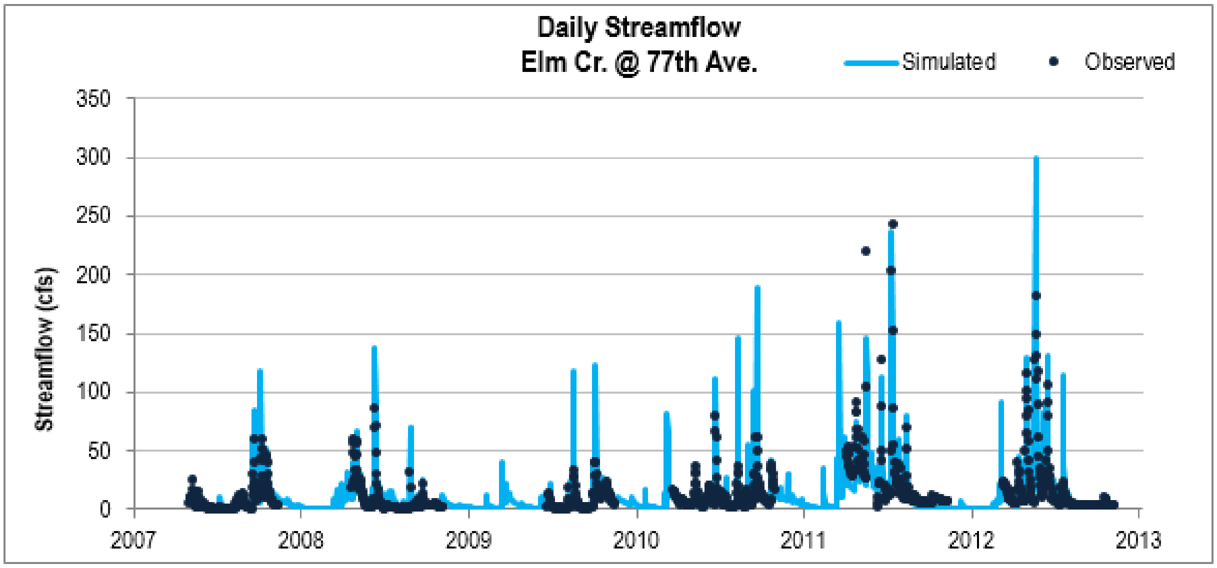


Figure C-18. Daily average simulated and observed streamflow at confirmation site EC77 (Elm Creek @ 77th Ave.) for years 2007-2012.

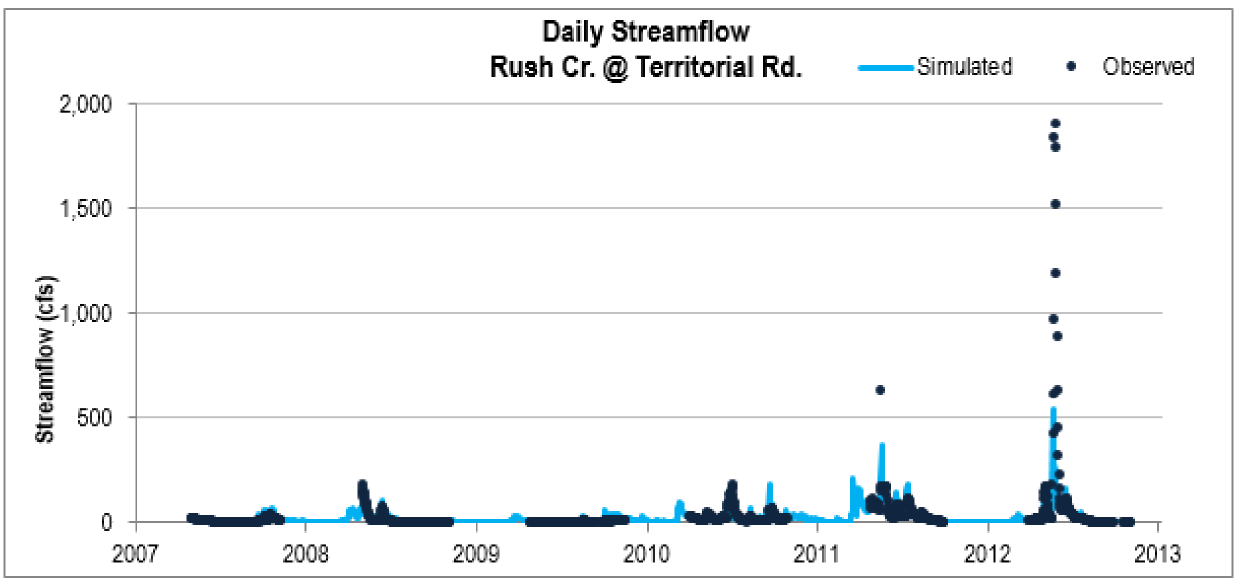


Figure C-19. Daily average simulated and observed streamflow at confirmation site RT (Rush Creek @ Territorial Rd.) for years 2007-2012.

Appendix E
Aquatic Vegetation Surveys for Lakes within the Elm Creek Watershed

Fish Lake									
Date Sampled	Max depth sampled (ft.)	Max depth of submerged plant growth (ft.)	Vegetated depth range sampled (ft.)	Number of points sampled	Number of points sampled with native submersed vegetation	Percentage of points sampled with native submersed vegetation	Percentage of points sampled with submersed vegetation	Average # of native submersed taxa per sample point	Submersed species richness (number of submerged species)
6/17/2008	10.5	10.5	2.3 - 10.5	128	65	50.78%	60.15%	0.47	5
10/2/2008	16.4	12.1	0.98 - 12.1	151	100	66.23%	80.13%	0.72	5
6/9/2011	15.4	12.5	0.98 - 12.5	154	77	50.00%	66.88%	0.58	7
9/2/2011	15.4	10.6	0.6 - 10.6	154	100	64.94%	64.94%	0.66	4
5/17/2012	20.0	8.5	1.3 - 8.5	154	77	50.00%	61.88%	0.53	6
8/2/2012	17.8	13.2	0.98 - 13.2	154	94	61.04%	68.18%	0.72	9

Fish Lake	% Frequency					
	6/17/2008	10/2/2008	6/9/2011	9/2/2011	5/17/2012	8/2/2012
Potamogeton crispus	2.34	0.00	1.95	0.00	9.09	9.09
Myriophyllum spicatum	25.00	47.02	42.86	12.99	14.29	21.49
Ceratophyllum demersum	42.19	50.33	45.45	64.94	46.10	62.81
Elodea canadensis	1.56	0.00	8.44	0.00	0.00	0.00
Najas guadalupensis	13.28	18.54	0.00	0.00	0.00	0.00
Najas flexilis	0.00	0.00	2.60	5.19	0.00	6.61
Potamogeton foliosus	0.00	0.00	0.00	0.00	3.25	0.00
Potamogeton pusillus	0.00	0.00	0.00	0.00	0.00	0.83
Potamogeton richardsonii	0.00	1.99	0.00	0.00	0.00	0.00
Potamogeton zosterformis	0.00	0.00	0.65	0.65	0.65	0.00
Stuckenia pectinata	0.00	3.31	0.65	0.65	2.60	4.96
Chara	0.00	0.00	0.00	0.00	0.00	1.65
Nuphar advena	5.47	7.95	1.30	8.44	4.55	9.09
Nymphaea odorata	14.06	23.18	17.53	38.31	23.38	26.45
Wolffia columbiana	0.00	0.00	0.00	0.65	0.00	0.00
Lemna trisulca	0.00	0.66	0.00	0.65	0.00	1.65
Lemna minor	0.00	1.32	1.30	2.60	0.00	0.00
Spirodela polyrhiza	0.78	0.00	0.00	1.95	0.00	0.83
Algae	0.00	0.00	27.92	15.58	67.53	18.18

Rice Lake									
Date Sampled	Max depth sampled (ft)	Max depth of submerged plant growth (ft)	Vegetated depth range sampled (ft)	Number of points sampled	Number of points sampled with native submersed vegetation	Percentage of points sampled with native submersed vegetation	Percentage of points sampled with submersed vegetation	Average # of native submersed taxa per sample point	Submersed species richness (number of submerged species)
6/1/2009	11.5	7.5	1.0 - 7.5	207	45	21.74%	22.22%	0.39	8
6/1/2012	12.8	10.2	1.0 - 10.2	207	51	24.64%	32.85%	0.4	9
7/25/2014	10.8	7.9	1.0 - 7.9	207	71	34.30%	35.75%	1.28	11

Rice Lake	% Frequency		
	6/1/2009	**6/1/2012**	**7/25/2014**
Potamogeton crispus	9.66	21.74	18.84
Myriophyllum spicatum	1.93	0.48	7.73
Ceratophyllum demersum	18.36	18.36	31.40
Elodea canadensis	3.86	2.42	9.66
Potamogeton foliosus	0	1.93	4.83
Potamogeton zosteriformis	3.38	3.86	8.21
Stuckenia pectinata	8.70	8.70	12.08
Zannichelia palustris	2.90	3.86	1.93
Zosterella dubia	1.93	0.48	1.93
Najas flexilis	0	0	0.97
Nymphaea odorata	0	0.48	2.42
Lemna minor	3.38	0	13.04
Lemna trisulca	1.45	6.28	6.76
Spirodela polyrhiza	0	4.35	12.08
Wolffia columbiana	0	6.28	10.14

Diamond Lake									
Date Sampled	Max depth sampled (ft.)	Max depth of submerged plant growth (ft.)	Vegetated depth range sampled (ft.)	Number of points sampled	Number of points sampled with native submersed vegetation	Percentage of points sampled with native submersed vegetation	Percentage of points sampled with submersed vegetation	Average # of native submersed taxa per sample point	Submersed species richness (number of submerged species)
6/30/2011	8.2	8.2	0.3 - 8.2	105	73	69.52%	98.10%	1.49	7
9/9/2011	7.6	7.6	0.4 - 7.6	105	86	81.90%	81.90%	1.3	5
5/18/2012	8.2	8.2	3.0 - 8.2	105	65	61.90%	100.00%	0.95	4
8/31/2012	7.9	6.7	1.0 - 6.7	105	84	80.00%	81.00%	1.29	5

Diamond Lake	**% Frequency**			
	6/30/2011	**9/9/2011**	**5/18/2012**	**8/31/2012**
Potamogeton crispus	92.38	1.90	88.57	3.85
Ceratophyllum demersum	43.81	50.48	46.67	59.62
Stuckenia pectinata	8.57	3.81	0.00	2.88
Potamogeton pusillus	52.38	0.00	0.00	0.96
Elodea canadensis	40.95	73.33	46.67	68.27
Nitella spp	0.95	0.00	0.00	0.00
Zannichellia palustris	1.90	0.00	0.00	0.00
Lemna minor	2.86	0.00	0.00	3.85
Spirodela polyrhiza	3.81	0.00	0.00	0.96
Algae	1.90	22.86	17.14	25.00
Potamogeton foliosus	0.00	2.86	1.90	0.00
Nymphaea odorata	0.00	0.95	0.95	0.96
Wolffia columbiana	0.00	0.95	0.00	0.00

Cowley Lake									
Date Sampled	Max depth sampled	Max depth of submerged plant growth	Vegetated depth range sampled	Number of points sampled	Number of points sampled with native submersed vegetation	Percentage of points sampled with native submersed vegetation	Percentage of points sampled with submersed vegetation	Average # of native submersed taxa per sample point	Submersed species richness (number of submerged species)
6/5/2012	7.9	7.5	2.0 - 7.9	82	49	59.76%	82.90%	0.92	6
8/29/2012	6.9	0	0	82	0	0	0	0	0

Cowley Lake	% Frequency	
	6/5/2012	8/29/2012
Potamogeton crispus	68.29	0
Ceratophyllum demersum	3.66	0
Elodea canadensis	30.49	0
Potamogeton foliosus	1.22	0
Potamogeton pusillus	47.56	0
Stuckenia pectinata	9.76	0
Lemna minor	24.39	0

Henry Lake									
Date Sampled	Max depth sampled (ft)	Max depth of submerged plant growth (ft)	Vegetated depth range sampled (ft)	Number of points sampled	Number of points sampled with native submersed vegetation	Percentage of points sampled with native submersed vegetation	Percentage of points sampled with submersed vegetation	Average # of native submersed taxa per sample point	Submersed species richness (number of submerged species)
5/25/2012	8.3	8.3	0.6-8.3	89	65	73.03%	97.80%	1.37	6
8/20/2012	8.6	7.8	1.3-7.8	95	66	69.47%	69.47%	1.48	5

Henry Lake	**% Frequency**	
	5/25/2012	**8/20/2012**
Potamogeton crispus	85.39	0.00
Ceratophyllum demersum	35.96	47.37
Elodea canadensis	57.30	47.37
Potamogeton foliosus	2.25	0.00
Potamogeton zosterifomris	32.58	69.47
Utricularia vulgaris	8.99	47.37
Heteranthera dubia	0.00	5.26
Spirodela polyrhiza	33.71	3.16
Lemna minor	8.99	31.58
Lemna trisulca	5.62	32.63
Wolffia columbiana	0.00	1.05
Algae	2.25	25.26
Schoenoplectus fluvi	13.48	0.00

Slyvan Lake									
Date Sampled	Max depth sampled (ft)	Max depth of submerged plant growth (ft)	Vegetated depth range sampled (ft)	Number of points sampled	Number of points sampled with native submersed vegetation	Percentage of points sampled with native submersed vegetation	Percentage of points sampled with submersed vegetation	Average # of native submersed taxa per sample point	Submersed species richness (number of submerged species)
6/8/2012	15	13.9	2.1-13.9	93	23	24.73%	59.14%	0.28	5
9/6/2012	14.7	6	1.8-6.0	93	17	18.28%	19.35%	0.23	3

Sylvan Lake	% Frequency	
	6/8/2012	**9/6/2012**
Potamogeton crispus	58.06	8.60
Ceratophyllum demersum	1.08	4.30
Elodea canadensis	9.68	18.28
Potamogeton pusillus	5.38	0.00
Potamogeton zosterifomris	11.83	0.00
Spirodela polyrhiza	10.75	1.08
Lemna minor	6.45	1.08

Goose Lake									
Date Sampled	Max depth sampled (ft)	Max depth of submerged plant growth (ft)	Vegetated depth range sampled (ft)	Number of points sampled	Number of points sampled with native submersed vegetation	Percentage of points sampled with native submersed vegetation	Percentage of points sampled with submersed vegetation	Average # of native submersed taxa per sample point	Submersed species richness (number of submerged species)
6/5/2012	5.91	5.91	0.13-5.91	85	28	32.94%	32.94%	0.44	6
8/9/2012	6.1	5	1.0 - 5.0	85	28	32.94%	32.94%	0.49	5

Goose Lake	**% Frequency**	
	6/5/2012	**8/9/2012**
Potamogeton crispus	2.35	0.00
Ceratophyllum demersum	0.00	3.53
Elodea canadensis	31.76	23.53
Potamogeton zosterifomris	1.18	2.35
Potamogeton foliosus	4.71	0.00
Stuckenia pectinata	4.71	17.65
Najas spp.	1.18	2.35
Nymphaea odorata	0.00	1.18
Spirodela polyrhiza	1.18	0.00
Lemna minor	0.00	5.88
Algae	0.00	4.71

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

19 February, 2013

William F. James
University of Wisconsin - Stout
Sustainability Sciences Institute
123E Jarvis Hall
Menomonie, Wisconsin 54751
715-338-4395
williamfjames@charter.net
jamesw@uwstout.edu

OBJECTIVES

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

APPROACH

Laboratory-derived rates of P release from sediment under oxic and anoxic conditions: Sediment cores were collected at two stations by personnel from the Three Rivers Park District in November, 2012, for determination of rates of P release from sediment under oxic (2 replicates) and anoxic (2 replicates) conditions. The cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from the lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water (~ 10-cm water column depth) contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 to 25 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling air (oxic) or nitrogen (anoxic) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment.

Water samples (~ 7 mL) for soluble reactive P were collected from the center of each system using a 10-cc syringe and filtered through a 0.45 µm membrane filter. The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment (mg m^{-2} d^{-1}) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: The upper 10 cm of an additional core was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P and total iron (Fe; all expressed at mg/g). A known volume of sediment was dried at 105 ^{o}C for determination of moisture content and sediment density and burned at 500 ^{o}C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total P and Fe using standard methods (EPA method 200.7).

Phosphorus fractionation (Table 1) was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

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

RESULTS AND INTERPRETATION

Rates of Phosphorus Release from Sediment

P mass and concentration increased rapidly and linearly in the overlying water column of sediment systems maintained under anoxic conditions (Figure 1). P mass and concentration increases were also very similar for replicate anoxic sediment core incubations collected from station 1. The rate of P mass and concentration increase was generally greater for cores collected from station 2 versus station 1; however, there was much more variation between replicates. The mean P concentration maximum in the overlying water at the end of the incubation period was 0.218 mg/L (± 0.013 standard error; S.E.) and 0.452 mg/L (± 0.142 S.E.) for station 1 and 2, respectively. Mean rates of P release under anoxic conditions were moderate at 2.6 mg m^{-2} d^{-1} (± 0.3 S.E.) for station 1 and 3.8 mg m^{-2} d^{-1} (± 1.7 S.E.) for station 2 (Table 2), but indicative of eutrophic conditions (Nürnberg 1988).

P mass and concentration increases in the overlying water column were much lower for sediment cores incubated under oxic conditions (Figure 2). After an initial equilibration period, P mass and concentration increased linearly between day 5 and 21 of incubation for sediment cores collected from station 1. In contrast, P increases were much lower in the overlying water column for sediment cores collected from station 2. Mean rates of P release under oxic conditions were moderately low at 0.172 mg m^{-2} d^{-1} (± 0.046 S.E.) and 0.107 mg m^{-2} d^{-1} (± 0.078 S.E.) for station 1 and 2, respectively (Table 2). The maximum SRP concentration attained in the overlying water column toward the end of the incubation period was ~ 0.080 mg/L (± 0.015 S.E.) for station 1, which was moderate and could represent an important available P source for assimilation by algae. In contrast, the SRP concentration maximum was very low for station 2 at only 0.014 mg/L (± 0.006 S.E.).

Sediment Textural and Chemical Characteristics

The upper 10-cm sediment layer exhibited a moderately high moisture content and low bulk density, indicating fined-grained flocculent sediment with moderately high porosity (i.e., interstitial volume for porewater; Table 3). Sediment organic matter content was moderately high at ~29 to 31%, typical for productive lake sediments. Concentrations of biologically-labile (i.e., subject to recycling back to the overlying water column; loosely-bound P, iron-bound P, and labile organic P) and refractory (i.e., aluminum-bound, calcium-bound, and refractory organic P) P concentrations were also moderate (Table 4 and Figure 3). Overall, biologically-labile P represented greater than 50% of the sediment total P concentration at station 1 but only 37% at station 2 (Table 5 and Figure 4).

Redox-sensitive P concentrations (i.e., the sum of loosely-bound and iron-bound P) were moderate and accounted for ~ 39% of the biologically-labile P (Table 4). Anoxic P release rates for Diamond Lake appeared to be correlated with iron-bound P (expressed on a µg P/g fresh sediment mass basis; Nürnberg 1988), suggesting that the iron-bound P concentration was an important factor in anoxic P release (Figure 5). Overall, iron-bound

P was moderate to low in concentration at 0.11 to 0.14 mg/g DW and accounted for ~ 40% of the biologically-labile P and ~ 18% of the sediment total P. Labile organic P, which can be recycled to the water column as a result of bacterial metabolic processes, represented a large portion of the biologically-labile P pool at 59% to 62% (Table 4). The loosely-bound P fraction was relatively low and accounted for only ~ 4% to 5% of the biologically-labile P and 11% of the redox-sensitive P. Loosely-bound P typically represents P in interstitial water and concentrations are usually low relative to other sediment P fractions.

Refractory organic P represented 38 to 71% of the biologically-refractory P fraction (Table 4 and Figure 4). In addition, calcium-bound P (i.e., P associated with apatite minerals) represented a large portion of the biologically-refractory P fraction at station 1 (~ 49%). Aluminum-bound P concentrations were moderately low, accounting for only ~ 8% to 13% of the biologically-refractory P (Table 4).

Total sediment Fe concentrations were moderately high for Diamond Lake (Table 5). They were also high relative to the concentration of total sediment P, resulting in an Fe:P ratio (mass:mass) of ~16:1. Ratios greater than 10:1 to 15:1 have been associated with regulation of P release from sediments under oxic (aerobic) conditions due to efficient binding of P onto iron oxyhydroxides in the sediment oxic microzone (Jensen et al. 1992). Strong and complete P binding at higher relative concentrations of Fe were suggested explanations for patterns reported by Jensen et al. At lower Fe:P ratios, Fe binding sites become increasingly saturated with P, allowing for diffusion of excess porewater P into the overlying water column, even in the presence of a sediment oxic microzone. Oxic P release rates for Diamond Lake sediments were very low in conjunction with a high Fe:P ratio, a pattern that could be attributed to the Jensen et al. model.

REFERENCES

APHA (American Public Health Association). 2005. Standard Methods for the Examination of Water and Wastewater. 21th ed. American Public Health Association, American Water Works Association, Water Environment Federation.

Boström B. 1984. Potential mobility of phosphorus in different types of lake sediments. Int. Revue. Ges. Hydrobiol. 69:457-474.

Gächter R., Meyer JS, Mares A. 1988. Contribution of bacteria to release and fixation of phosphorus in lake sediments. Limnol. Oceanogr. 33:1542-1558.

Gächter R, Meyer JS. 1993. The role of microorganisms in mobilization and fixation of phosphorus in sediments. Hydrobiologia 253:103-121.

Håkanson L, Jansson M. 2002. Principles of lake sedimentology. The Blackburn Press, Caldwell, NJ USA.

Hjieltjes AH, Lijklema L. 1980. Fractionation of inorganic phosphorus in calcareous sediments. J. Environ. Qual. 8: 130-132.

Hupfer M, Gächter R., Giovanoli R. 1995. Transformation of phosphorus species in settling seston and during early sediment diagenesis. Aquat. Sci. 57:305-324.

Jensen HS, Kristensen P, Jeppesen E, Skytthe A. 1992. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiol. 235/236:731-743.

Mortimer CH. 1971. Chemical exchanges between sediments and water in the Great Lakes – Speculations on probable regulatory mechanisms. Limnol. Oceanogr. 16:387-404.

Nürnberg GK. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45:453-462.

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

Table 1. Sequential phosphorus (P) fractionation scheme, extractants used, and definitions of recycling potential.

Variable	Extractant	Recycling Potential
Loosely-bound P	1 M Ammonium Chloride	Biologically labile; Soluble P in interstitial water and adsorbed to $CaCO_3$; Recycled via direct diffusion, eH and pH reactions, and equilibrium processes
Iron-bound P	0.11 M Sodium Bicarbonate-dithionate	Biologically labile; P adsorbed to iron oxyhydroxides (Fe(OOH); Recycled via eH and pH reactions and equilibrium processes
Labile organic P	Persulfate digestion of the NaOH extraction	Biologically labile; Recycled via bacterial mineralization of organic P and mobilization of polyphosphates stored in cells
Aluminum-bound P	0.1 N Sodium Hydroxide	Biologically refractory; Al-P minerals with a low solubility product
Calcium-bound P	0.5 N Hydrochloric Acid	Biologically refractory; Represents Ca-P minerals such as apatite with a low solubility product
Refractory organic P	Determined by subtraction of other forms from total P	Biologically refractory; Organic P that isresistant to bacterial breakdown

Table 2. Mean (1 standard error in parentheses; n=2) rates of phosphorus (P) release for sediments collected in Diamond Lake.

Station	Diffusive P flux	
	Oxic ($mg\ m^{-2}\ d^{-1}$)	Anoxic ($mg\ m^{-2}\ d^{-1}$)
Diamond 1	0.172 (0.046)	2.6 (0.3)
Diamond 2	0.107 (0.078)	3.8 (1.7)

Table 3. Textural characteristics for sediments collected in Diamond Lake.

Station	Moisture Content (%)	Bulk Density (g/cm^3)	Sediment Density (g/cm^3)	Loss-on-ignition (%)
Diamond 1	90.1	1.044	0.114	31.1
Diamond 2	90.1	1.045	0.124	28.8

Table 4. Concentrations of biologically labile and refractory P for sediments collected in Diamond Lake. DW = dry mass, FW = fresh mass.

Station	Redox-sensitive and biologically labile P				Refractory P		
	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
Diamond 1	0.018	0.144	14	0.257	0.049	0.185	0.146
Diamond 2	0.017	0.113	11	0.187	0.043	0.118	0.385

Table 5. Concentrations of sediment total iron (Fe), phosphorus (P), the total Fe to total P ratio (Fe:P), redox-sensitive P (Redox P; the sum of the loosely-bound and iron-bound P fraction), biologically-labile P (Bio-labile P; the sum of redox-P and labile organic P), and refractory P (the sum of the aluminum-bound, calcium-bound, and refractory organic P fractions) for sediments collected in Diamond Lake. DW = dry mass.

Station	Total Fe	Total P	Fe:P	Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	(mg/g DW)	(mass:mass)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Diamond 1	13.073	0.798	16.4	0.162	20.3%	0.419	52.5%	0.380	47.6%
Diamond 2	13.561	0.862	15.7	0.130	15.1%	0.317	36.8%	0.546	63.3%

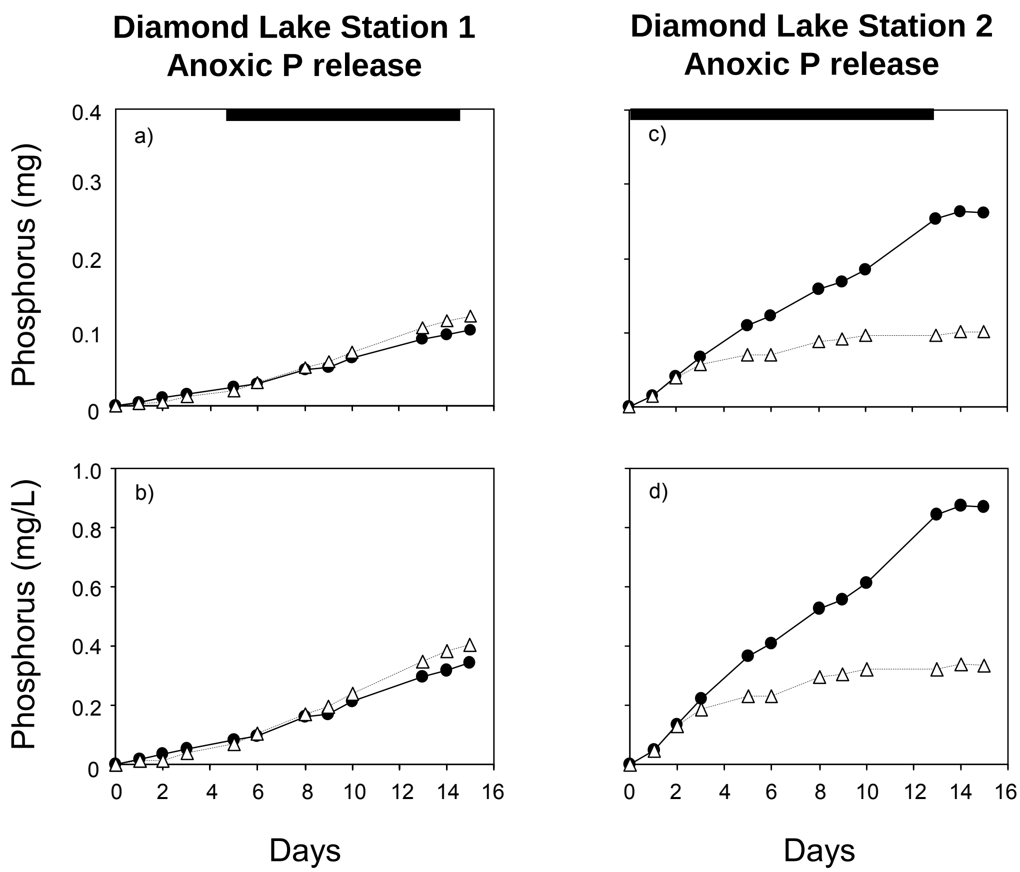


Figure 1. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under anoxic conditions versus time for sediment cores collected in Diamond Lake. Black horizontal bars denote the time period used for estimating rates.

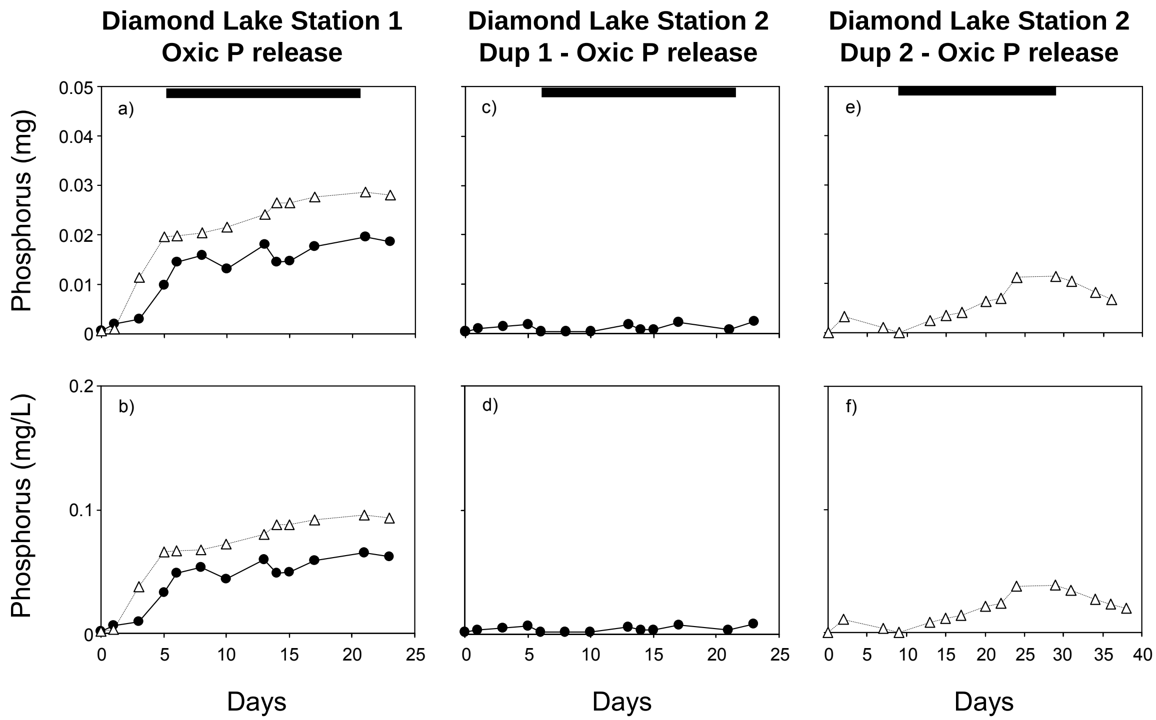


Figure 2. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under oxic conditions versus time for sediment cores collected in Diamond Lake. Duplicate core 2 collected from station 2 was incubated over a longer time period. Black horizontal bars denote the time period used for estimating rates.

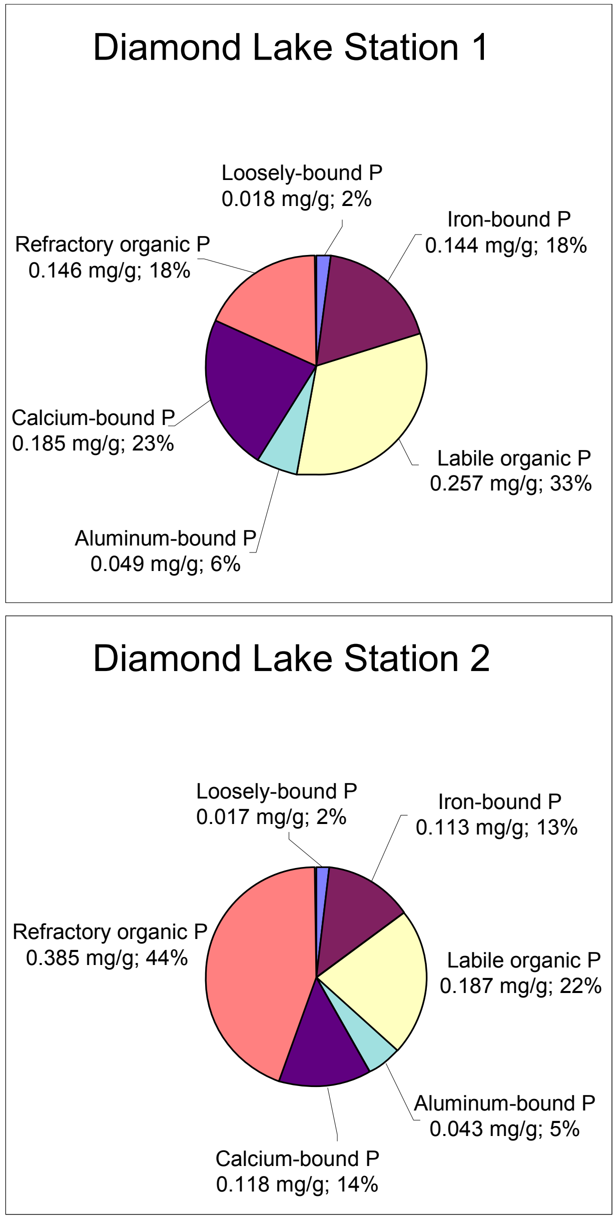


Figure 3. Total phosphorus (P) composition for sediment collected in Diamond Lake. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration (mg/g sediment dry mass) and percent of the total sediment P concentration, respectively.

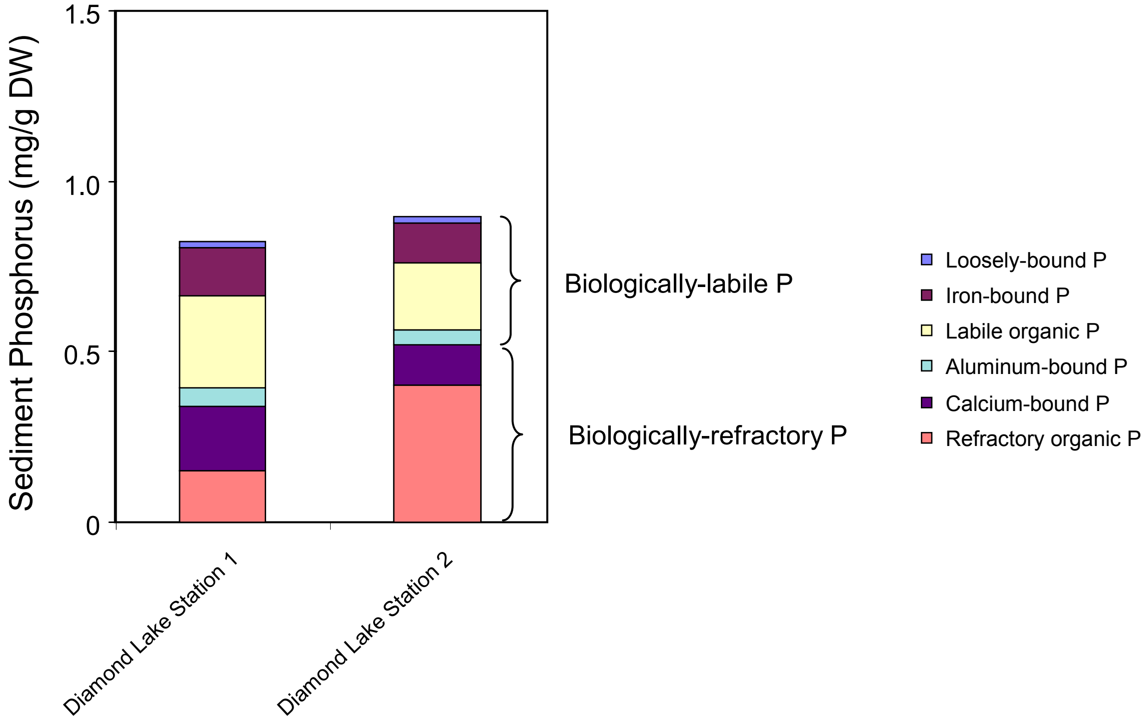


Figure 4. Vertically-stacked bar graph showing the total phosphorus (P) composition for sediment collected in Diamond Lake.

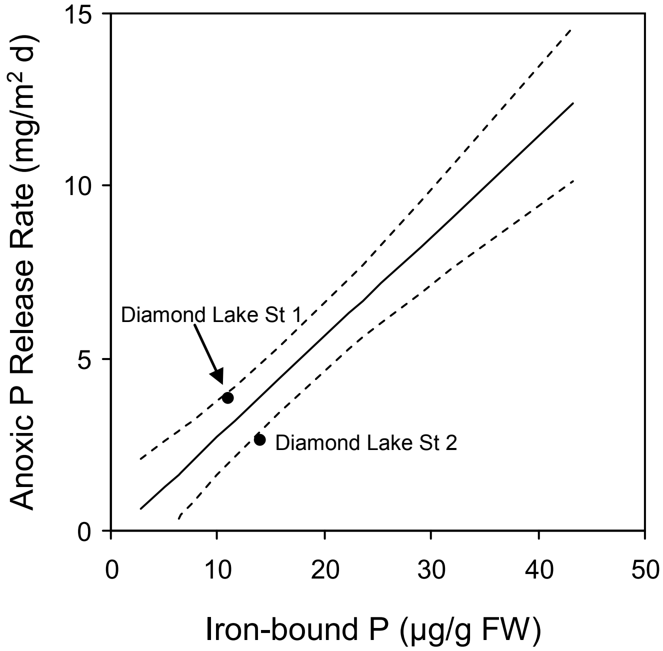


Figure 5. Relationships between iron-bound phosphorus (P; µg g^{-1} fresh sediment mass) and rates of P release from sediments under anoxic conditions. Regression line and 95% confidence intervals from Nürnberg (1988) are shown for comparison.

Elm Creek Management Commission
KAP Study Report

June 30 2013 FINAL

Karlyn Eckman
Department of Forest Resources
University of Minnesota

Contact information: eckma001@umn.edu

Executive Summary

1. A knowledge, attitudes and practices (KAP) study was conducted in 2013 by the University of Minnesota Water Resources Center (WRC) for the Elm Creek Watershed Management Commission (ECWMC). The study focused on three agricultural audiences (crop farmers, livestock operators and horse owners) in the watershed. Staff and public officials from the seven member municipalities were also invited to take the survey. While the relatively small sample cannot be considered representative of all operators in the watershed, study findings highlight audience knowledge, constraints, information needs, attitudes and current practices. It also highlights suggestions and recommendations for civic engagement, education and outreach.

2. Several residents contacted the researcher to express their views about "big government" not interfering in their lives about water quality issues. The low survey response rate is attributed in part to local distrust in government, and to some residents that actively encouraged neighbors not to take the survey. Despite low response rates, the survey highlights a number of opportunities for civic engagement, outreach and education. In addition, respondent information needs, barriers and constraints were identified. The data highlight a number of possible actions and steps that can be taken by ECWMC as the TMDL process unfolds.

3. A key finding is that most respondents believe that runoff from housing developments has the greatest impact on water quality. Very few respondents flagged manure as having the greatest impact on water quality in this watershed, which most ranked as third or fourth in terms of impact. Furthermore, livestock operators do not seem to be aware that manure is impacting local water resources, and most believe that they are already doing the right thing.

4. While most respondents believe that everyone is responsible for water quality, the majority do not seem to feel that their own operation is responsible for water quality issues in local water bodies. Agricultural operators tend to attribute problems to runoff from residential developments. A major challenge will be to raise awareness among all respondents about the specific causes of water impairments, and convincing property owners to accept responsibility for their role in contributing to the impairments.

5. There is an impression in this study that respondents and stakeholders are unaware of the potential of civic engagement in the watershed planning process. Civic engagement is a *requirement* of a TMDL, and is best described as a democratic process whereby local citizens become directly involved in watershed planning, activities, education, and determining outcomes. However, civic engagement takes time and cannot be rushed, and does not happen simply by holding a facilitated public meeting. Civic engagement should be as something that is not an add-on activity. Rather it should be seamlessly embedded in the day-to-day work on water bodies in the watershed. Most steps in the WRAPS process could include some kind of engagement activity, which when linked together over time could help ECWMC to build trusting relationships, and engage civic imagination and skills of the public in the process. Civic

engagement can help to get work done, but it takes a committed person on the ground making this their focus and passion.

6. Some respondents appear to be ready to take a more active role, and there may be good potential to engage them in the TMDL process. There are many positive findings upon which to develop mechanisms for civic engagement, outreach and education.
6. Most respondents understand the linkage between people's actions and water quality, and have some basic knowledge about clean water. Most are generally interested in trying something new to improve water quality, and the various sampling groups express different preferences for ways to learn about and to adopt BMPs. It is likely that people will respond to communications that are positive in tone and content, and that recognize and reward stewardship and water conservation efforts. This study did not explore social networks or peer-to-peer communication, but there is no reason to believe that these strategies would not be successful.

7. A constraints and barriers question revealed that people believe that they are already doing the right thing. Although this view may prevent them changing their practices, this is actually a very positive finding. It is likely that a communication strategy focusing on stewardship and "doing the right thing" will resonate with this worldview. The second most important constraint for respondents is cost. In particular, agricultural groups (and especially horse business operators) seem to be more sensitive to cost concerns. A financial incentive could be of interest to some individuals (but not necessarily all) to better enable them to adopt a BMP. A third concern for all groups is the need for more information and not knowing about how to install a BMP. There appears to be an unmet need for technical information across all groups. At least some respondents noted other constraints (lack of equipment, lack of time etc.).

8. Most of the possible mechanisms and incentives appealed to at least some sample sub-groups, but not necessarily to all groups equally (e.g., one size does not fit all). Results suggest that the best approach is to offer multiple opportunities for different subgroups to learn about different BMPs. A targeted educational strategy should be developed, emphasizing the impacts of manure on water quality. This should not be done in a putative or scolding manner, as it will likely turn off message recipients. Given the small sample size, and diverse nature of the sub-groups, ECWMC should consider offering small hands-on workshops or other learning opportunities for targeted groups. This will require developing audience-specific and content-specific workshop materials and curricula. To do that, it is recommended that ECWMC consider recruiting an experienced full-time staff member dedicated to education and outreach.

Acronyms

BMP	Best management practice
CATA	Check all that apply
CE	Civic engagement
COOR	Check only one response
DNR	Minnesota Department of Natural Resources
ECWMC	Elm Creek Watershed Management Commission
KAP	Knowledge, attitudes and practices
MPCA	Minnesota Pollution Control Agency
n	Number
Q	Question
TMDL	Total maximum daily load
WRC	Water Resources Center (University of Minnesota)

Introduction

A KAP (knowledge, attitudes and practices) study was conducted in the spring of 2013 by the University of Minnesota Water Resources Center (WRC) on behalf of the Elm Creek Watershed Management Commission (ECWMC). The purpose of the study is to explore the motivations, interests, concerns and constraints for three local audiences within the watershed (crop farmers, livestock farmers and horse owners). The survey is characterized as a formative study that will provide baseline (pre-project) information. The results will contribute to the development of a civic engagement strategy for the three audiences.

This study followed the KAP study protocol outlined in Eckman (2013). The process began with a small group of stakeholders, comprised of ECWMC board members and local residents. A “gap exercise” identified what was not known about the population of interest, but should be learned in order to successfully engage people and develop educational content. The exercise participants identified a number of questions that became the basis for questionnaire construction. A first draft questionnaire was prepared and circulated back to the group for comments and revisions. Some questions used in a manure management KAP study in Rock County were selected by ECWMC for inclusion in the ECWMC KAP study.

The questionnaire draft was then reviewed by peers and colleagues, and revised to be sure that it was neutral in tone and did not suggest that farmers or livestock owners are to blame for water quality issues. The draft questionnaire was then pre-tested. Respondents were informed that taking the survey was voluntary and were assured of strict confidentiality. The questionnaire mentioned government entities three times, to determine whether agencies such as ECWMC, DNR or MPCA are sources of information for farmers; to determine if respondents would be willing to work with their local government on water quality issues; and to ask who respondents believe are responsible for improving water quality.

From verbal and written comments received it is clear that this study area has unusually strong opinions about the role of government and taxation, which likely influenced response rates.

Sampling Frame

The survey sampled 246 property owners who were determined to keep livestock within the ECWMC boundaries, and who may contribute nutrients and bacteria to the Elm Creek TMDL. The sample population was obtained from a database created by ECWMC staff members based on the location of known agricultural properties. In addition, watershed staff used Goggle Earth street-view to determine the approximate number and types of livestock housed on each parcel. From this exercise a spreadsheet was created listing the property owner and addresses of those known to keep livestock. This was the core sampling group targeted by the KAP study. This exercise found that more property owners than expected kept livestock (Table 1 below).

Table 1: Approximate livestock numbers in the ECWMC

Livestock type	Census
Cattle	2027 (1132 beef; 895 dairy cows)
Horses	1382
Sheep	104
Hogs	35
Llamas	6
Elk	40
Total animal units	3594

The sample is considered to be purposive and non-random. 40 respondents completed the survey on-line, for a 16% response rate of all livestock operators of operators in the watershed boundaries. The survey link was also made available on the ECWMC website and to staff and officials of the seven member municipalities of the watershed district. 20 municipal staff took the survey, for a total of 60 responses (24%). While this response rate is disappointing, it is comparable to an undated survey conducted by Betsy Wieland (Minnesota UM Extension) of livestock owners in Medina (21 questionnaires out of 85 were returned for a 25% response rate).

A possible factor influencing the low response rate is the apparent conservative political and libertarian inclination of this region of the state. Two of the respondents telephoned the researcher complaining that any survey on water quality would only lead to more government intervention. One caller said that he would not be taking the survey and was going to encourage his neighbors and friends to do the same, because of his belief that social research would bring more taxes and government intrusion. Other comments suggested that government should not intrude on their farming practices. These comments were made despite care taken to make the questionnaire and survey materials neutral and non-threatening.

Survey Administration

Three options were developed for respondents to access the survey. First, a web-link was posted on the ECWMC website for the general public. Second, a targeted mailing was sent by ECWMC staff to all property owners on the sampling list, with an announcement of the on-line survey. A follow-up postcard was then sent to those individuals that had not yet taken the survey. Third, the ECWMC Commissioner from the City of Medina requested that the survey also be taken by municipal staff and officials from the seven member municipalities. An emailed invitation was sent to the seven city administrators with a request to circulate the invitation among their staff and officials. Respondents took the survey on-line through a link to Survey Monkey. Survey Monkey was also used for secure on-line data storage.

Results and Findings

It is important to note the limitations of this particularly survey. As with the earlier Wieland survey, the response rate was low, and is attributed in part to local distrust in government. Furthermore, total responses for all three agricultural groups are low, so results should not be considered representative of the larger population. The data do, however, provide some useful insights.

Raw data will be presented separately for two groups (the agricultural audiences and municipal employees) in this section. Results will be presented in graph formats for each question. Q8 (type of farming operation) identifies the sub-groups of interest in this KAP study, so all questions are cross-tabulated by sub-group. All groups in the sample are shown in Table 1 below.

Table 1.1
Q8. What type of farming operation do you have? Check all that apply.

	Ag respondents (n = 40)	**Municipal respondents (n = 20)**	**All**
Dairy or beef	6.5% (2)	17% (1)	8% (3)
Field crops	13% (4)	17% (1)	13.5% (5)
Both livestock and crops	16% (5)	50% (3)	22% (8)
Horses (hobby)	68% (21)	33% (2)	62% (23)
Horses (business)	6.5% (2)	17% (1)	8% (3)
Other	-	-	7
Answered question	31	6	37
Skipped question	8	14	23
Totals	40	20	60

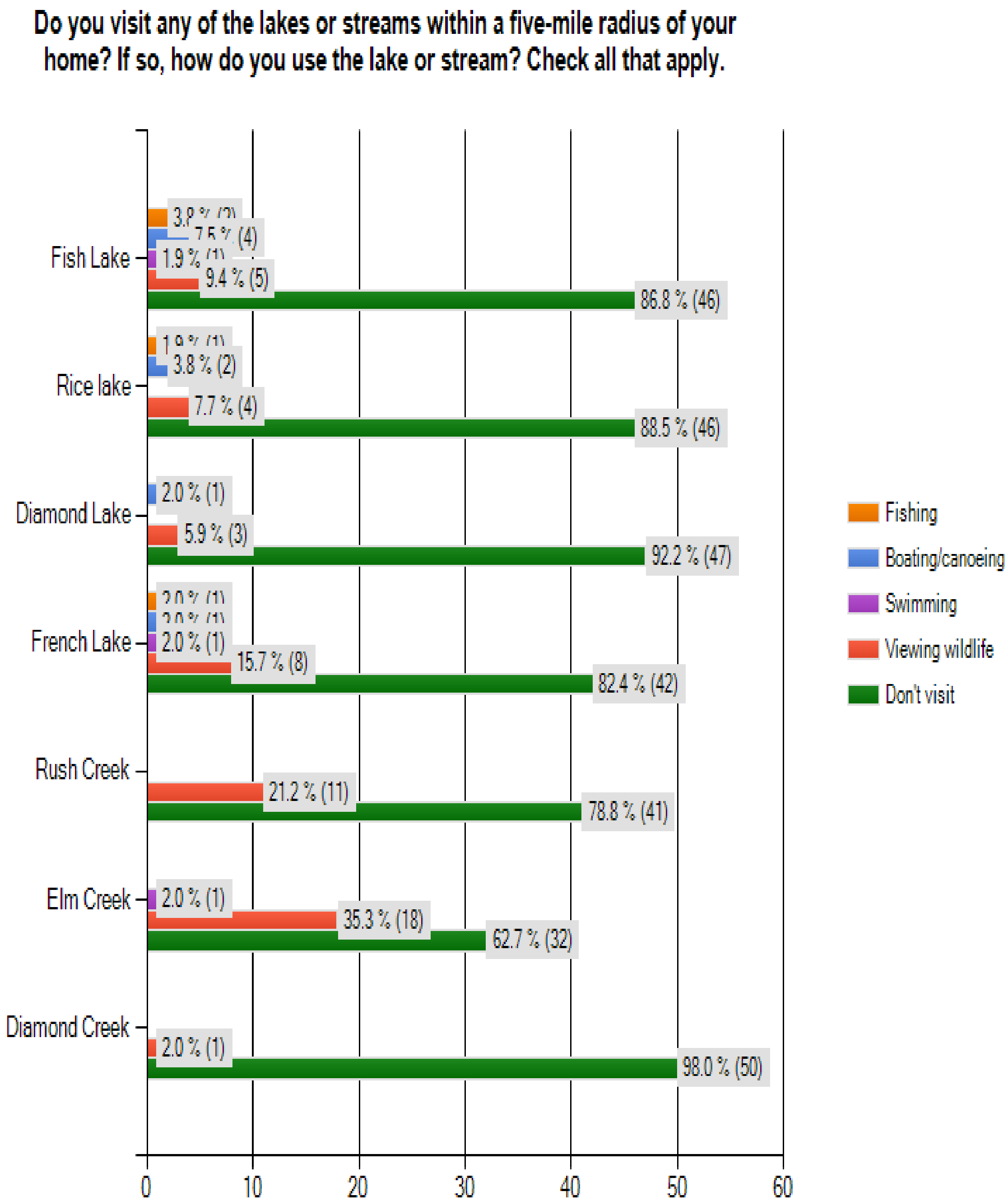
It is interesting to note that of the twenty municipal staff respondents, six report that they are also agricultural operators. It is not possible to know their location, however, and one of these respondents noted that s/he does not live within the ECWMC boundaries.

Use of local water resources

Introductory questions were posed to gauge respondent awareness of local streams and lakes, and their relative condition. Question 1 (Q1 below) explored all respondents' use of local streams and rivers (see Table 1.1 below). Table 1.2 presents municipal staff responses only. Table 1.3 presents responses for agricultural respondents only. In this table, Q1 results were cross-tabulated with Q8 (type of farming operation) to determine which groups use local waters more or less than other groups.

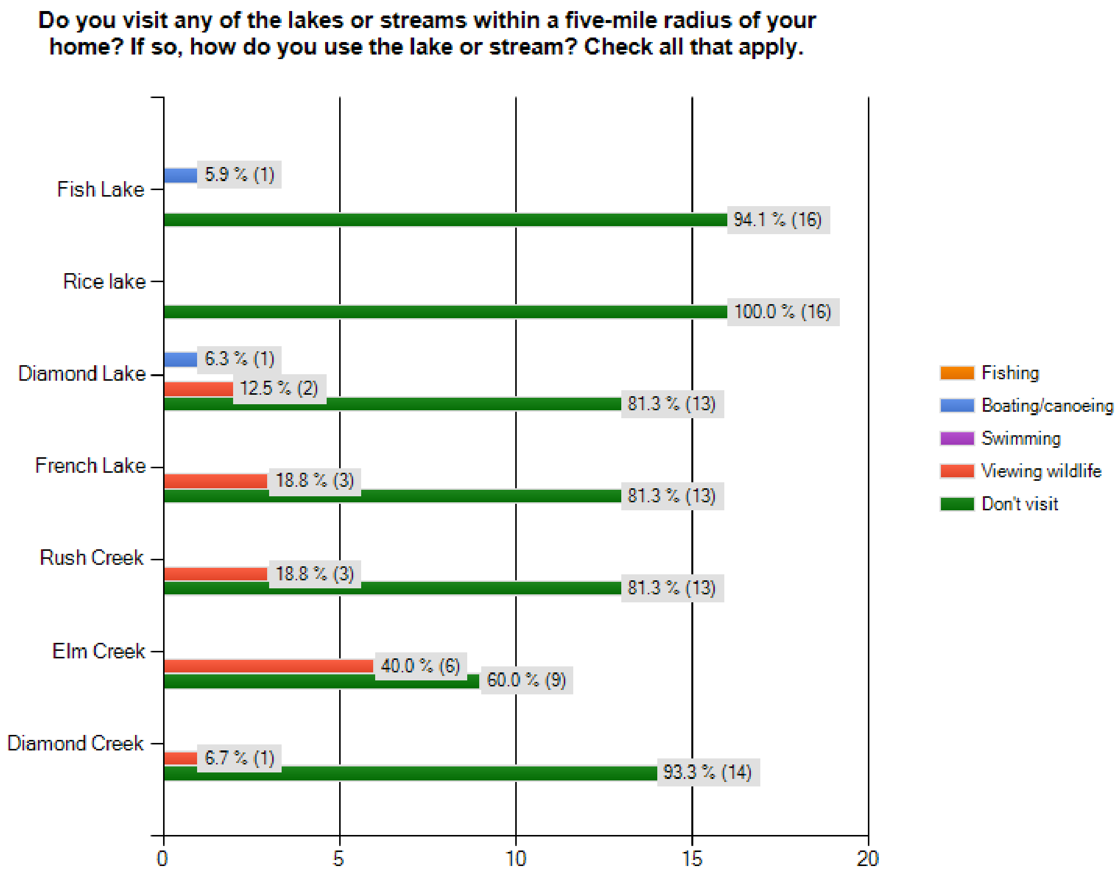
Q1. Do you visit any of the lakes or streams within a five-mile radius of your home? If so, how do you use the lake or stream? Check all that apply.

Table 1.1 All responses



Answered question: 55
Skipped question: 5

Table 1.2 Responses of Municipal Staff



Answered question: 17
Skipped question: 3

Table 1.3 Responses by Subgroup
Crosstab - Q1 x Q8 Type of Farming Operation (n = 40)

Elm Creek Water Survey

Do you visit any of the lakes or streams within a five-mile radius of your home? If so, how do you use the lake or stream? Check all that apply.		What type of farming operation do you have? Check all that apply.					
		Dairy or beef	Field crops	Both livestock and crops	Horses (hobby or personal use)	Horses (business such as breeding, boarding or training)	Response Totals
Fish Lake	Fishing	0.0% (0)	14.3% (1)	0.0% (0)	4.8% (1)	0.0% (0)	
	Boating/canoeing	0.0% (0)	14.3% (1)	0.0% (0)	4.8% (1)	0.0% (0)	
	Swimming	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	
	Viewing wildlife	0.0% (0)	14.3% (1)	33.3% (2)	9.5% (2)	0.0% (0)	
	Don't visit	**100.0% (3)**	**57.1% (4)**	**66.7% (4)**	**81.0% (17)**	**100.0% (3)**	
		3	7	6	21	3	31
Rice lake	Fishing	0.0% (0)	16.7% (1)	0.0% (0)	5.0% (1)	0.0% (0)	
	Boating/canoeing	0.0% (0)	16.7% (1)	0.0% (0)	5.0% (1)	0.0% (0)	
	Swimming	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	
	Viewing wildlife	0.0% (0)	16.7% (1)	16.7% (1)	10.0% (2)	0.0% (0)	
	Don't visit	**100.0% (3)**	**50.0% (3)**	**83.3% (5)**	**80.0% (16)**	**100.0% (3)**	

1 of 3

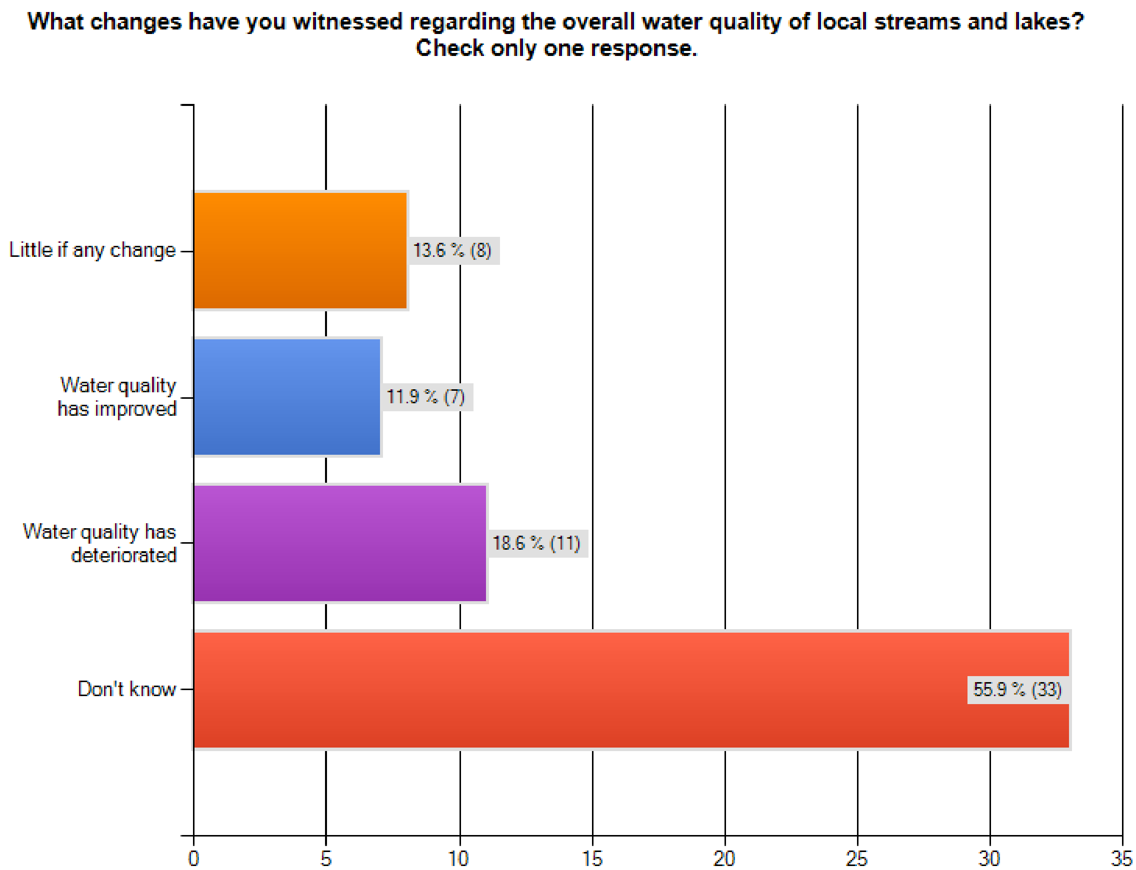
Elm Creek is the local water body most visited by respondents, with six municipal staff, two ag producers and eighteen other respondents reporting viewing wildlife there. Elm Creek was visited most often by municipal employees, although overall 67% of them do not visit Elm Creek. Of the agricultural respondents, Elm Creek is most often used for viewing wildlife (n= 13) followed by Rush Creek (10), French Lake (8), Fish Lake (5), Rice Lake (4) and Diamond Lake (3). Ag respondents reported boating on Fish Lake (n = 4), Rice Lake (n = 2), and Diamond and French Lakes (one each). Swimming was reported by one respondent respectively at Fish Lake, French Lake and Elm Creek. Eleven respondents reported visiting Rush Creek for viewing wildlife but for no other purpose. Diamond Lake is least visited by agricultural operators, with only one person viewing wildlife there. In general, however, most respondents do not visit local waters.

TAKEAWAY: The majority of respondents in all sub-groups do not visit local streams and lakes. It is not clear whether the reason is due to disinterest or lack of familiarity (or both). However, several respondents entered comments suggesting that they are not very aware of local water resources. The apparent lack of familiarity with local water bodies for many respondents suggests that opportunities to raise awareness could be created by organizing or sponsoring outings and visits to local streams and lakes. These could be combined with educational messages, historical information, local lore and other aspects designed to raise the awareness about local waters.

Awareness of trends in water quality

A follow-up question asked whether respondents have noted changes in overall quality of local lakes and streams. Combined responses for all responses are given in Table 2.1. Responses for municipal respondents are summarized in Table 2.2, and agricultural sub-groups in Table 2.3.

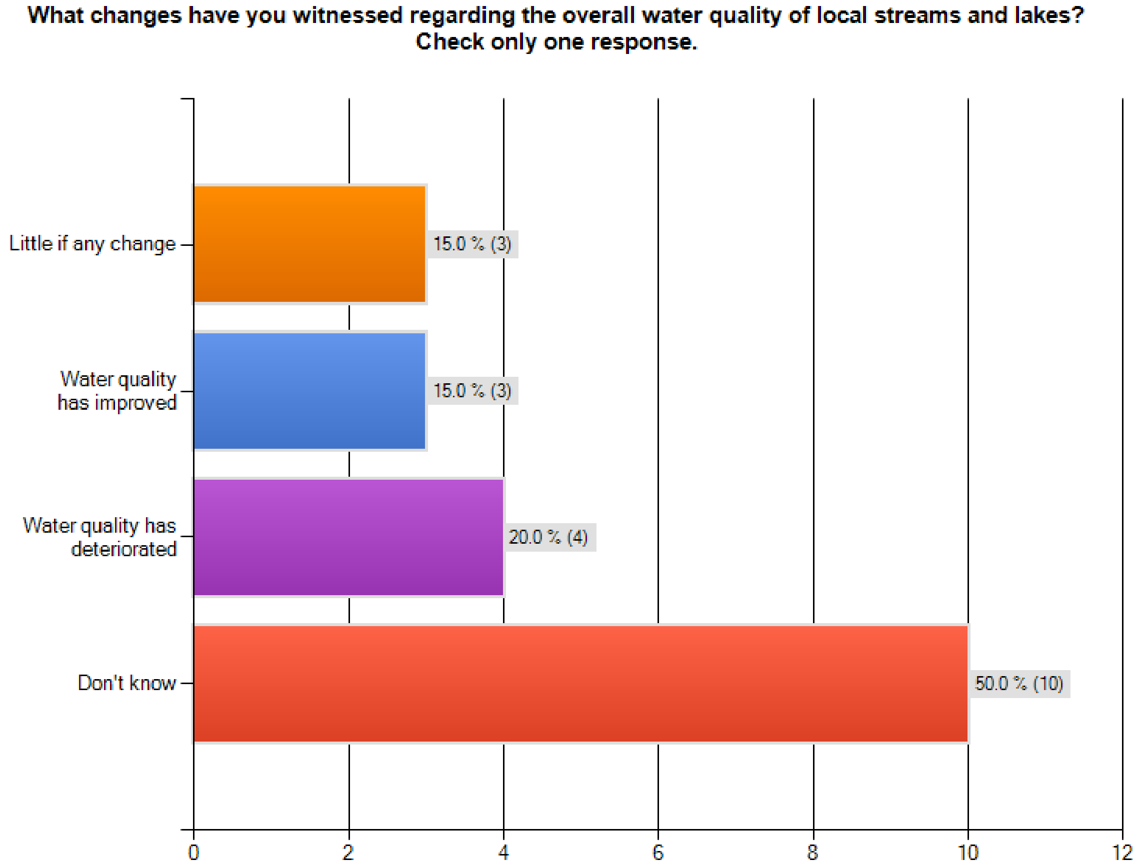
Table 2.1 All Responses (n = 60)



Answered question: 59
Skipped question: 1

A slightly smaller percentage (50%) of municipal employees was uncertain about water quality trends. Twenty percent felt that water quality had deteriorated, again a higher value than the overall sample.

Table 2.2 Responses of Municipal Staff



Answered question: 20
Skipped question: 0

Among agricultural groups (Table 2.3 below), there was some variation by type of producer, although it must be cautioned that the sample sizes for each group are too small to be representative. Over half of all respondents in all groups (except horse-related businesses) expressed uncertainty about water quality trends.

Table 2.3: Responses by subgroup
Cross tabulation - Q8 Type of farming operation x Q2 What changes have you witnessed

Elm Creek Water Survey

What changes have you witnessed regarding the overall water quality of local streams and lakes? Check only one response.

	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	**Field crops**	**Both livestock and crops**	**Horses (hobby or personal use)**	**Horses (business such as breeding, boarding or training)**	**Response Totals**
Little if any change	0.0% (0)	20.0% (1)	37.5% (3)	18.2% (4)	**33.3% (1)**	16.7% (6)
Water quality has improved	33.3% (1)	0.0% (0)	12.5% (1)	9.1% (2)	0.0% (0)	11.1% (4)
Water quality has deteriorated	**66.7% (2)**	20.0% (1)	0.0% (0)	18.2% (4)	**33.3% (1)**	19.4% (7)
Don't know	0.0% (0)	**60.0% (3)**	**50.0% (4)**	**54.5% (12)**	33.3% (1)	**52.8% (19)**
Other (please specify)	0 replies	0 replies	0 replies	1 reply	0 replies	1
answered question	3	5	8	22	3	**36**
					skipped question	**1**

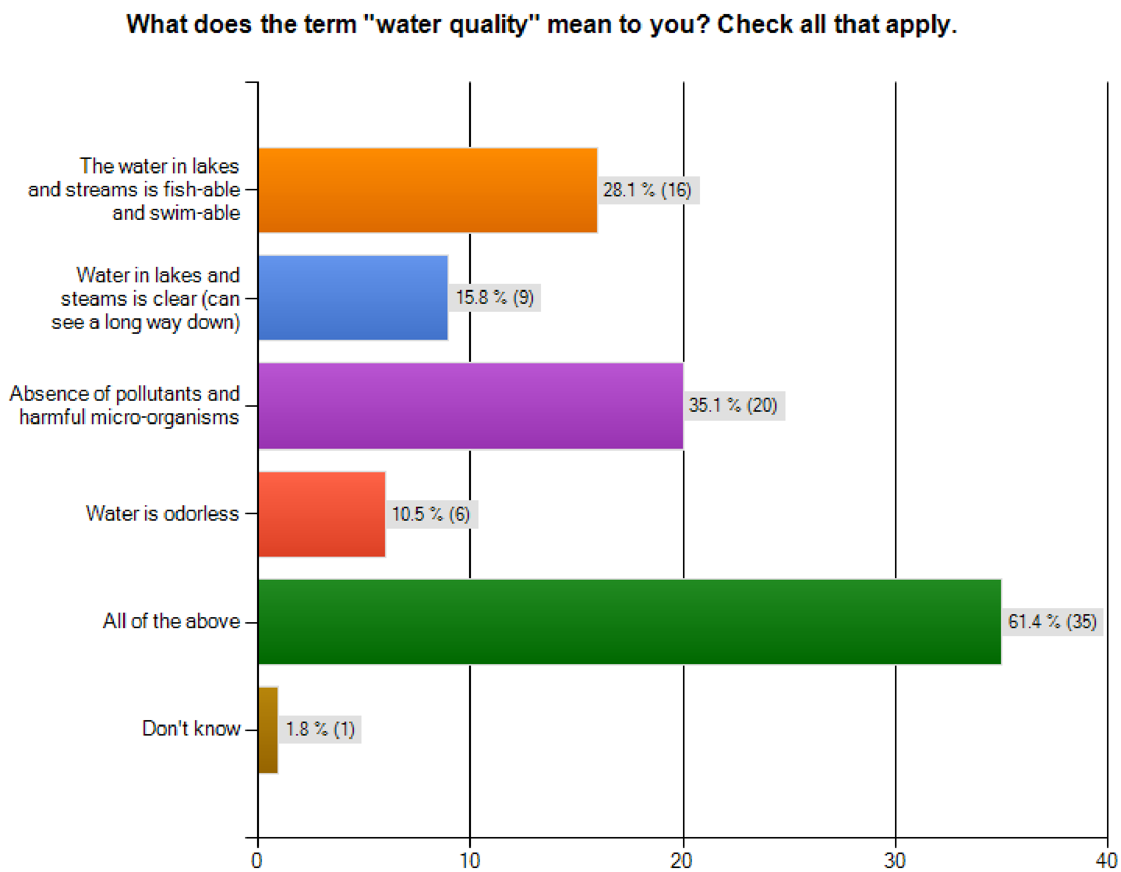
1 of 1

TAKEAWAY: Survey results show that there is considerable uncertainty among respondents about changes in water quality. Over half (60%) of all sixty respondents responded “Don’t know.” 14% saw little or no change, while 12% said that water quality had improved and 19% felt that water quality had deteriorated. The uncertainty about water quality trends among all groups presents an opportunity for targeted educational messaging aimed at improving respondent knowledge related to the TMDL.

Knowledge of water quality

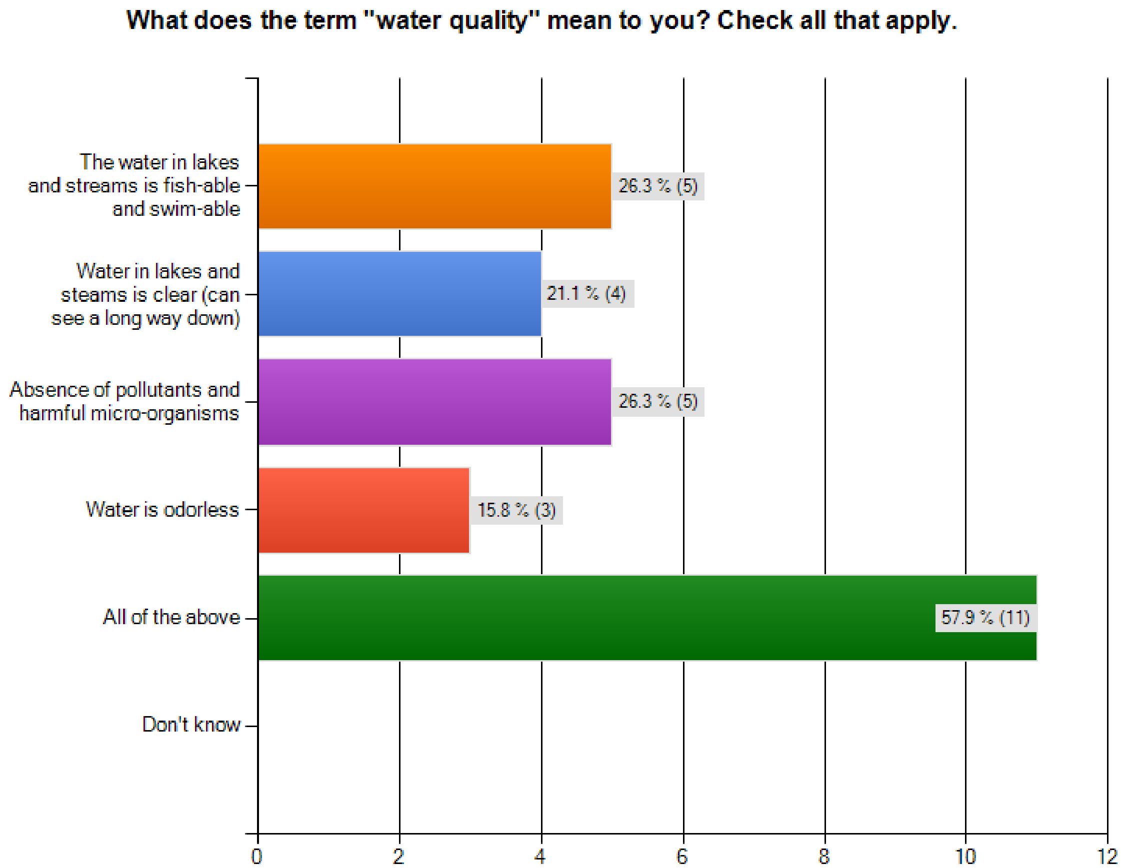
Q3: What does the term “water quality” mean to you? Check all that apply.
A question asked whether respondents understand basic characteristics of clean water. Combined responses for all responses are given in Table 3.1. Responses for municipal respondents are summarized in Table 3.2, and agricultural sub-groups in Table 3.3.

Table 3.1 All responses



Answered question: 57
Skipped question: 3

Table 3.2 Municipal staff responses



Answered question: 19
Skipped question: 1

Table 3.3: Responses by subgroup
Crosstab Q3 - What does the term water quality mean to you X Q8 Type of farming operation?

Elm Creek Water Survey

What does the term "water quality" mean to you? Check all that apply.

	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	**Field crops**	**Both livestock and crops**	**Horses (hobby or personal use)**	**Horses (business such as breeding, boarding or training)**	**Response Totals**
The water in lakes and streams is fish-able and swim-able	33.3% (1)	**60.0% (3)**	25.0% (2)	19.0% (4)	0.0% (0)	22.9% (8)
Water in lakes and steams is clear (can see a long way down)	**66.7% (2)**	40.0% (2)	25.0% (2)	9.5% (2)	0.0% (0)	17.1% (6)
Absence of pollutants and harmful micro-organisms	33.3% (1)	**60.0% (3)**	25.0% (2)	38.1% (8)	0.0% (0)	34.3% (12)
Water is odorless	**66.7% (2)**	0.0% (0)	0.0% (0)	14.3% (3)	0.0% (0)	11.4% (4)
All of the above	**66.7% (2)**	40.0% (2)	**62.5% (5)**	**61.9% (13)**	**100.0% (3)**	**60.0% (21)**
Don't know	0.0% (0)	0.0% (0)	12.5% (1)	0.0% (0)	0.0% (0)	2.9% (1)
Other (please specify)	0 replies	0 replies	0 replies	1 reply	0 replies	1
answered question	3	5	8	21	3	**35**
					skipped question	**2**

1 of 1

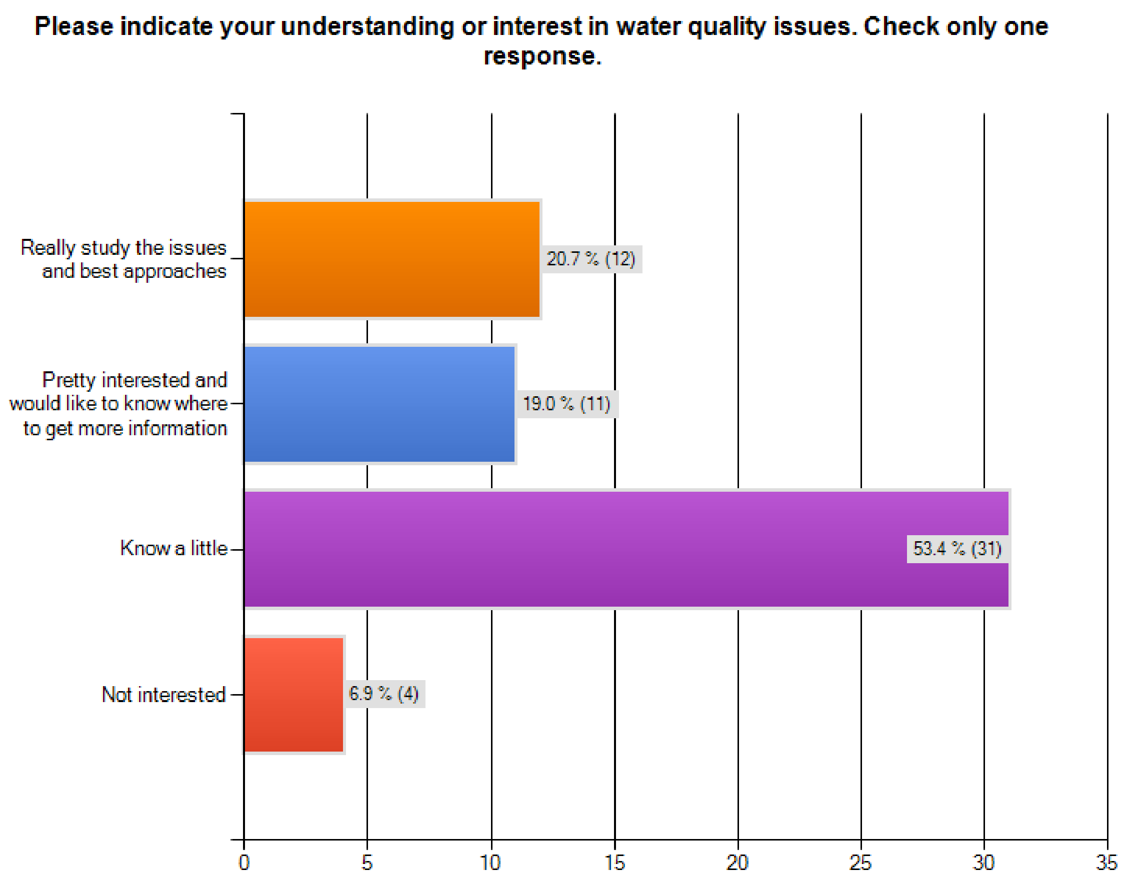
Takeaway: In all sampling groups, “all of the above” was the most common response. Only two respondents mentioned “Don’t know.” This suggests that most audiences have a clear and basic understanding and awareness of the characteristics of clean water. This positive understanding is a starting point and building block for educational content (*e.g.* basic characteristics don't need to be reinforced).

Understanding and interest about water quality

A follow-up question asked whether respondents have a general understanding and interest in water quality. Combined responses for all responses are given in Table 4.1. Responses for municipal respondents are summarized in Table 4.2, and agricultural sub-groups in Table 4.3.

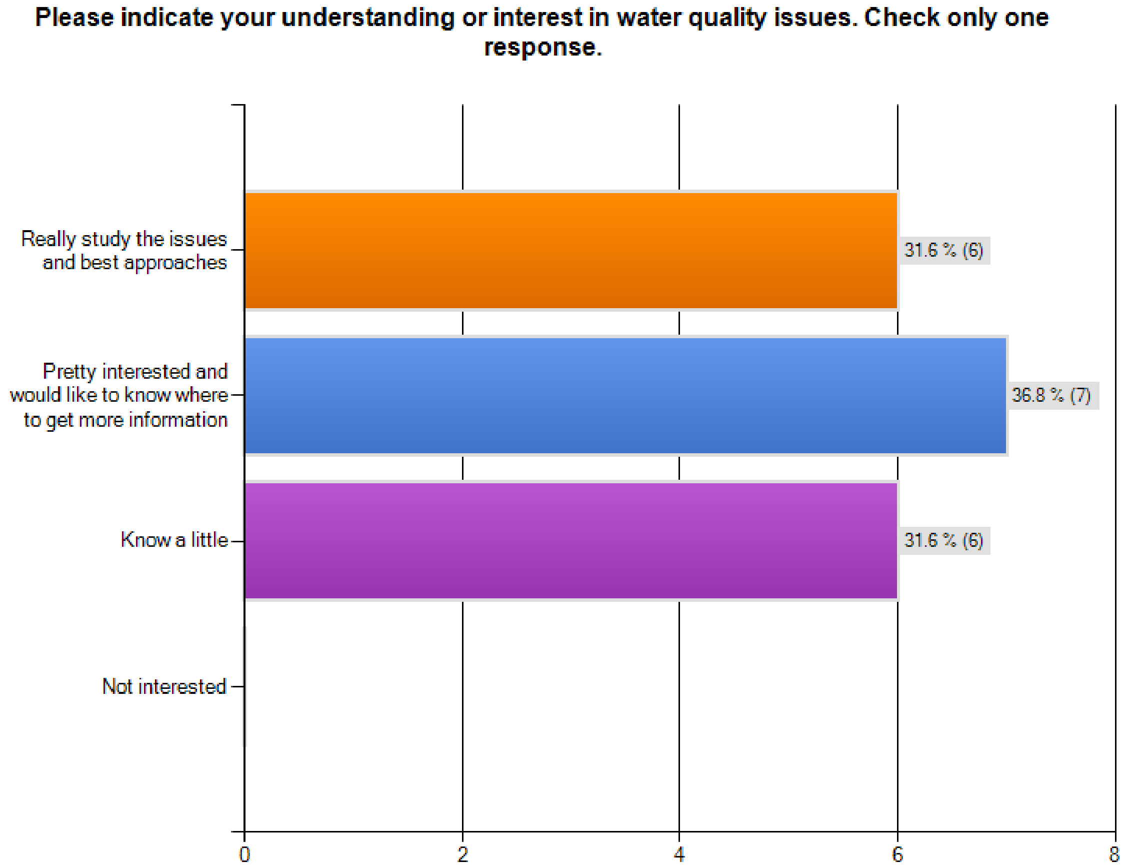
Q4: Please indicate your understanding or interest in water quality issues. Check only one response.

Table 4.1: All responses



Answered question: 58
Skipped question: 2

Table 4.2: Municipal staff responses



Answered question: 19
Skipped question: 1

Comparing the entire sample with municipal staff, the former has somewhat less understanding and interest in water quality issues than do municipal officials and staff. It is likely that at least some of the municipal respondents deal with water quality in their work. 19% of the entire sample, 39% of the municipal staff and seven agricultural operators would like to know more. Of the agricultural audiences, most know a little but few really study the issues. Only one or two noted that they were not interested.

Table 4.3: Responses by agricultural subgroup
Crosstab (Q4 Indicate your understanding of water issues X type of farming operation)

Elm Creek Water Survey

Please indicate your understanding or interest in water quality issues. Check only one response.

	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	**Field crops**	**Both livestock and crops**	**Horses (hobby or personal use)**	**Horses (business such as breeding, boarding or training)**	**Response Totals**
Really study the issues and best approaches	33.3% (1)	20.0% (1)	12.5% (1)	4.5% (1)	0.0% (0)	11.1% (4)
Pretty interested and would like to know where to get more information	0.0% (0)	**40.0% (2)**	25.0% (2)	18.2% (4)	33.3% (1)	19.4% (7)
Know a little	**66.7% (2)**	**40.0% (2)**	**50.0% (4)**	**72.7% (16)**	**66.7% (2)**	**63.9% (23)**
Not interested	0.0% (0)	0.0% (0)	12.5% (1)	4.5% (1)	0.0% (0)	5.6% (2)
Other (please specify)	1 reply	0 replies	1 reply	0 replies	0 replies	2
answered question	3	5	8	22	3	**36**
					skipped question	**1**

1 of 1

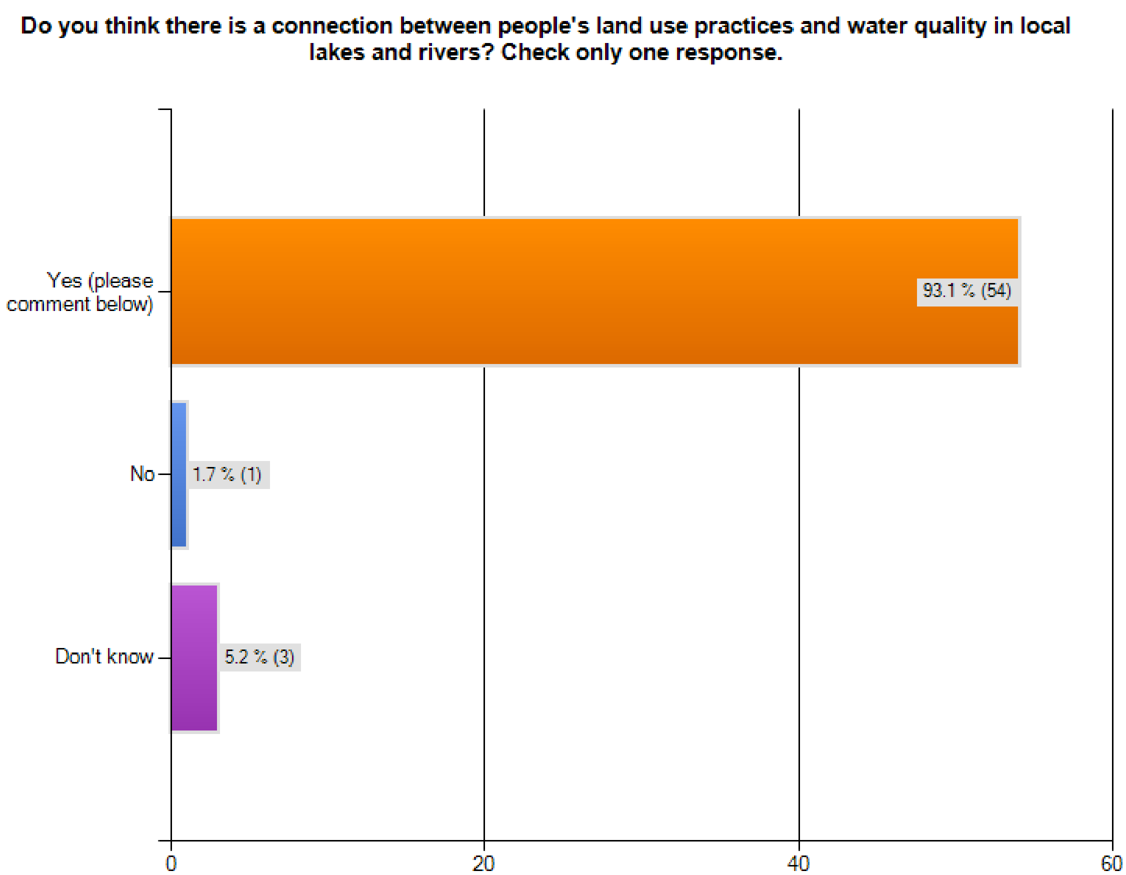
TAKEAWAY: Consistent with the responses in Q1, there may be good potential and interest for raising awareness and understanding of local water quality issues on a very basic level. The survey results suggest that educational content might be generally well-received by most people. Such content could feature informative messages about specific local lakes and streams, particularly about different types of wildlife habitats (building on existing behaviors), local wildlife sightings, and linking water quality messages to those habitats.

Awareness of human impacts on water

This question demonstrated that people draw a clear link between human activity and the condition of lakes and rivers. Table 5.1 presents results from all respondents. Table 5.2 shows results from municipal staff and officials, and Table 5.3 breaks down responses among agricultural audiences.

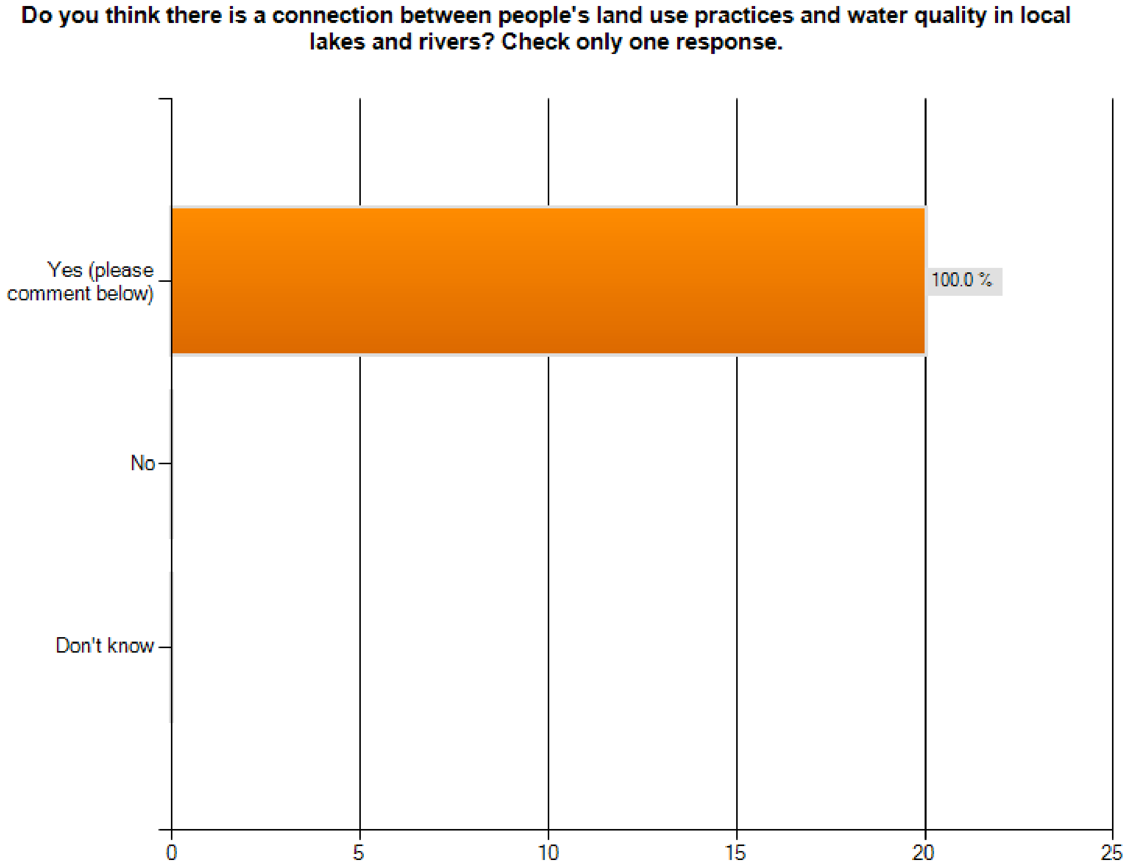
Q5: Do you think there is a connection between people's land use practices and water quality in local lakes and rivers? Check only one response.

Table 5.1: All responses



Answered question: 58
Skipped question: 2

Table 5.2: Municipal staff responses



Answered question: 19
Skipped question: 1

Table 5.3 Responses by agricultural sub-group – Crosstab Q5 x Q8

TAKE-AWAY: Responses to Q5 show that all respondents except for very few individuals understand that there is a clear link between human behavior and water quality in local lakes and streams. Of the entire sample, only two people (one a horse business owner) felt that there is no connection; three were uncertain.

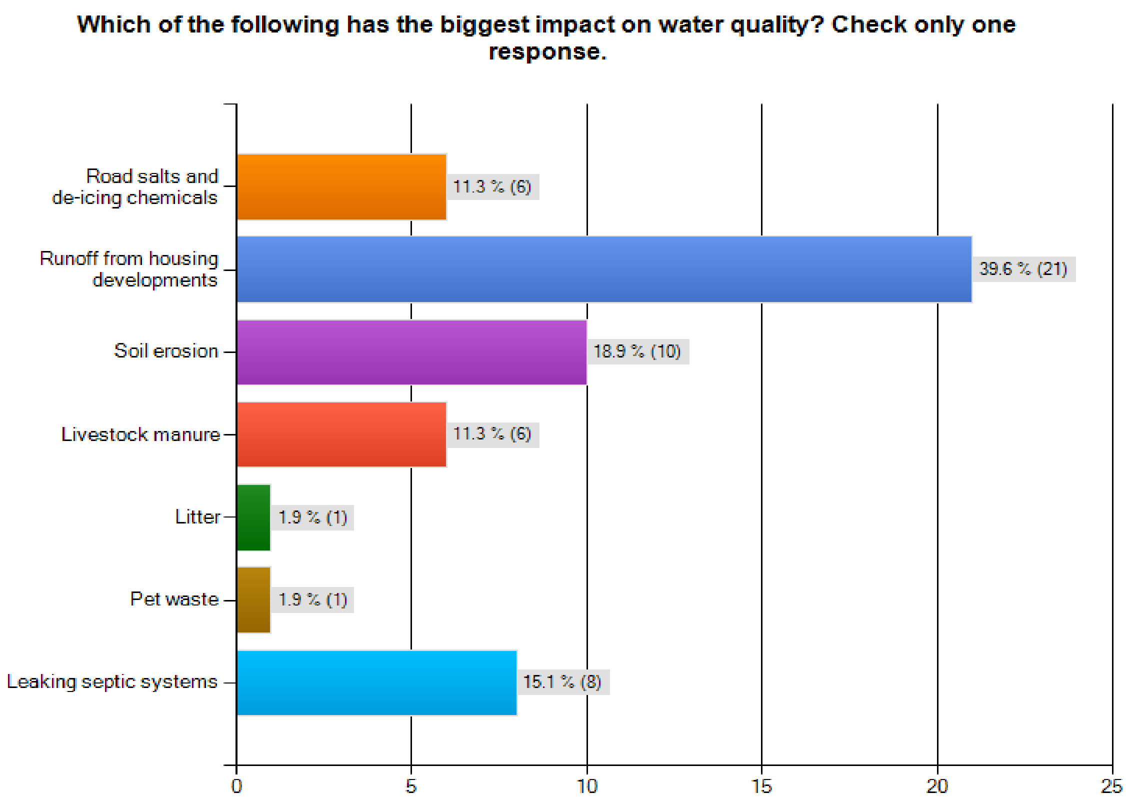
Almost all respondents "get" the big picture. Educational content does not need to dwell on this construct because most people already understand the human-water quality link very clearly. However, this could be a departure point upon which to build additional message content.

Knowledge of causes of water quality problems

This question was designed to gauge respondent knowledge about the cause or source of water impairments. Table 6.1 shows responses for all respondents. Table 6.2 shows responses for municipal staff, and Table 6.3 shows responses for agricultural audiences.

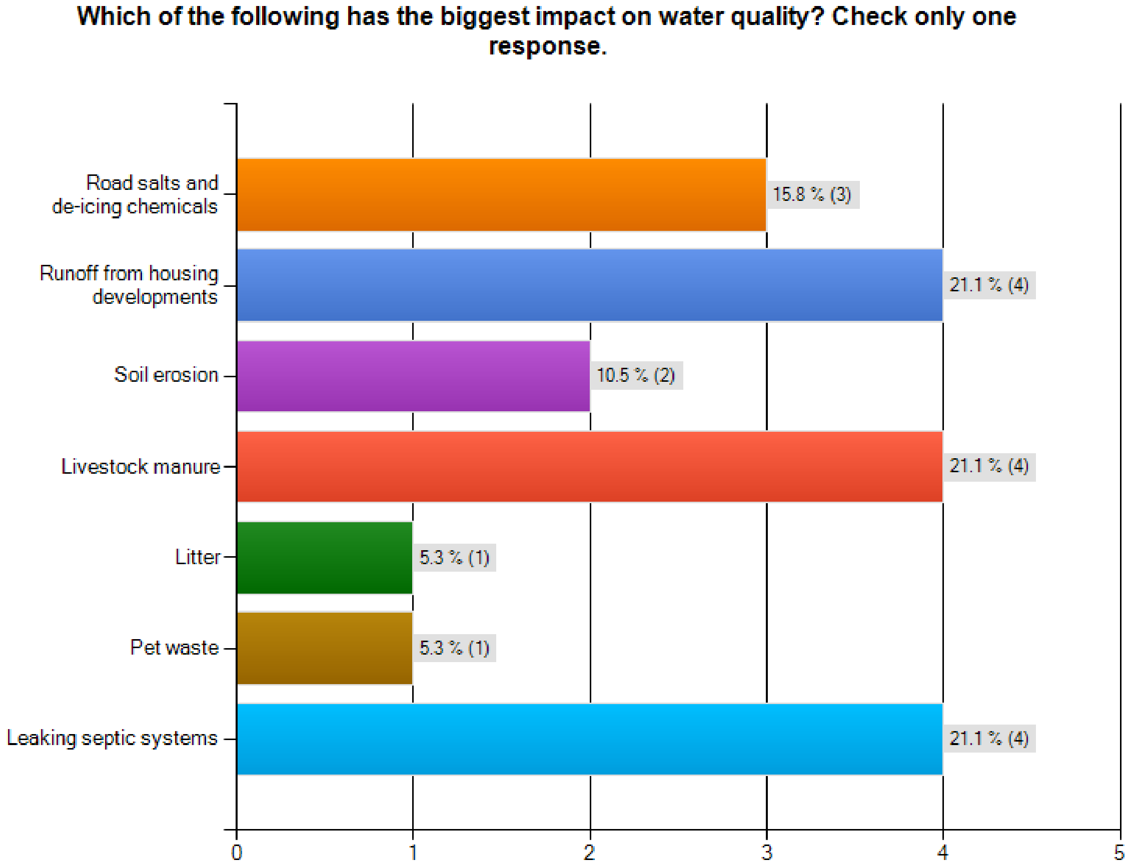
Q6: Which of the following has the biggest impact on water quality? Check only one response.

Table 6.1 All responses



Answered question: 53
Skipped question: 7

Table 6.2 Responses of municipal staff and officials



Answered question: 19
Skipped question: 1

Table 6.3 Responses by sub-group – Crosstab Q 6 x Q8

These results show a clear need and opportunity for education about manure as a pollutant source in this watershed. The majority of all respondents believe that runoff from housing developments has the greatest impact on water quality, possibly due to visible ex-urban development and growth. Very few respondents flagged manure as having the greatest impact on water quality in this watershed, which most ranked as third or fourth in terms of impact. Furthermore, livestock operators do not seem to be aware that manure can impact local water resources, and (as noted below) most believe that they are already doing the right thing.

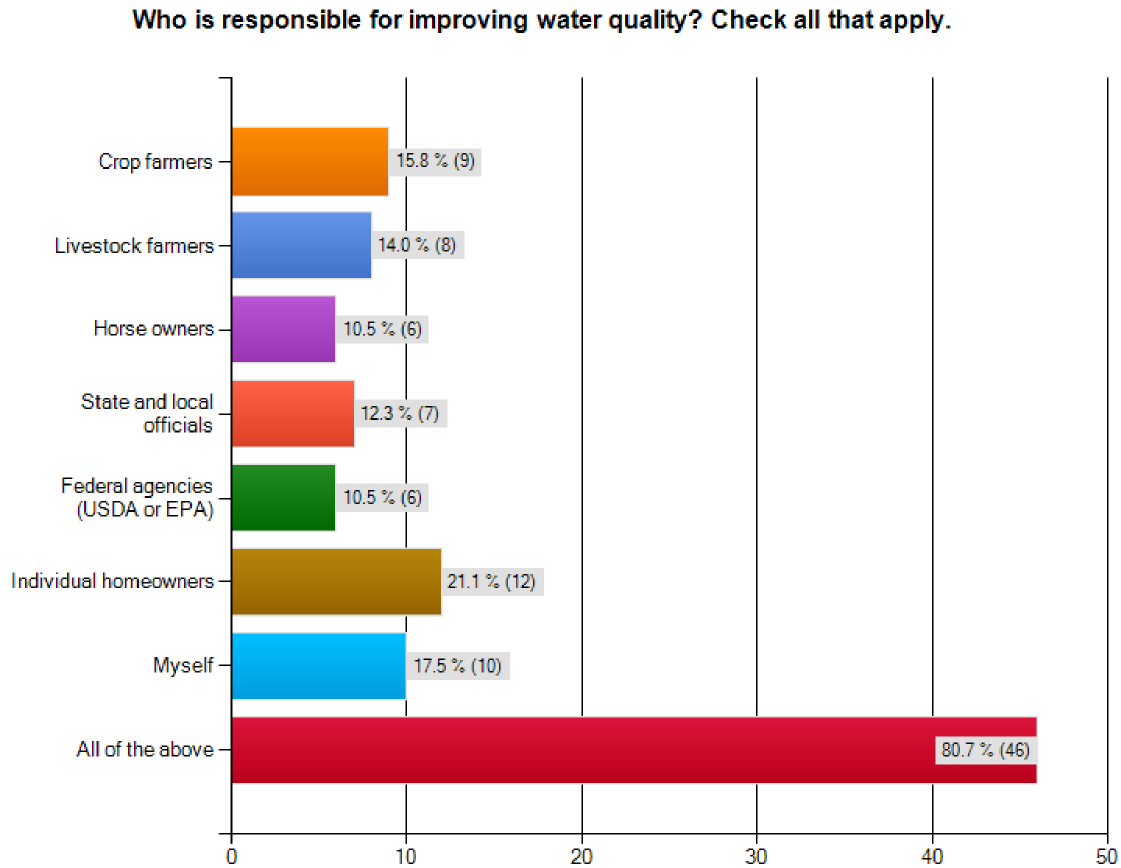
Take-away: A strong educational and outreach strategy should be developed with broad targeting, emphasizing the impacts of manure on clean water. This should not be done in a putative or scolding manner, as it will likely turn off message recipients. The message content and medium should be carefully designed and pre-tested to ensure that it is effective and positively received.

Responsibility for water quality

An attitudes question was then posed about responsibility for water quality, to gauge whether respondents have a sense of personal responsibility. Responses for the overall sample are presented in Table 7.1. Municipal staff responses are found in Table 7.2. Agricultural producers are summarized in Table 7.3.

Q7: Who is responsible for improving water quality? Check all that apply

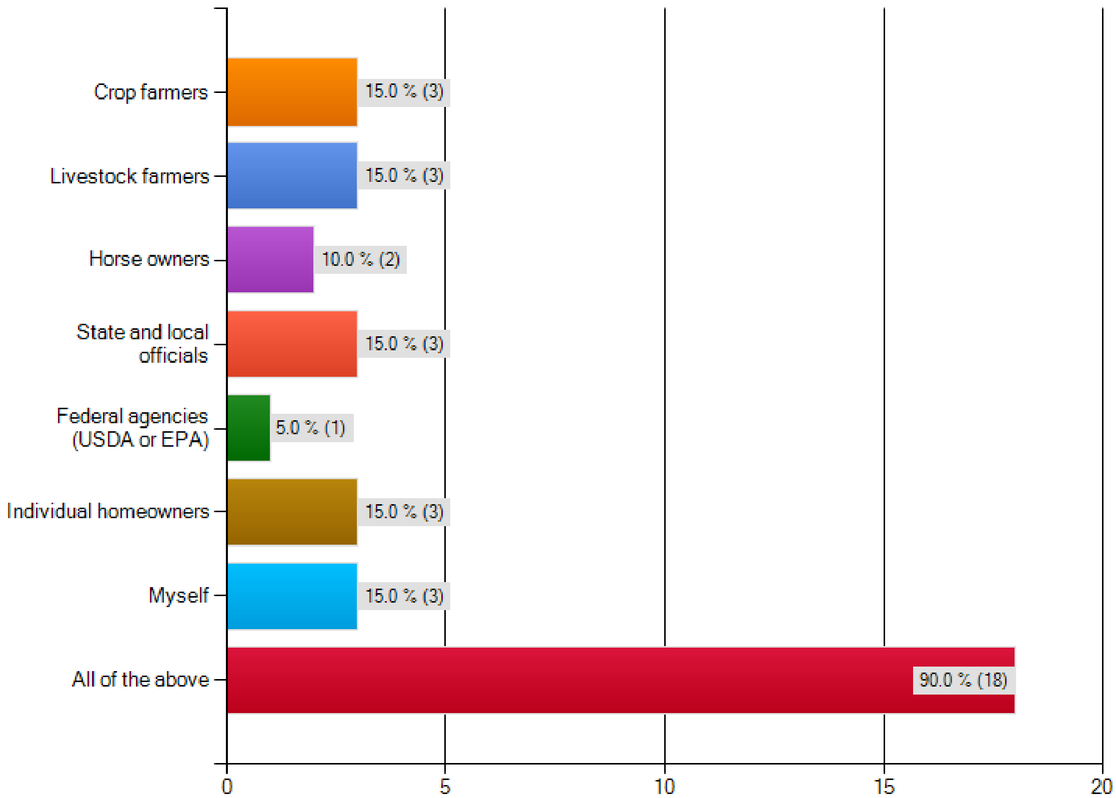
Table 7.1: All Responses



Answered question: 57
Skipped question: 3

Table 7.2 Municipal responses

Who is responsible for improving water quality? Check all that apply.



Answered question: 20
Skipped question: 0

Table 7.3 Responses by subgroup – Crosstabs Q7 x Q8

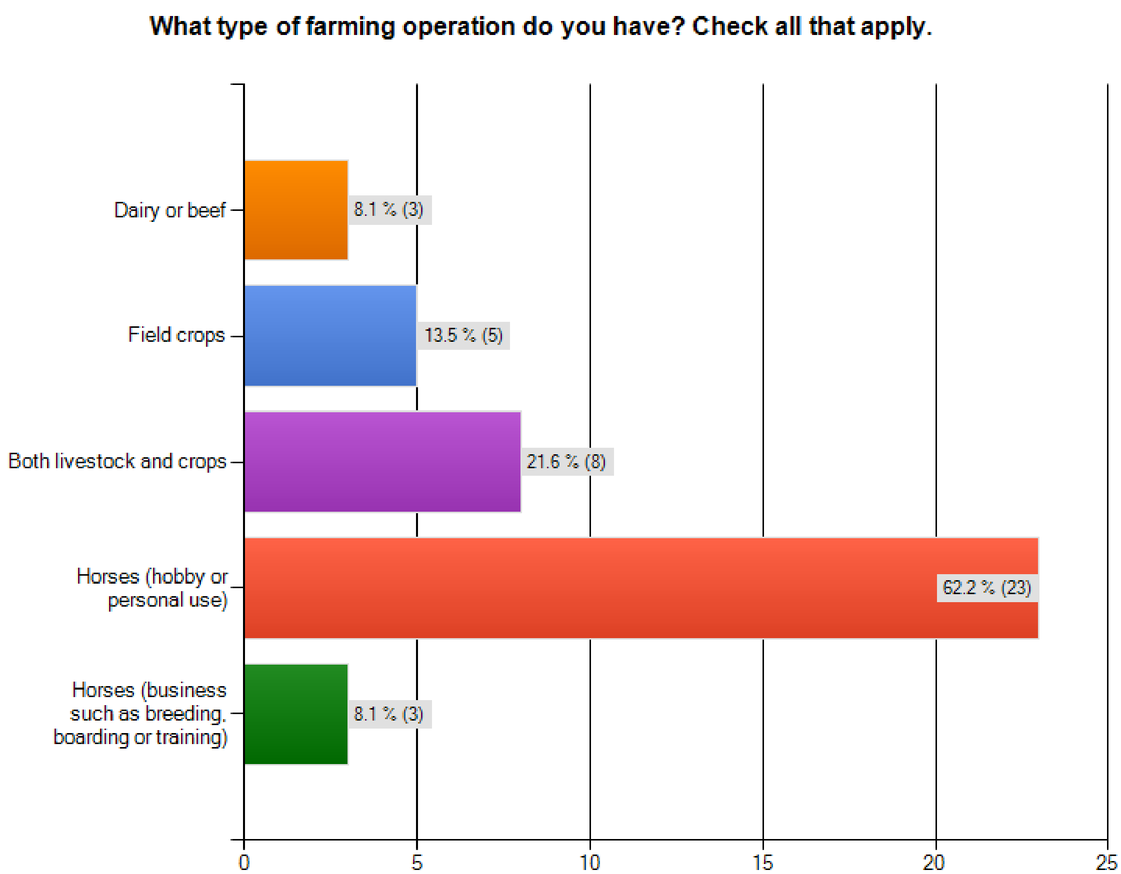
TAKEAWAY: This is generally a positive finding with implications for civic engagement. Responses to this question show that almost all respondents believe that everyone is responsible for water quality. However, individual responsibility does not rank highly compared with other options, especially among agricultural respondents. A critical challenge will be to foster a sense of personal responsibility for water quality, especially for agricultural operators.

Types of agricultural operations

Q8 was essentially a sampling question to determine the numbers of respondents who are beef/dairy farmers, crop farmers, and horse owners. The results of this question were used to cross-tabulate responses of the agricultural audience for the remainder of questions in this survey. Table 8.1 summarizes results for all respondents, while Table 8.2 gives results for municipal officials and staff.

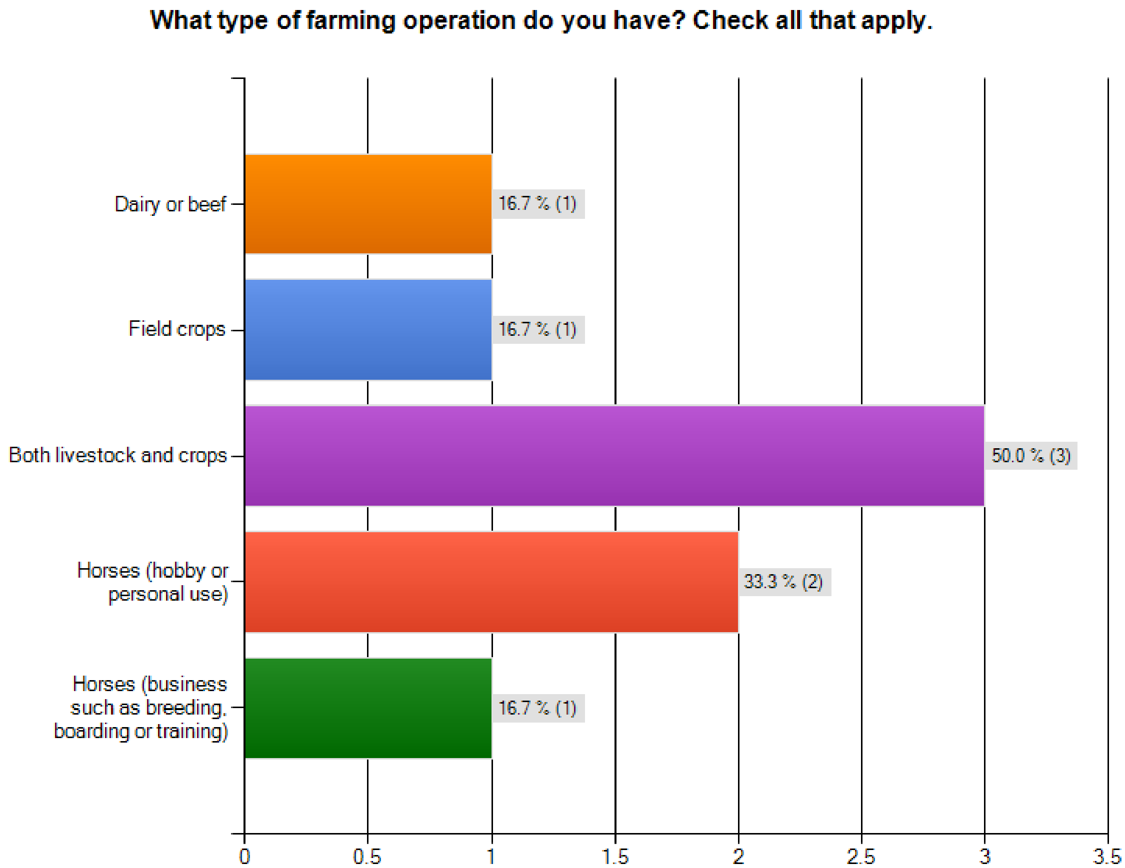
Q8: What type of farming operation do you have? Check all that apply.

Table 8.1 All responses



Answered question: 37
Skipped question: 23

Table 8.2 Responses of municipal staff/officials



Answered question: 6
Skipped question: 14

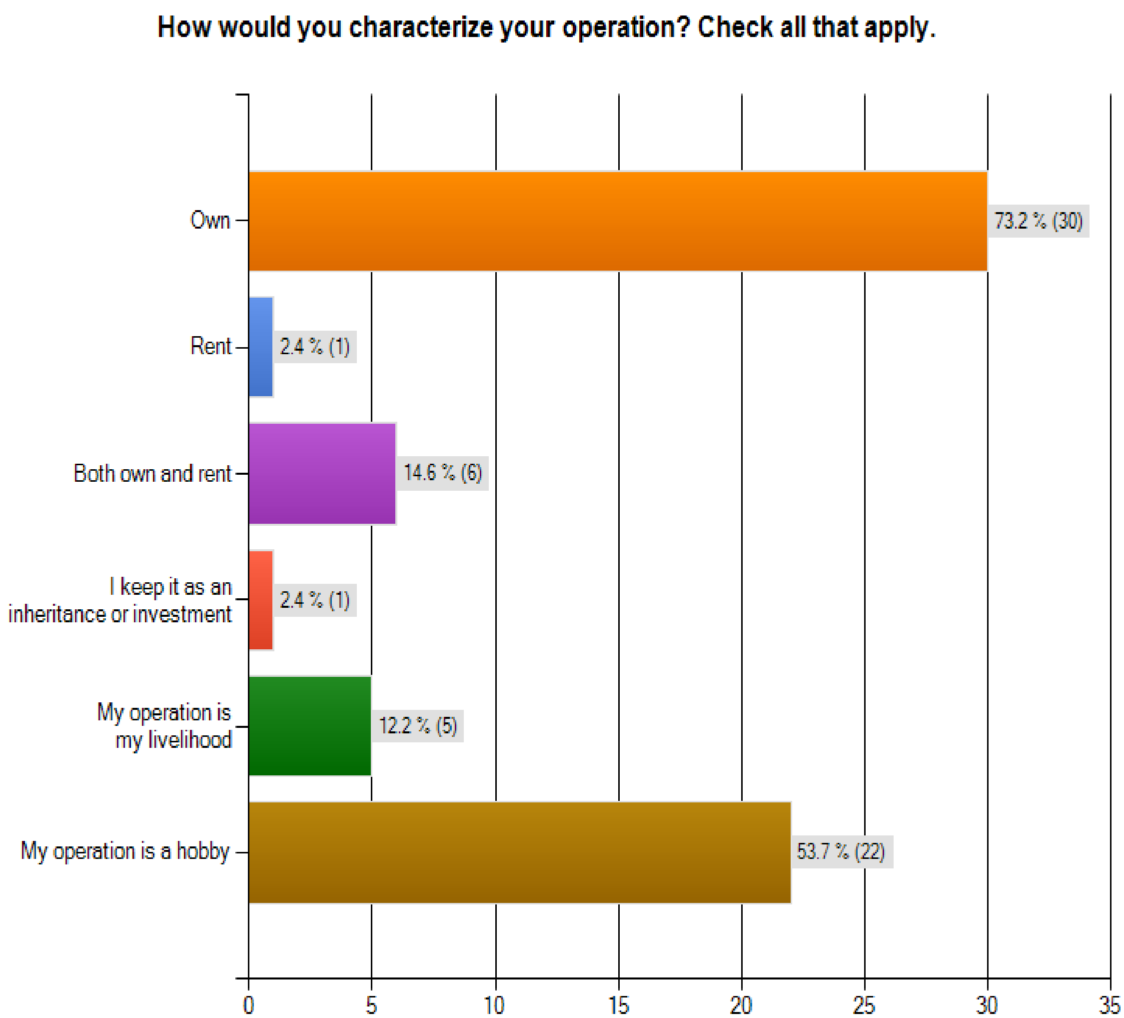
Of note, six municipal staff members or officials are also livestock operators or crop producers. It cannot be determined whether these respondents live within the boundaries of ECWMC.

Type of agricultural livelihood

Q9 asked whether operators own or rent their farm, and whether farming is a livelihood or hobby. Table 9.1 below summarizes results for all respondents. Table 9.2 gives results for municipal staff and officials. Table 9.3 summarizes results for agricultural operators.

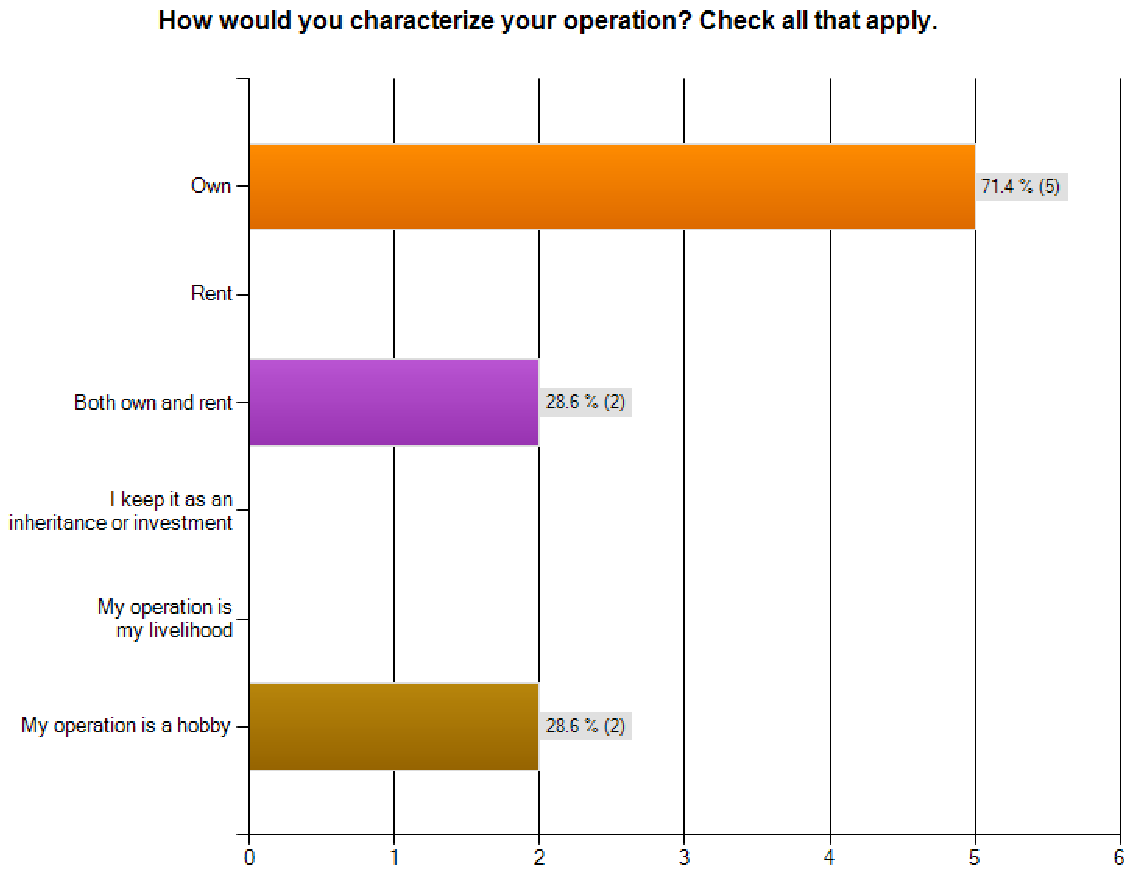
Q9: How would you characterize your operation? Check all that apply.

Table 9.1 All responses



Answered question: 41
Skipped question: 19

Table 9.2 Responses of municipal staff and officials



Answered question: 7
Skipped question: 13

Table 9.3 Responses by subgroup – Crosstab Q 8 x Q9

Elm Creek Water Survey

How would you characterize your operation? Check all that apply.

	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	Field crops	Both livestock and crops	Horses (hobby or personal use)	Horses (business such as breeding, boarding or training)	Response Totals
Own	**66.7% (2)**	**80.0% (4)**	37.5% (3)	**78.3% (18)**	**66.7% (2)**	**70.3% (26)**
Rent	0.0% (0)	20.0% (1)	0.0% (0)	0.0% (0)	0.0% (0)	2.7% (1)
Both own and rent	0.0% (0)	20.0% (1)	**62.5% (5)**	4.3% (1)	33.3% (1)	16.2% (6)
I keep it as an inheritance or investment	0.0% (0)	20.0% (1)	0.0% (0)	0.0% (0)	0.0% (0)	2.7% (1)
My operation is my livelihood	33.3% (1)	0.0% (0)	25.0% (2)	4.3% (1)	**66.7% (2)**	13.5% (5)
My operation is a hobby	33.3% (1)	60.0% (3)	25.0% (2)	73.9% (17)	0.0% (0)	56.8% (21)
Other (please specify)	0 replies	0 replies	0 replies	0 replies	0 replies	0
answered question	3	5	8	23	3	**37**
					skipped question	**0**

1 of 1

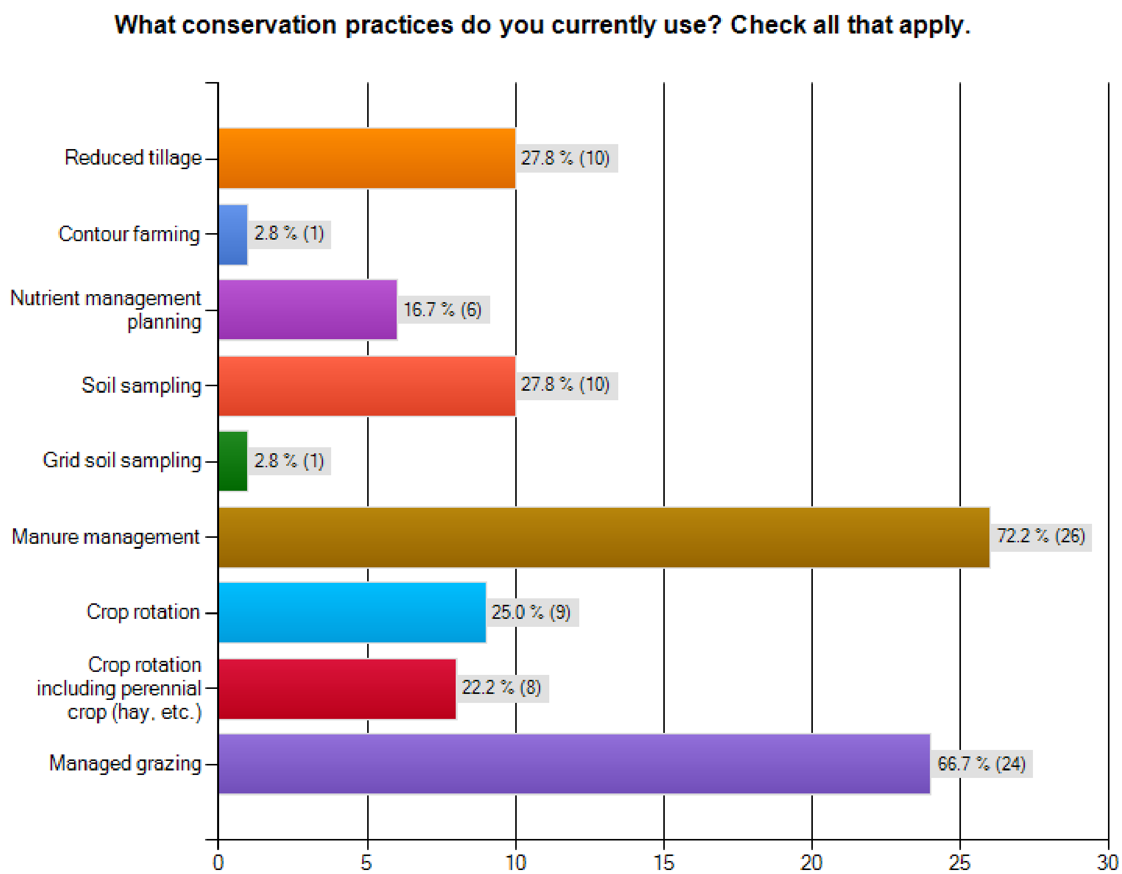
Takeaway: There is a mix of ownership patterns across these groups. Almost three-fourths of all respondents and municipal staff own their operations. For the sample overall, 54% report that their operation is a hobby, likely reflecting the large number of horse owners in the study area. Results suggest that it may be useful to consider a variety of engagement options and educational content to meet the needs and interests of the different sub-groups.

Use of conservation practices

Respondent use of conservation practices was explored in a series of questions about farming and field practices, manure management and grazing. Many of the questions in the following series (Q10 through Q24) were taken from an earlier KAP study on manure management planning conducted in Rock and Pipestone counties. Results for all respondents are given in Table 10.1 below. Responses for municipal officials and staff are found in Table 10.2. Agricultural audience responses are in Table 10.3.

Q10: What conservation practices do you currently use? Check all that apply.

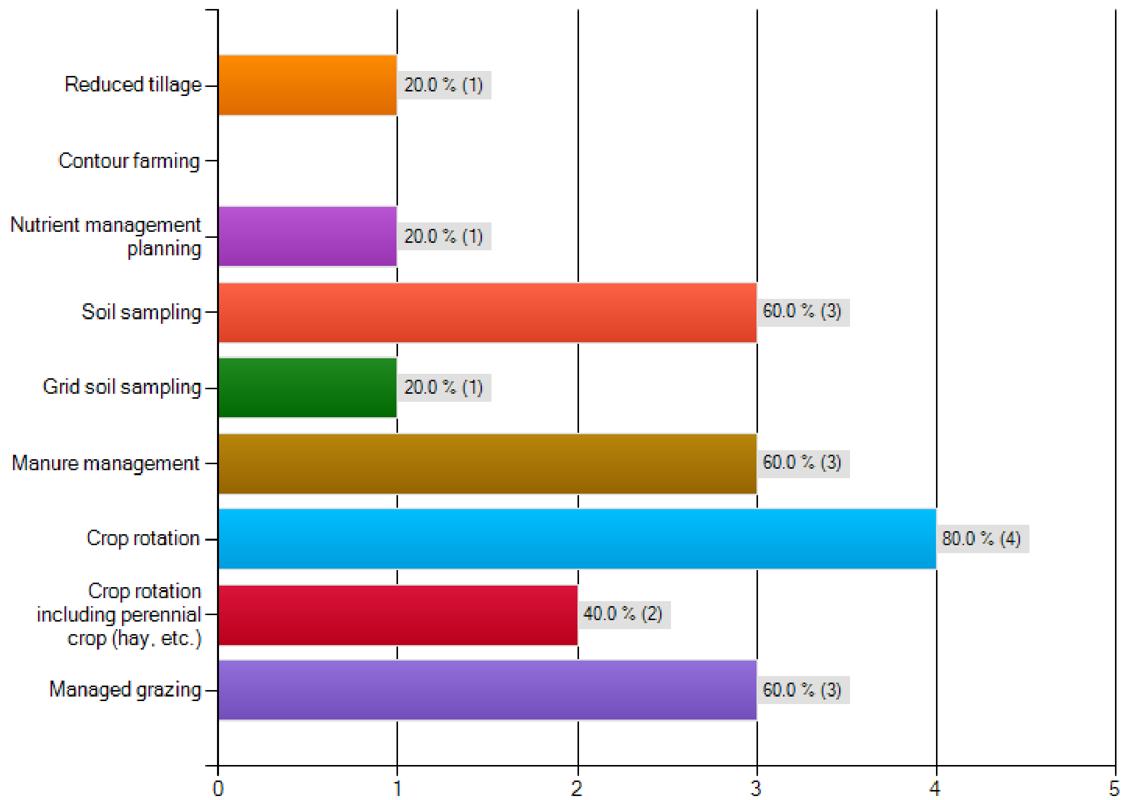
Table 10.1 All responses



Answered question: 36
Skipped question: 24

Table10.2 Municipal staff and officials

What conservation practices do you currently use? Check all that apply.



Answered question: 5
Skipped question: 15

Table 10.3 Responses by Subgroup – Crosstab Q 8 x Q10

Results show that manure management and managed grazing are the most commonly reported practices by the overall sample for this question. However, the much smaller sample (*n* = 5) of municipal staff/officials reported a different pattern, with crop rotation and soil sampling also used by respondents to a significant degree. Agricultural respondents reported a somewhat different pattern, with manure management being the most commonly reported practice (71%), followed by managed grazing (67%), reduced tillage and soil sampling (29% each), crop rotation (24%), nutrient management planning (18%), and contour farming and grid soil sampling (3% each). Among horse owners and horse businesses, the majority practiced manure management, although some comments suggested that the meaning of this term is that manure is allowed to decompose where it falls from the animal. 85% of horse owners report that they practice managed grazing.

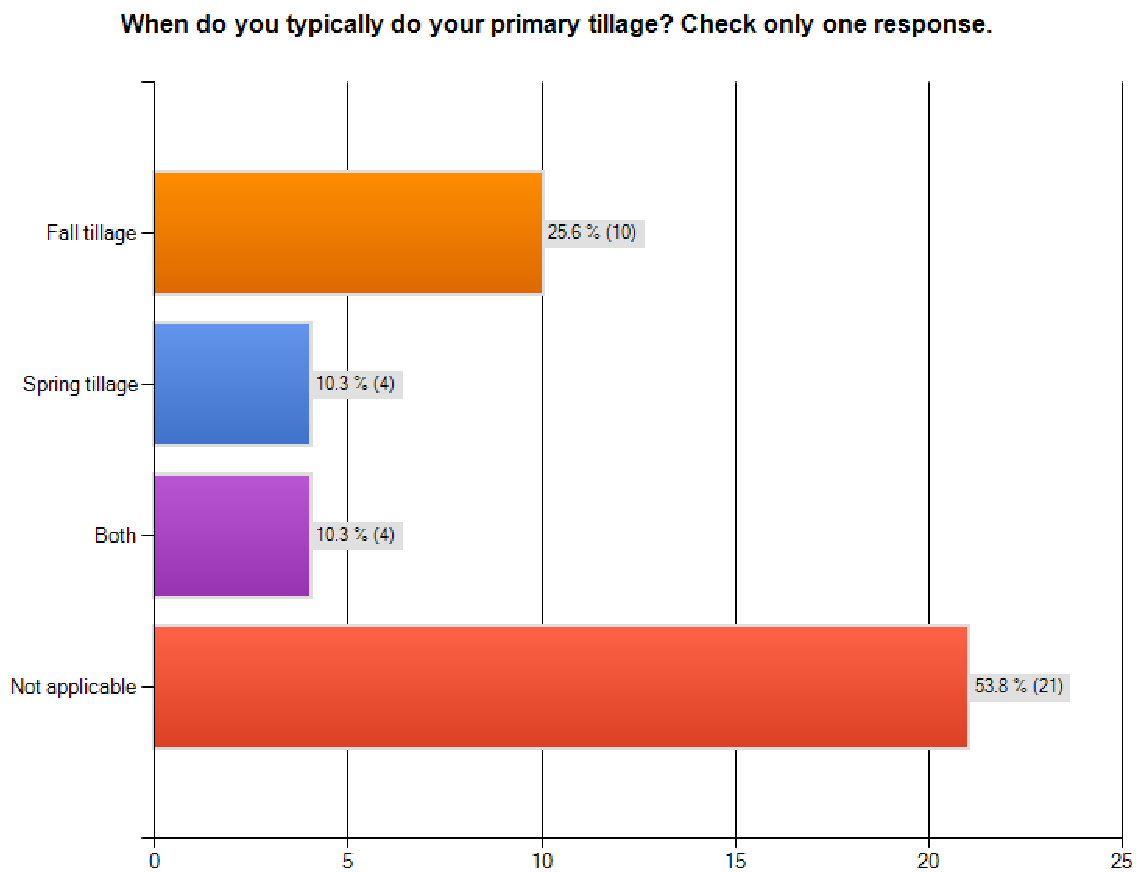
Takeaway: most groups report doing at least some best management practice (BMP), but there is considerable room to do more. Among horse owners, there appears to be a lack of knowledge about various BMPs.

Timing of primary tillage

Respondents were asked about tillage timing in Question 11. Table 11.1 shows answers for all respondents. Table 11.2 gives results for municipal staff and officials. Table 11.3 gives results for agricultural audiences.

Q11: When do you typically do your primary tillage? Check only one response.

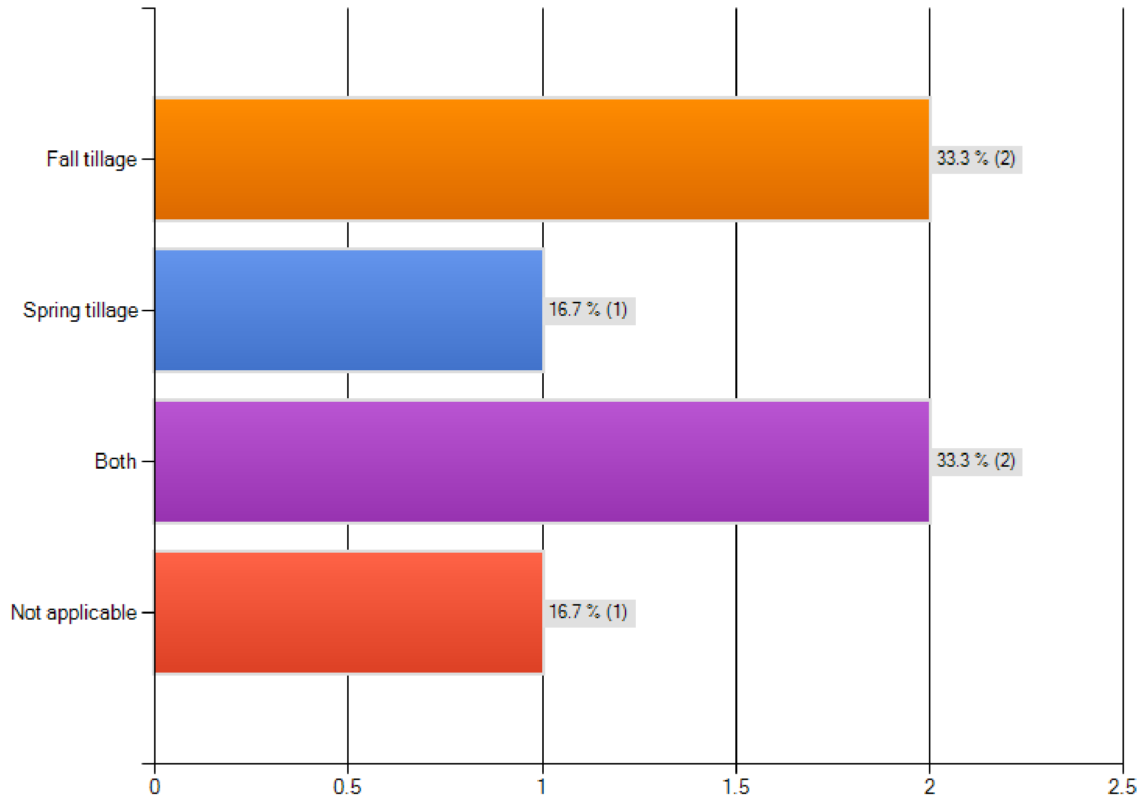
Table 11.1: All responses



Answered question: 39
Skipped question: 21

Table 11.2 Municipal officials and staff

When do you typically do your primary tillage? Check only one response.



Answered question: 6
Skipped question: 14

Table 11.3 Agricultural audiences (Response by subgroup – Crosstab Q 11 x Q 8)

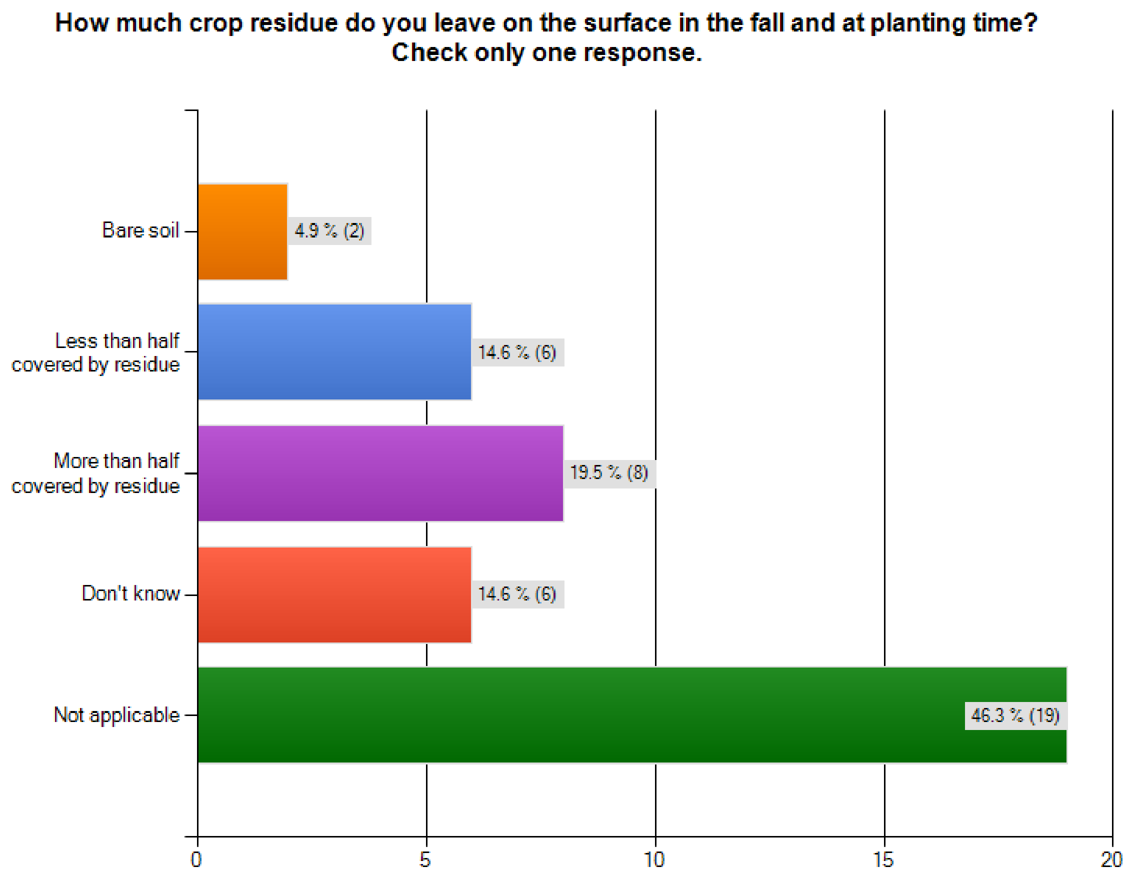
Take-away: Fall tillage was the most common response in the overall sample. Municipal staff tends to do both fall and spring tillage. Among the small sample of agricultural producers, dairy and beef respondents (n = 3) do both fall and spring tillage. Field crop farmers and both livestock/crop producers tend to do fall tillage. Very few (n = 4) of the horse owners or horse business operators do any tillage, and they report doing both fall and spring tillage. 73% of horse operators do no tillage.

Crop residue

A follow-up question (Q12) asked about the amount of crop residue left on fields. Table 12.1 gives responses for the entire sample. Table 12. 2 shows results for municipal staff and officials. Table 12.3 gives results for agricultural respondents.

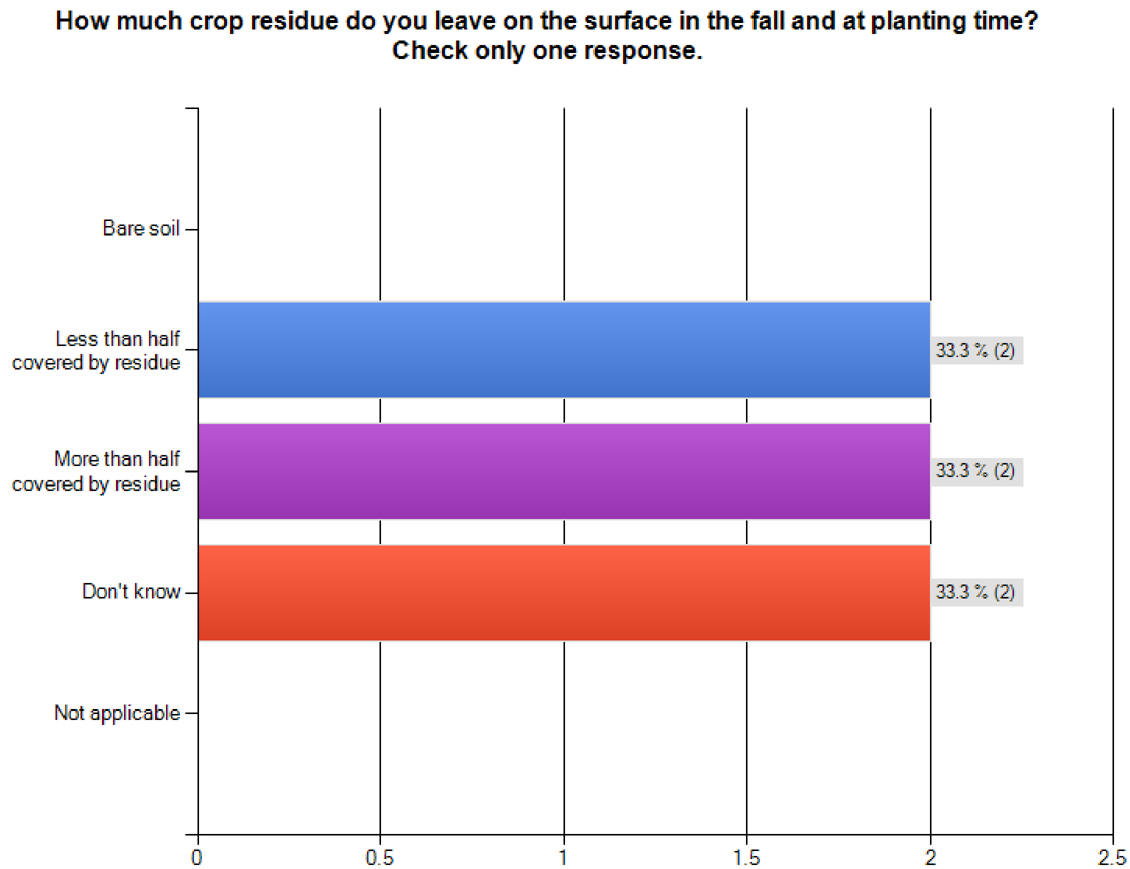
Q12: How much crop residue do you leave on the surface in the fall and at planting time? Check only one response.

Table 12:1 All responses



Answered question: 41
Skipped question: 19

Table 12.2 Responses by municipal staff



Answered question: 6
Skipped question: 14

Table 12.3 Responses by subgroup – Crosstab Q12 x Q8

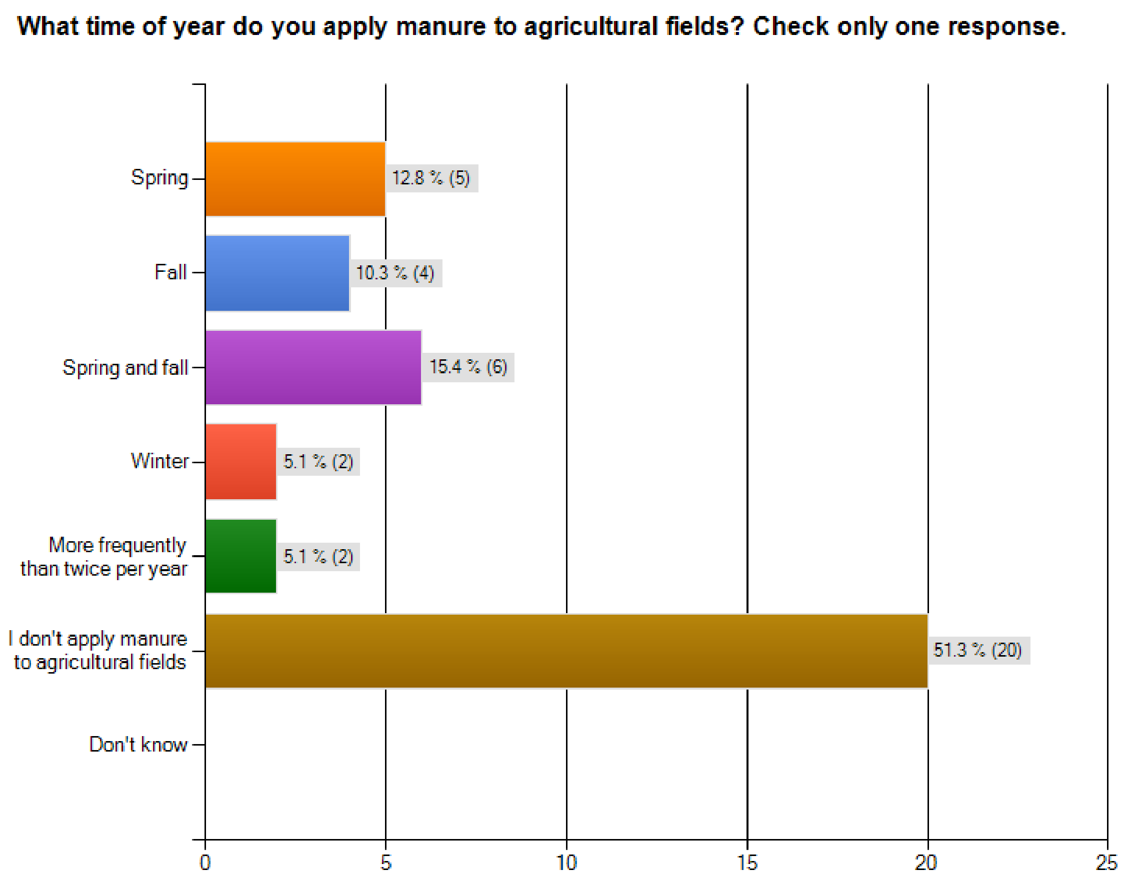
Takeaway: There is a wide variation among respondents related to this practice, with a fair number of respondents checking "don't know." Lack of awareness for this practice among respondents suggests an opportunity for an educational message to be developed about crop residue.

Timing of manure application

Another question in the series about best management practices asked about the timing of manure application. Table 13.1 gives responses for the entire sample. Table 13. 2 shows results for municipal staff and officials. Table 13.3 gives results for agricultural respondents.

Q13: What time of year do you apply manure to agricultural fields? Check only one response.

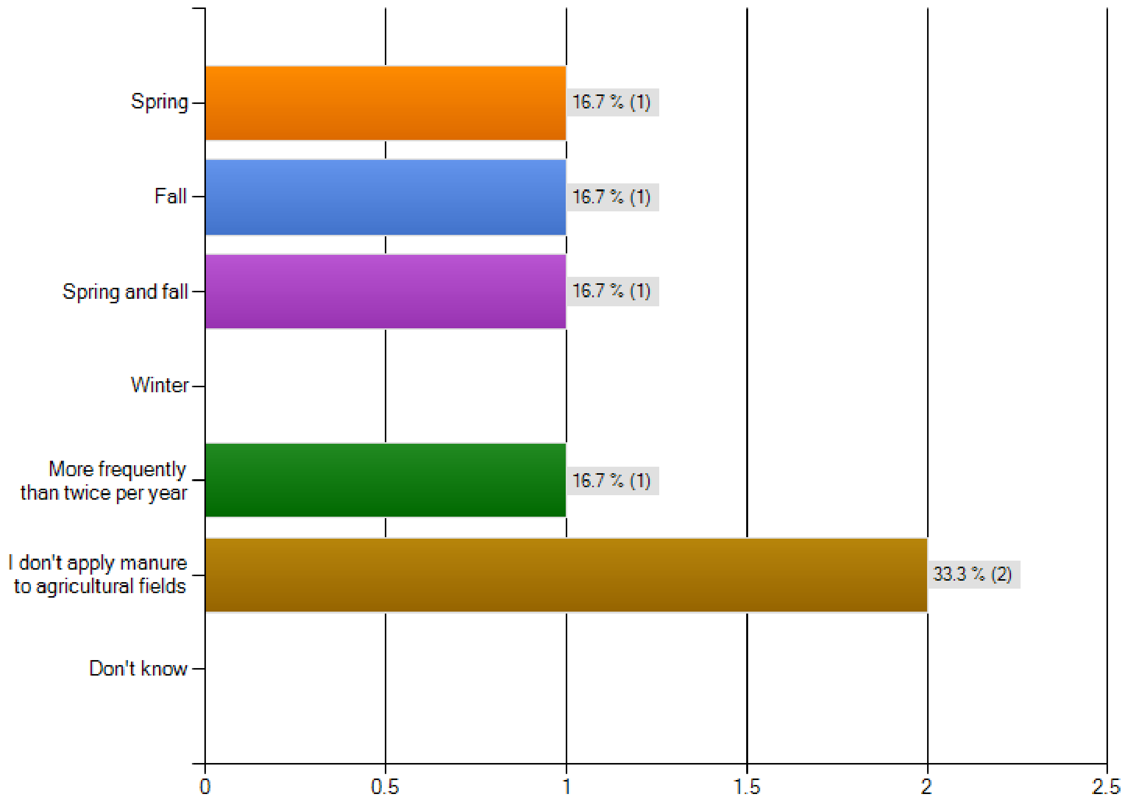
Table 13.1 All Responses



Answered question: 39
Skipped question: 21

Table 13.2 Responses of municipal officials and staff

What time of year do you apply manure to agricultural fields? Check only one response.



Answered question: 6
Skipped question: 14

Table 13.2 Response by subgroup – Crosstab Q 8 x Q 13

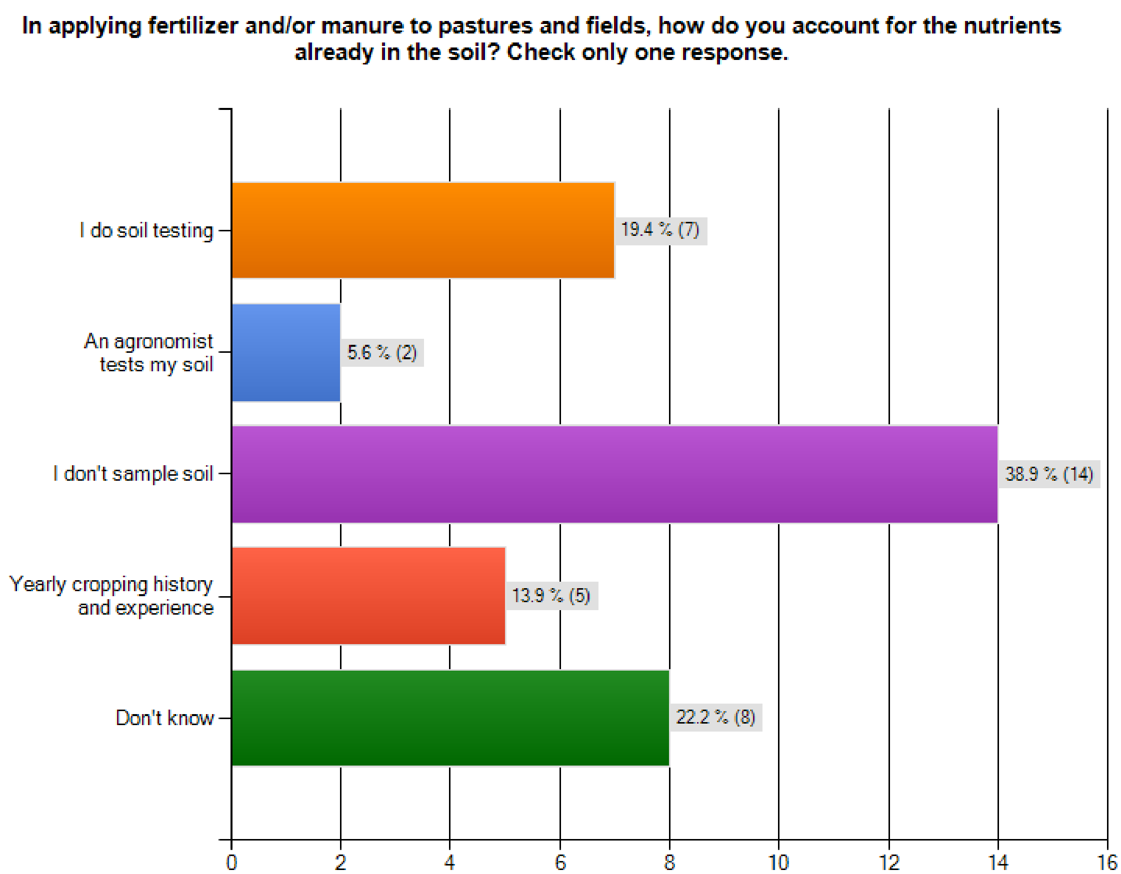
Take-away: Just over half of the entire sample does not apply manure to agricultural fields. Of those that do, most reply doing spring and fall application. Of the four municipal officials applying manure, timing is both spring and fall. The majority (19 respondents, or 51%) of all agricultural groups do not apply manure. Of these, 61% of horse owners do not apply manure. A few individuals report application in spring and fall.

Accounting for soil nutrients

Question 14 in the practices series explores how respondents account for soil nutrients. Table 14.1 gives responses for the entire sample. Table 14. 2 shows results for municipal staff and officials. Table 14.3 gives results for agricultural respondents.

Q14: In applying fertilizer and/or manure to pastures and fields, how do you account for the nutrients already in the soil? Check only one response.

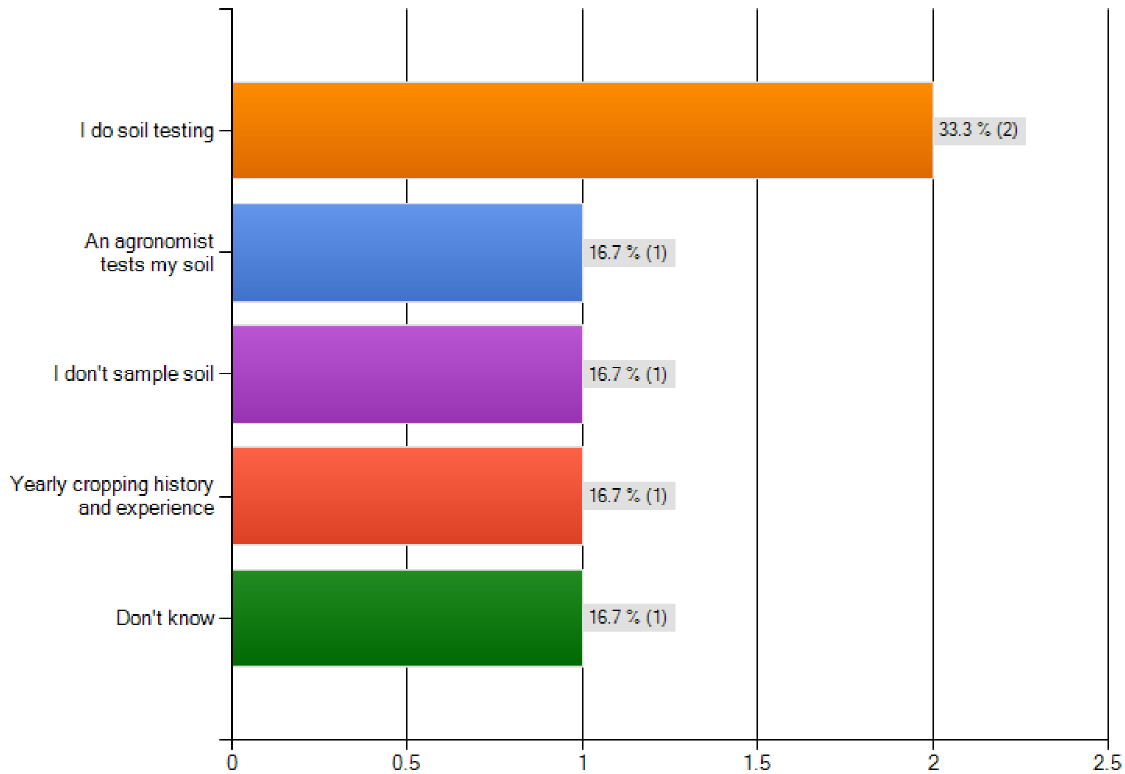
Table 14.1 All responses



Answered question: 36
Skipped question: 24

Table 14.2 Responses of municipal officials and staff

In applying fertilizer and/or manure to pastures and fields, how do you account for the nutrients already in the soil? Check only one response.



Answered question: 6
Skipped question: 14

Table 14.3 Response by subgroup – Crosstab Q14 x Q8

Elm Creek Water Survey

In applying fertilizer and/or manure to pastures and fields, how do you account for the nutrients already in the soil? Check only one response.	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	Field crops	Both livestock and crops	Horses (hobby or personal use)	Horses (business such as breeding, boarding or training)	Response Totals
I do soil testing	0.0% (0)	**40.0% (2)**	**50.0% (4)**	4.8% (1)	0.0% (0)	20.0% (7)
An agronomist tests my soil	**33.3% (1)**	0.0% (0)	12.5% (1)	0.0% (0)	0.0% (0)	5.7% (2)
I don't sample soil	**33.3% (1)**	0.0% (0)	0.0% (0)	**52.4% (11)**	33.3% (1)	**37.1% (13)**
Yearly cropping history and experience	**33.3% (1)**	20.0% (1)	25.0% (2)	14.3% (3)	0.0% (0)	14.3% (5)
Don't know	0.0% (0)	**40.0% (2)**	12.5% (1)	28.6% (6)	**66.7% (2)**	22.9% (8)
Other (please specify)	0 replies	1 reply	1 reply	3 replies	0 replies	5
answered question	3	5	8	21	3	**35**
					skipped question	**2**

1 of 1

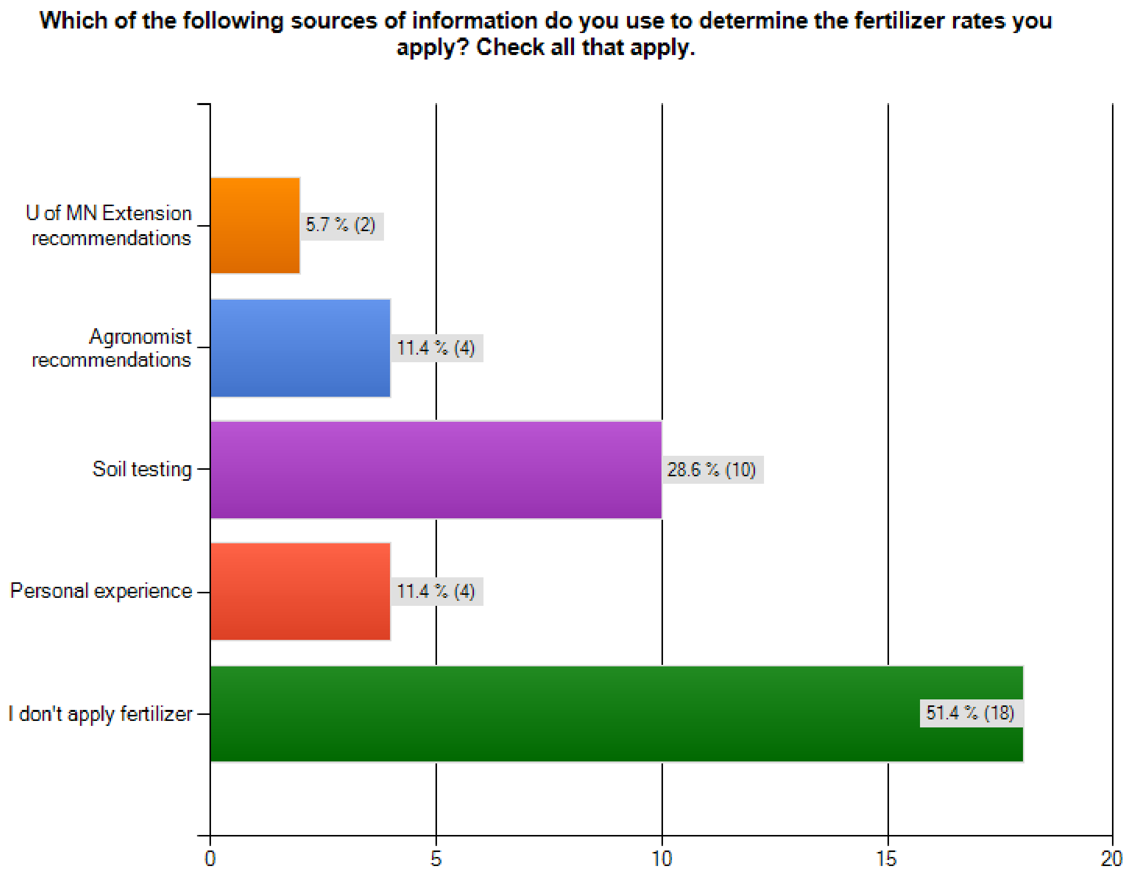
Take-away: 39% of all respondents do not sample soil, and 22% seem not to know about nutrient accounting. 33% of municipal staff do sample soil, in comparison with only 19% of the overall sample. Of the farming groups, 40% (n = 2) of field crop farmers sample soil, and 50% (n = 4) of those doing both livestock rearing and field cropping sample soil. Only one horse owner samples soil. Results suggest that there is a need and an opportunity to provide information to respondents about soil testing.

Sources of information about fertilizer rates

Question 15 in the practices series examines where respondents seek information on nutrient application. Table 15.1 gives responses for the entire sample. Table 15. 2 shows results for municipal staff and officials. Table 15.3 gives results for agricultural respondents.

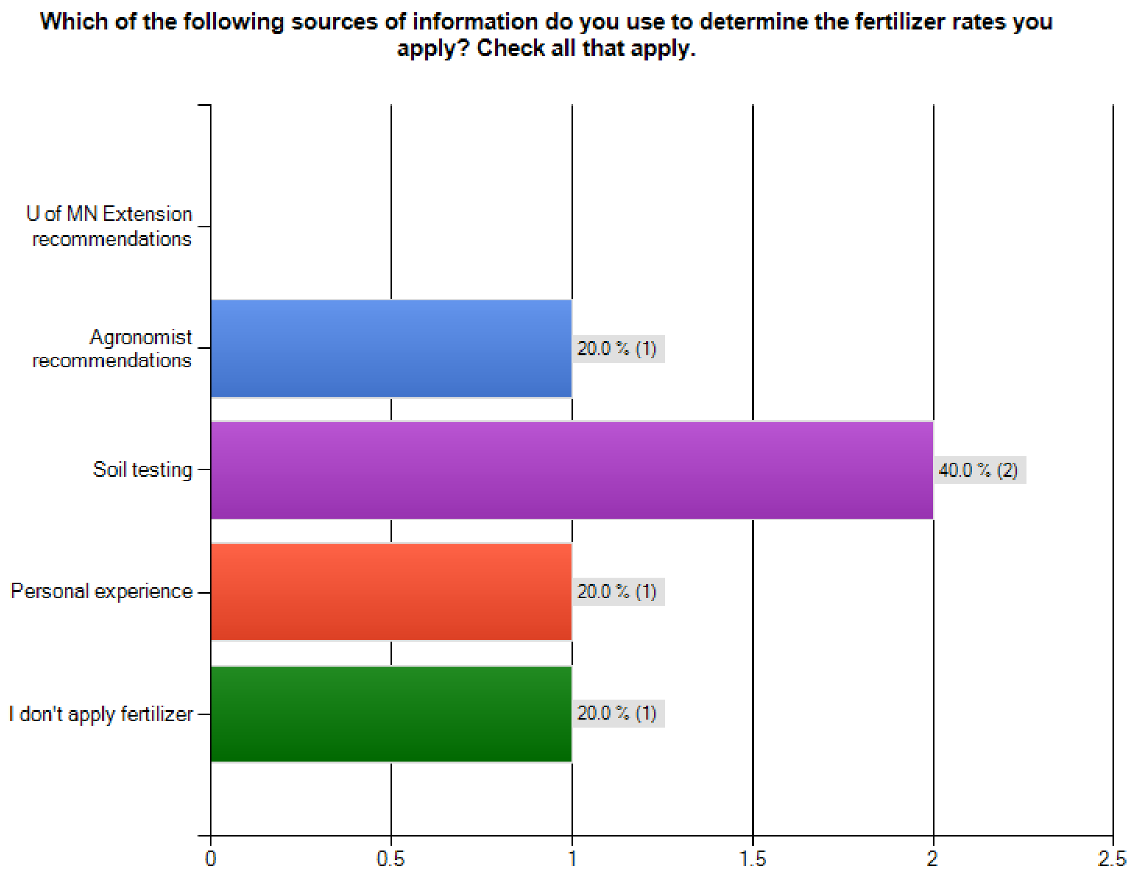
Q15: Which of the following sources of information do you use to determine the fertilizer rates you apply? Check all that apply.

Table 15.1 – All responses



Answered question: 35
Skipped question: 25

Table 15.2 Responses of municipal officials and staff



Answered question: 5
Skipped question: 15

Table 15.3 Responses by subgroup – Q 15 x Q8

Elm Creek Water Survey

Which of the following sources of information do you use to determine the fertilizer rates you apply? Check all that apply.

	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	Field crops	Both livestock and crops	Horses (hobby or personal use)	Horses (business such as breeding, boarding or training)	Response Totals
U of MN Extension recommendations	0.0% (0)	0.0% (0)	12.5% (1)	5.3% (1)	0.0% (0)	6.3% (2)
Agronomist recommendations	33.3% (1)	0.0% (0)	37.5% (3)	0.0% (0)	0.0% (0)	12.5% (4)
Soil testing	0.0% (0)	**100.0% (4)**	**62.5% (5)**	15.8% (3)	0.0% (0)	31.3% (10)
Personal experience	**66.7% (2)**	0.0% (0)	0.0% (0)	15.8% (3)	0.0% (0)	12.5% (4)
I don't apply fertilizer	33.3% (1)	0.0% (0)	12.5% (1)	**63.2% (12)**	**100.0% (3)**	**46.9% (15)**
Other (please specify)	0 replies	1 reply	0 replies	3 replies	0 replies	4
answered question	3	4	8	19	3	**32**
					skipped question	**5**

1 of 1

For all respondents, soil testing is the most commonly reported source (29%) of information used to apply fertilizers. Municipal employees use soil testing more often (40%) than the sample as a whole. 100% (n = 4) of field crop farmers report using soil testing, and those raising both crops and livestock (n = 5) rank soil testing at 63%.

Among horse owners, 16% (n = 3) use soil testing and personal experience to determine fertilizer rates, and only one uses U of M UM Extension recommendations. 63% of horse owners do not apply fertilizer.

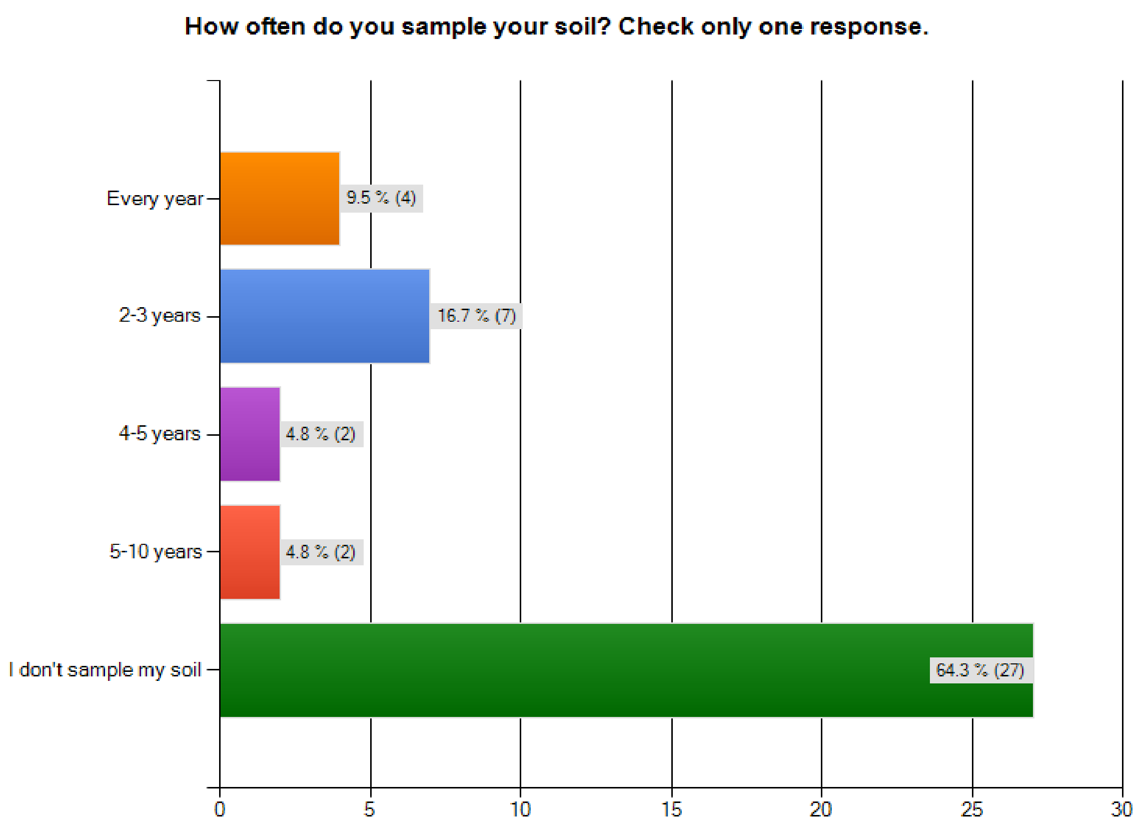
Take-away: While about half of all respondents don't use fertilizer, the remainder may benefit from information about soil testing and nutrient application. This may be an opportunity for the ECWMC to develop materials on proper nutrient application rates, and how those are determined (or alternatively provide materials already available through U of M UM Extension.

Frequency of soil sampling

Question 16 in the practices series examines where respondents seek information on nutrient application. Table 16.1 gives responses for the entire sample. Table 16. 2 shows results for municipal staff and officials. Table 16.3 gives results for agricultural respondents.

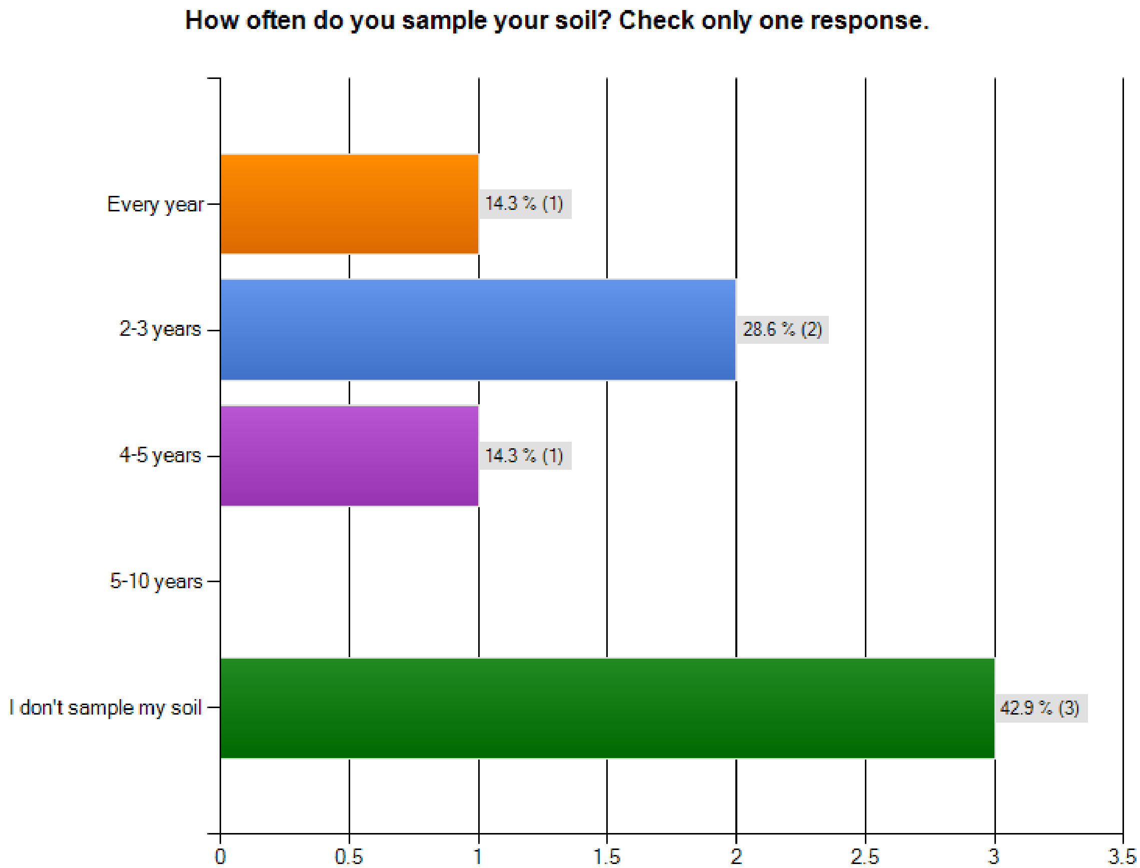
Q16: How often do you sample your soil? Check only one response.

Table 16.1 All responses



Answered question: 42
Skipped question: 18

Table 16.2 Responses of municipal staff and officials



Answered question: 7
Skipped question: 13

Table 16.3 Responses by subgroup – Crosstab Q 16 x Q8

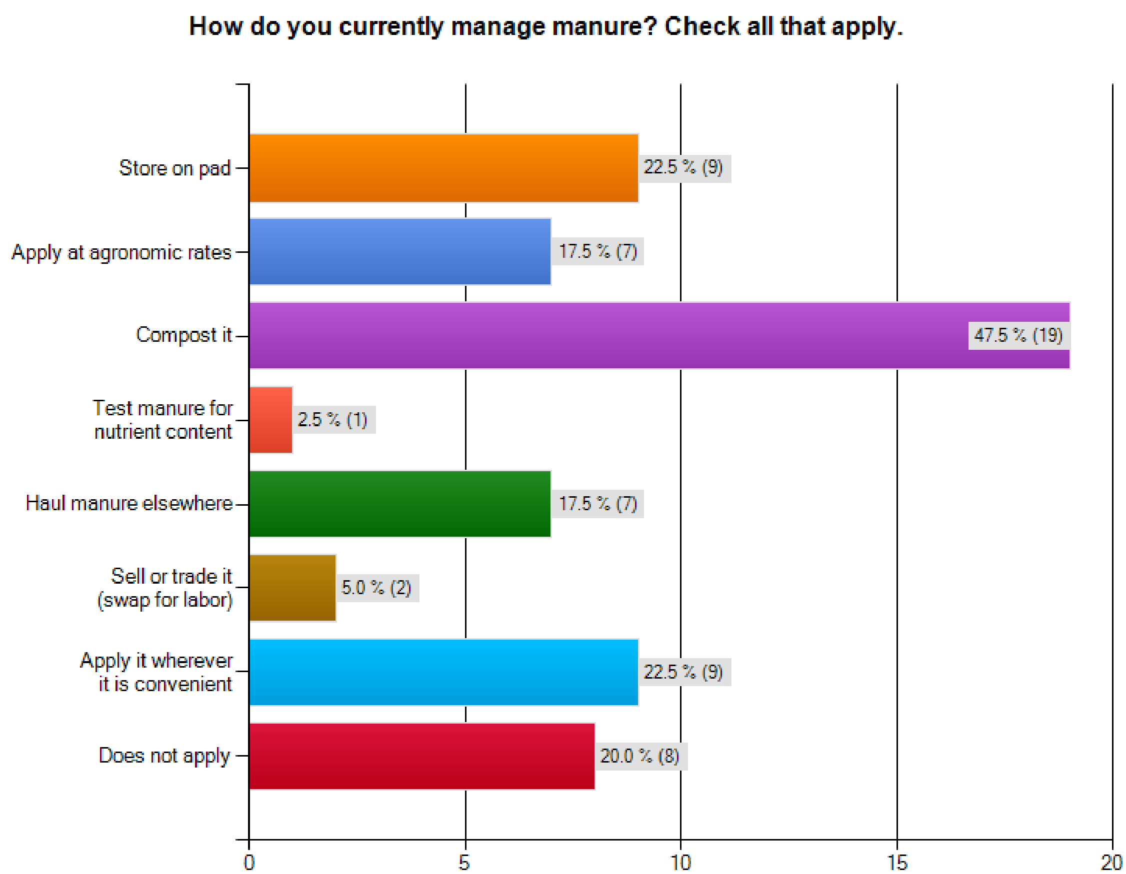
Take-away: Soil sampling is limited and practices are quite variable among the respondents. Most (64%) respondents generally do not sample their soil. Of those that do, 17% report sampling every two to three years. Of municipal staff, 43% do not sample soil, but the highest frequency for those that do is two to three years. Only two livestock farmers reported sampling soil; four field crop farmers sample; and seven livestock/crop producers sample. Only four horse owners reported sampling soil, and each sample at a different frequency. In fact, frequency varies with each respondent in all producer groups.

Manure Management

Question 17 in the practices series explores how respondents manage manure. This question was taken from the Rock County KAP study. Table 17.1 gives responses for the entire sample. Table 17. 2 shows results for municipal staff and officials. Table 17.3 gives results for agricultural respondents.

Q17: How do you currently manage manure? Check all that apply.

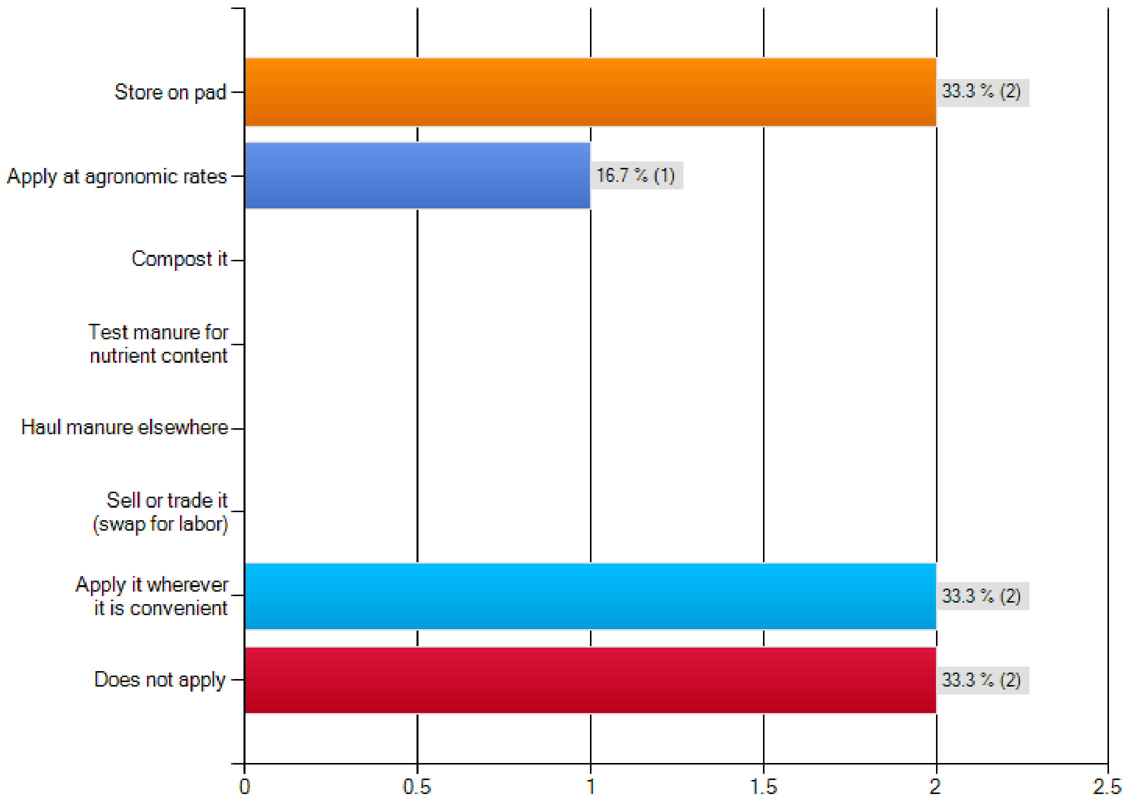
Table 17.1 All responses



Answered question: 40
Skipped question: 20

Table 17.2 Responses of municipal officials

How do you currently manage manure? Check all that apply.



Answered question: 6
Skipped question: 14

Table 17.3 Responses by sub-group – Crosstab Q17 x Q8

About half of all respondents (48%) reported composting manure, and 23% reported storing manure on a pad or spreading it wherever it is convenient. Among the small sample of municipal staff that answered this question, two reported storing it on a pad or spreading wherever convenient. Two livestock operators reported composting manure and one reported application at agronomic rates. Field crop producers reported storing on a pad (n = 1), applying at agronomic rates (n = 1) and composting (n = 2). For those raising both livestock and field crops, again the pattern is mixed with four reporting storage on a pad, two applying at agronomic rates, three composting, and one testing for nutrient content. The majority of horse owners and horse businesses reported composting as their most common practice. Two horse business operators indicated that they haul manure elsewhere.

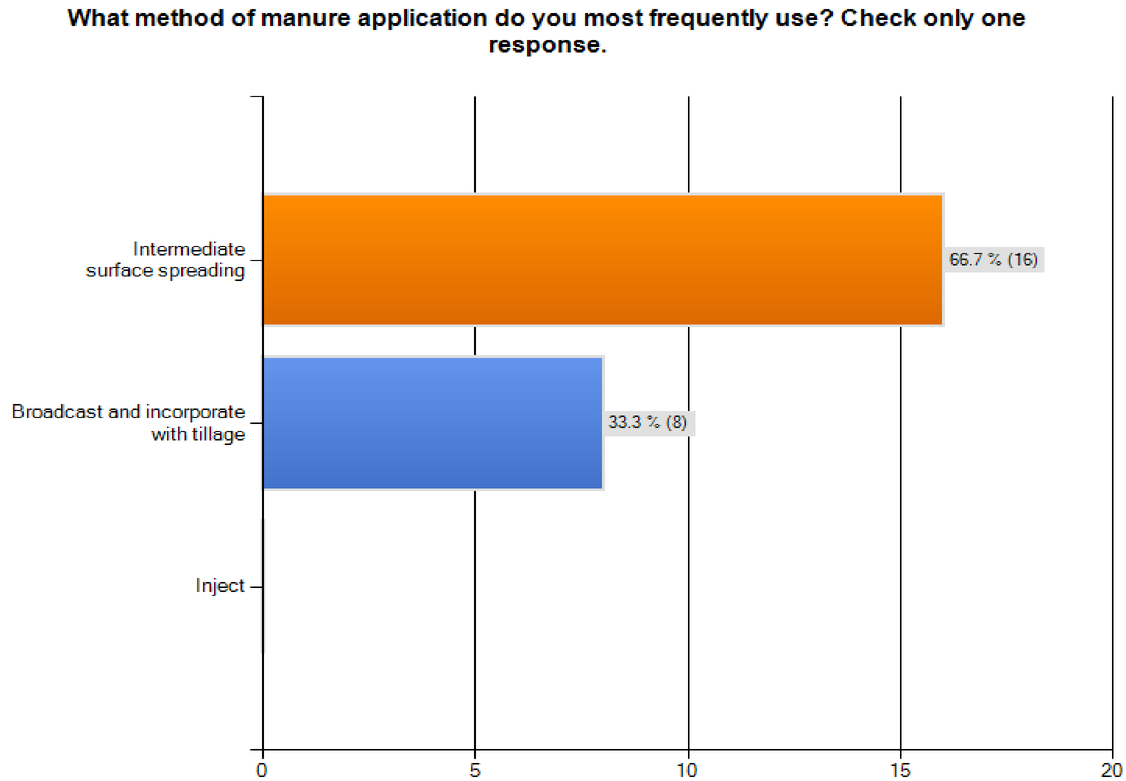
Take-away: The wording on this question may be interpreted differently. Several comments suggested that "composting" means "let it decompose wherever it falls," rather than actively using a composting method. Although there are a wide variety of practices in all sample groups, few respondents seem to actively manage manure.

Method of manure application

Question 18 in the practices series explores how respondents manage manure. As with others in the series, this question was taken from the Rock County KAP study. Table 18.1 gives responses for the entire sample. Table 18.2 shows results for municipal staff and officials. Table 18.3 gives results for agricultural respondents.

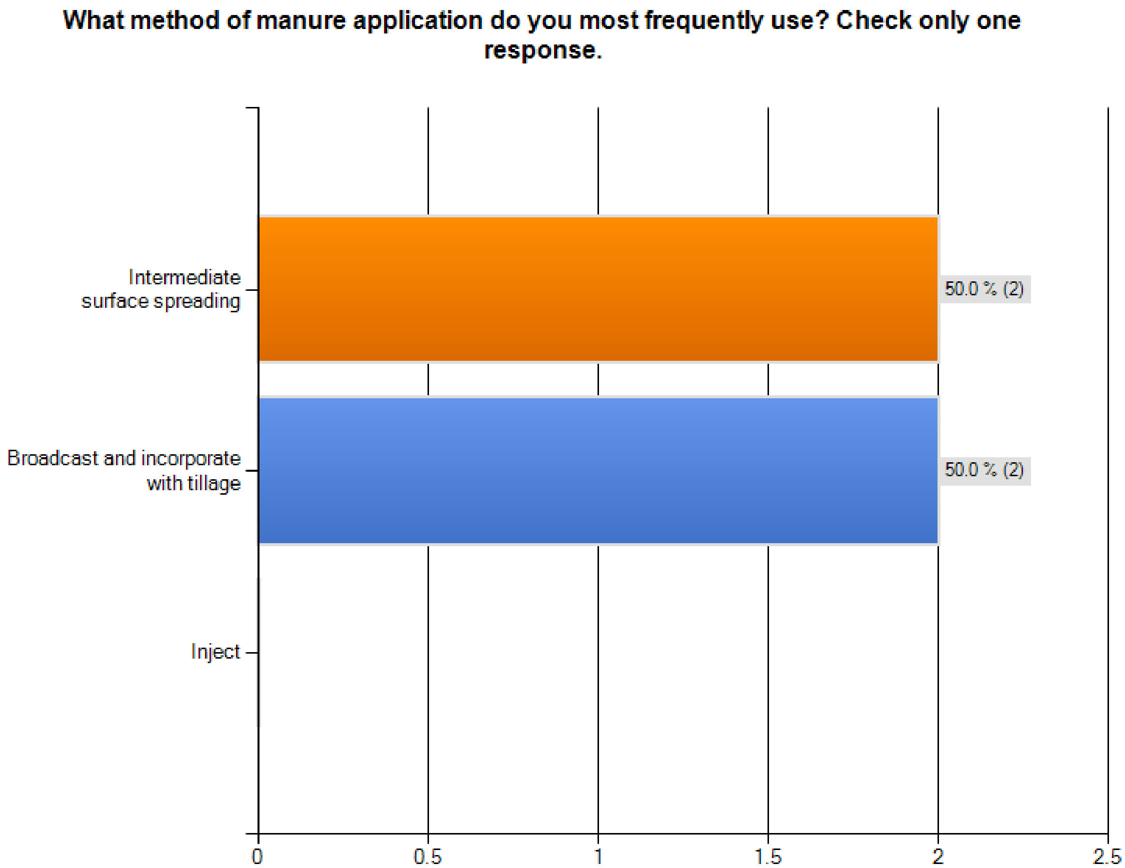
Q18: What method of manure application do you most frequently use? Check only one response.

Table 18.1 All responses



Answered question: 24
Skipped question: 36

Table 18.2 Responses of municipal officials



Answered question:16
Skipped question: 4

Table 18.3 Responses by subgroup – Crosstab Q 18 x Q8

Among all respondents, 67% reported doing intermediate surface spreading and 33% reported broadcasting with surface spreading. None reported injection. Among municipal staff, half reported intermediate surface spreading and half reported broadcasting. Among the agricultural subgroups, all dairy/beef producers reported intermediate surface spreading and no other method. Field crop producers reported intermediate surface spreading and broadcasting. Farmers raising both livestock and field crops reported intermediate surface spreading (*n* = 2) and broadcasting (*n* = 5). 92% of horse owners reported intermediate surface spreading, and only one reported broadcasting.

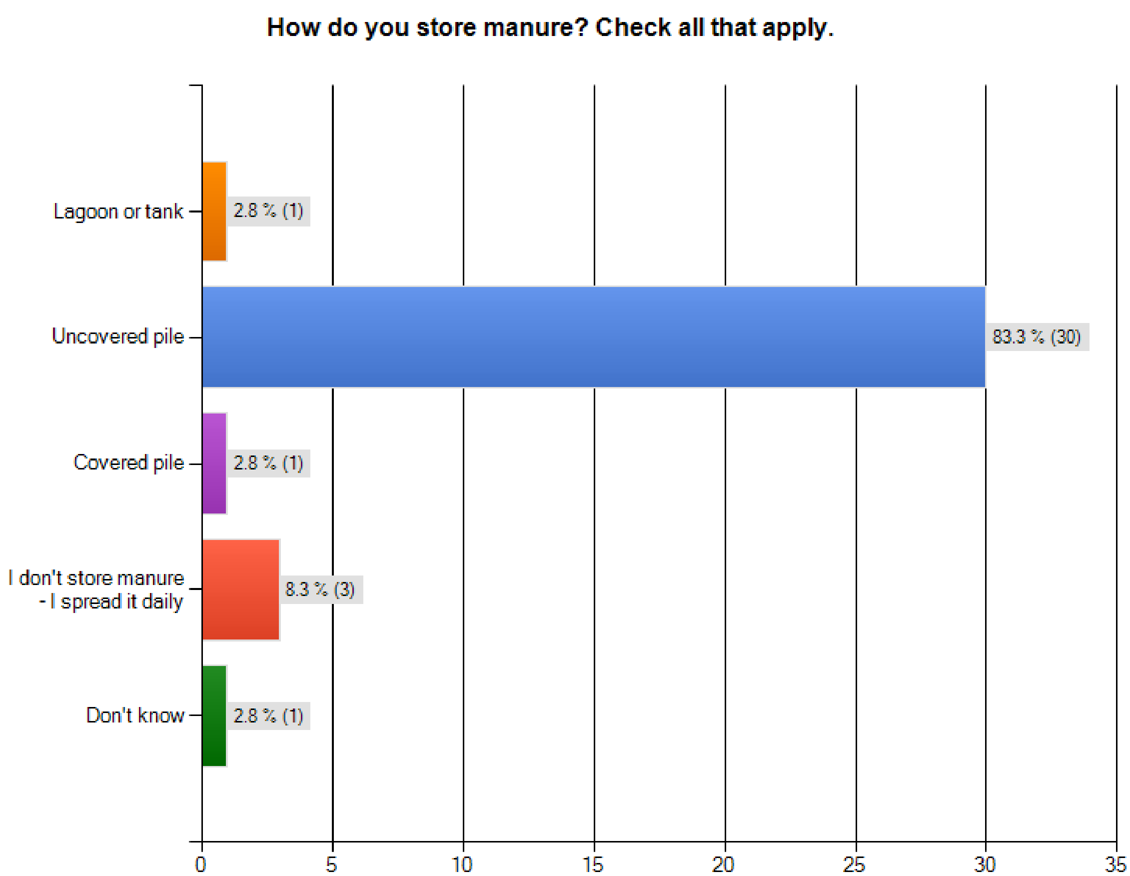
Takeaway: As with previous questions, there is a wide range of methods of manure application with no clear pattern except for intermediate surface spreading reported by horse owners.

Manure storage

Question 19 in the practices series explores how respondents manage manure. This question was taken from the Rock County KAP study. Table 19.1 gives responses for the entire sample. Table 19.2 shows results for municipal staff and officials. Table 19.3 gives results for agricultural respondents.

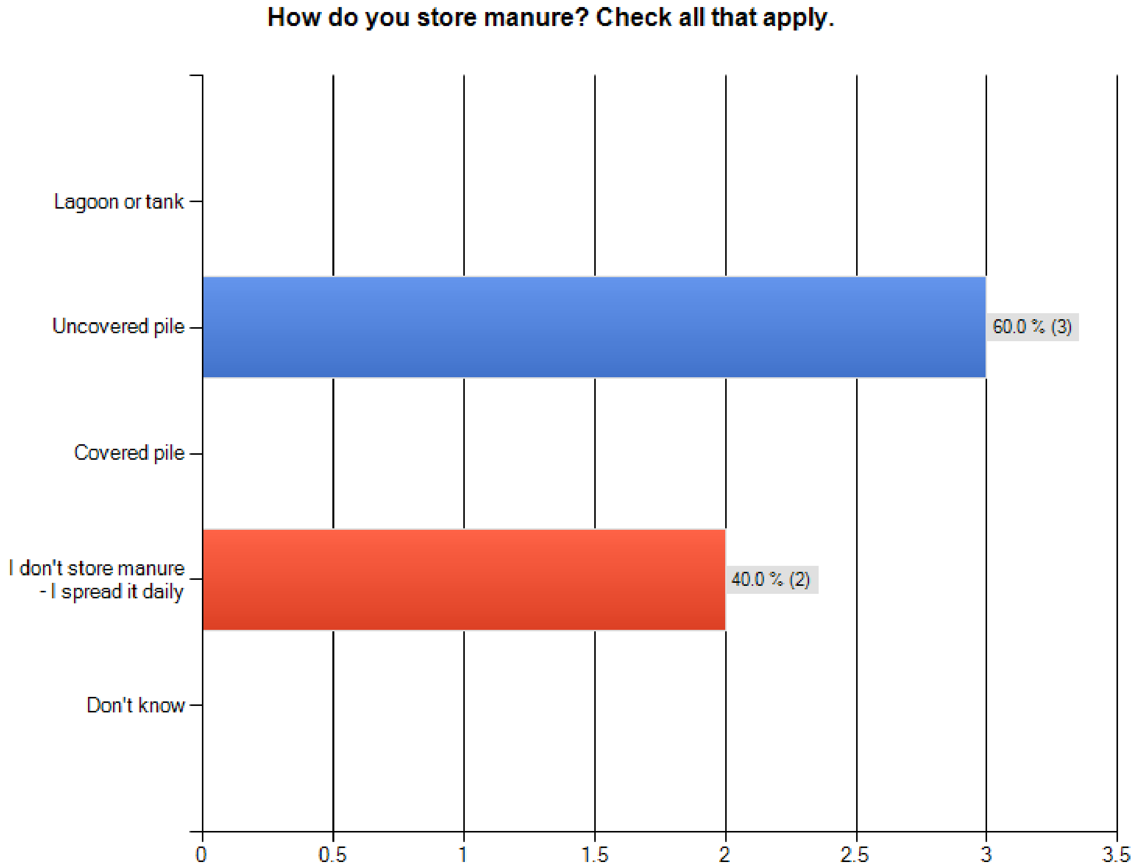
Q19: How do you store manure? Check all that apply.

Table 19.1 All responses



Answered question: 36
Skipped question: 24

Table 19.2 Responses of municipal staff



Answered question: 5
Skipped question: 15

Table 19.3 Responses by subgroup – Q 19 x Q 8

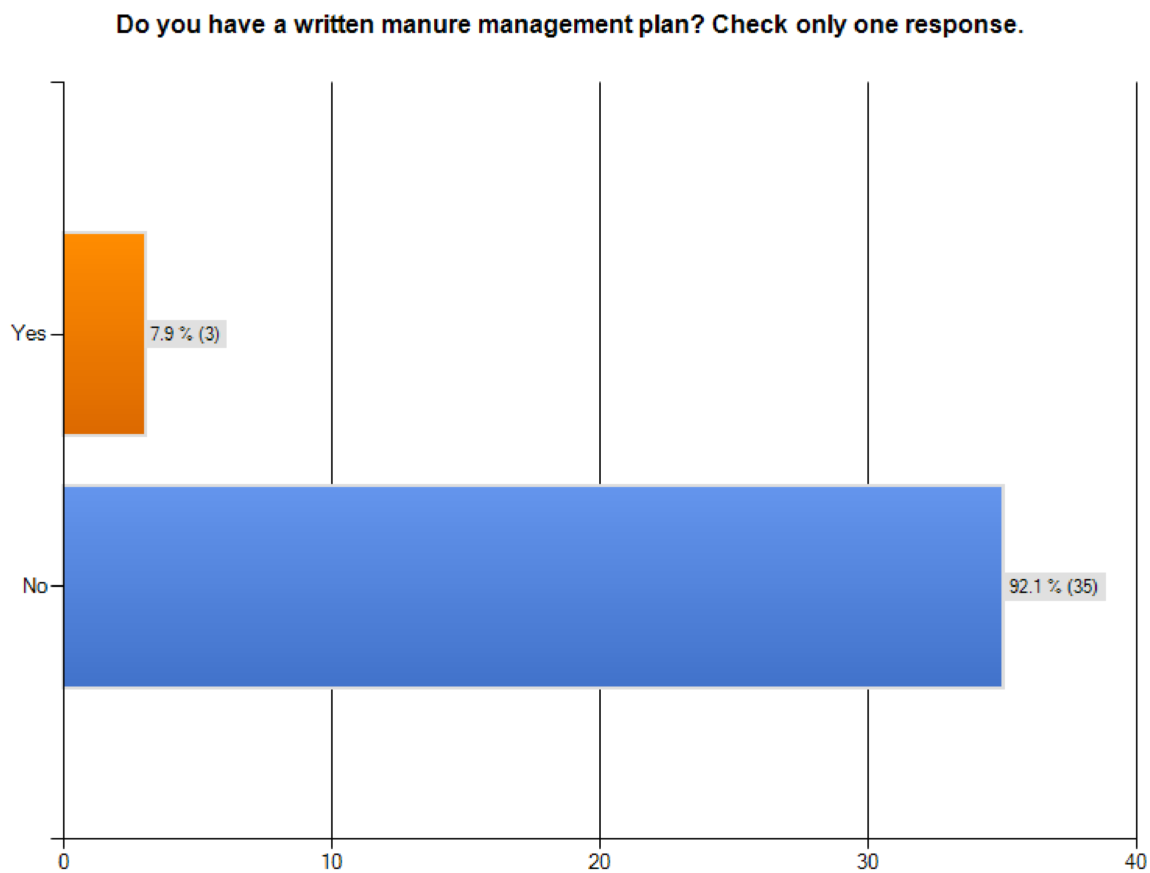
Take-away: The clear majority in all sample groups stores manure in an uncovered pile. Those using other practices (covered pile, daily spreading, and lagoon) are limited to just a few individuals. There is scope for providing educational information and technical content on other forms of manure storage.

Manure management planning

Question 20 in the practices series explores manure management planning. This question was also taken from the Rock County KAP study. Table 20.1 below gives responses for the entire sample. Table 20.2 shows results for municipal staff and officials. Table 20.3 gives results for agricultural respondents.

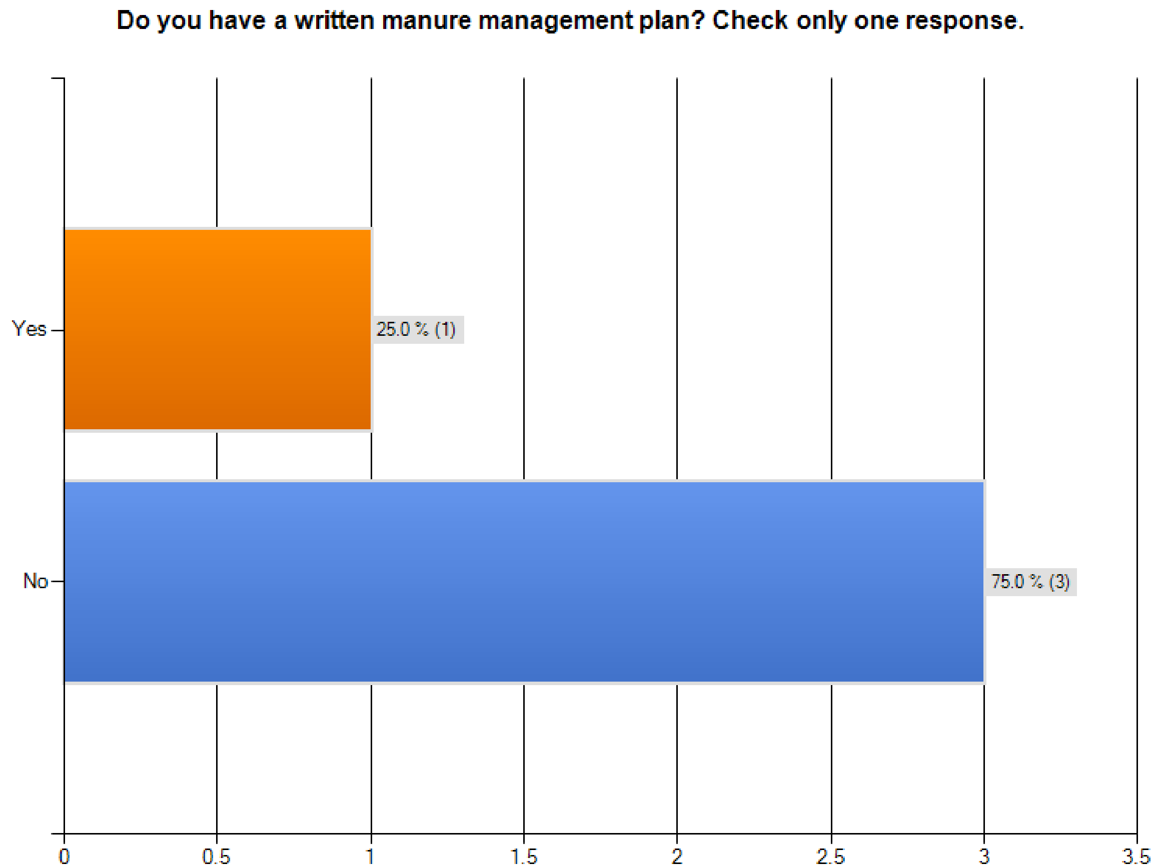
Q20: Do you have a written manure management plan? Check only one response.

Table 20.1 All responses



Answered question: 38
Skipped question: 22

Table 20.2 Responses of municipal staff



Answered question: 5
Skipped question: 15

Table 20.3 Responses by subgroup Q 20 x Q 8

For the entire sample, only three individuals have a manure management plan. This includes one municipal staff member. For the agricultural producer samples, one additional respondent indicated that s/he has a written manure management plan, for a total of four individuals. Of these, one has both crops and livestock; one is a horse owner; and the fourth has a horse-related business. Of note, none of the dairy/beef operators indicated that they have a written plan.

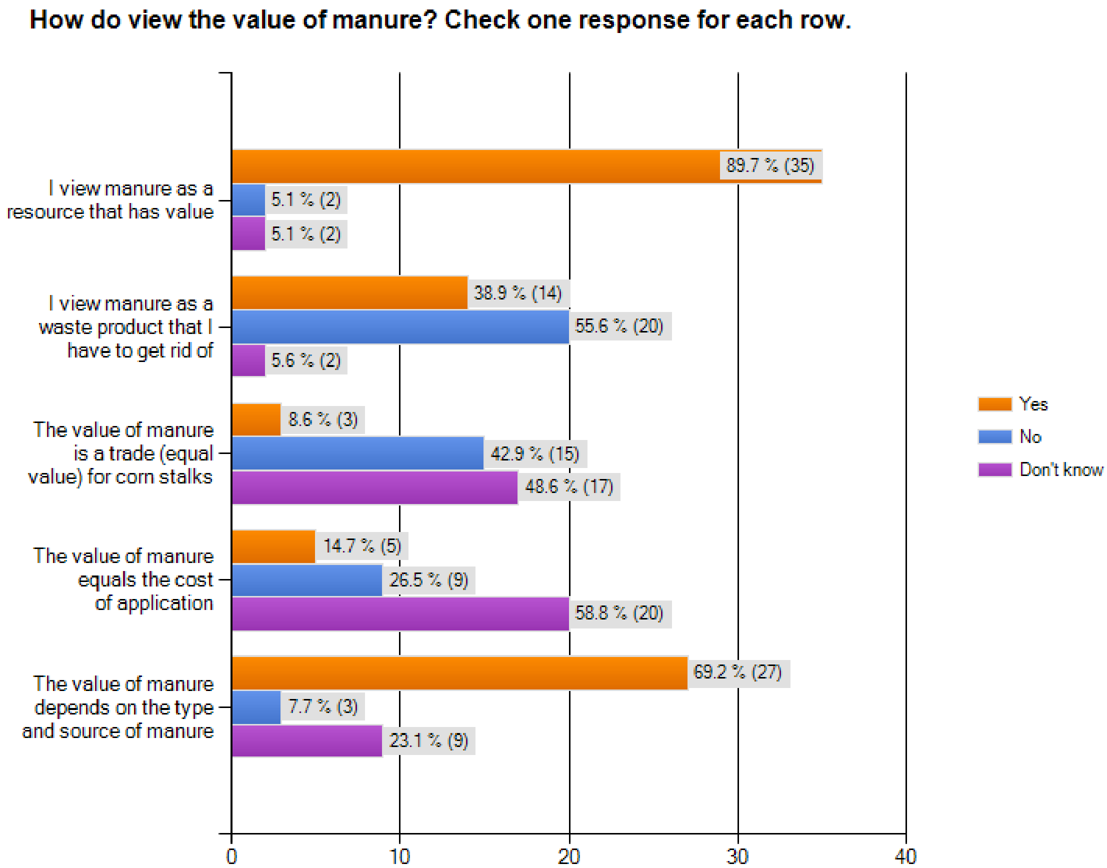
Take-away: There is ample scope to engage horse owners and agricultural producers in manure management planning. Q24 (below) explores options that may appeal to producers to take the next step.

Value of manure

Question 21 in the practices series explores how respondents value manure. This question was also taken from the Rock County KAP study. Table 21.1 below gives responses for the entire sample. Table 21.2 shows results for municipal staff and officials. Table 21.3 gives results for agricultural respondents.

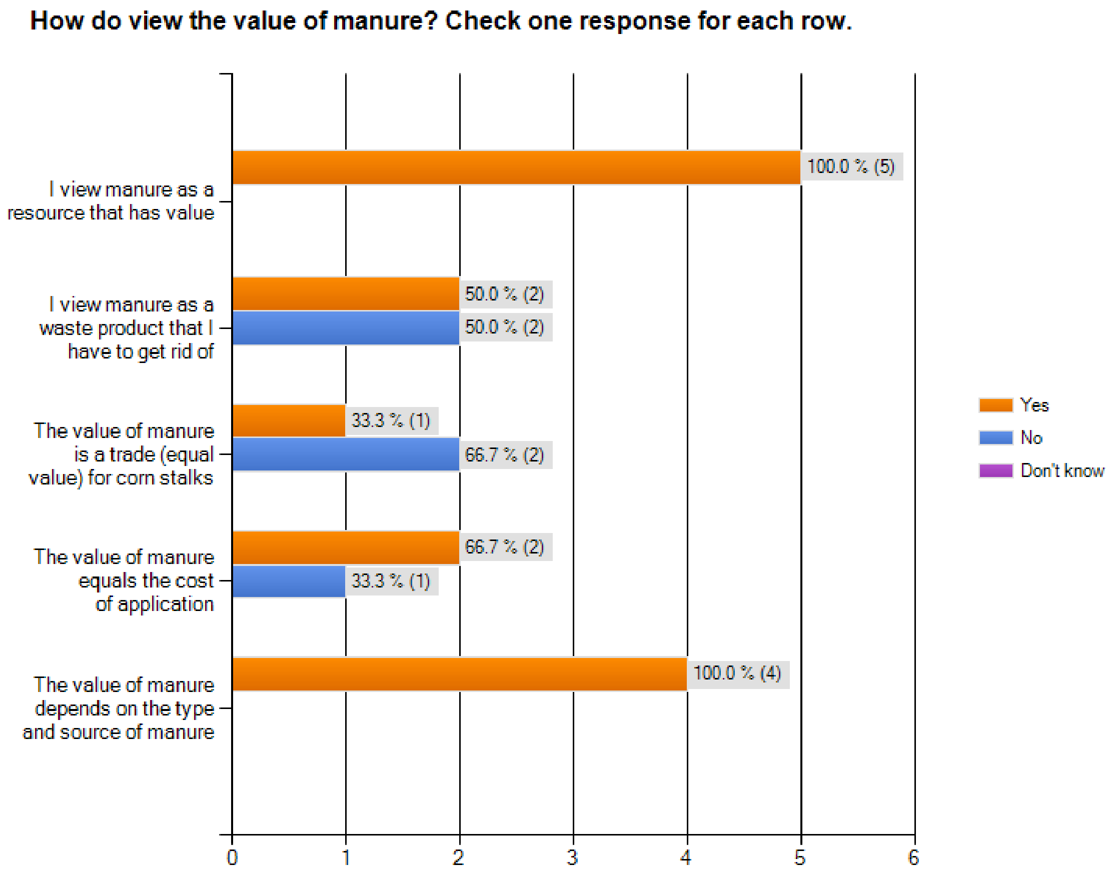
Q21: How do you view the value of manure? Check one response for each row.

Table 21.1 All responses



Answered question: 43
Skipped question: 17

Table 21.2 Responses of municipal staff



Answered question: 6
Skipped question: 14

Table 21.3 Responses by subgroup – agricultural producers

21. How do view the value of manure? Check one response for each row.
What type of farming operation do you have? Check all that apply.

		Dairy or beef	Field crops	Both livestock and crops	Horses (hobby or personal use)	Horses (business such as breeding, boarding or training)	Response Totals
I view manure as a resource that has value	Yes	100.0% (2)	75.0% (3)	100.0% (7)	85.0% (17)	100.0% (3)	
	No	0.0% (0)	0.0% (0)	0.0% (0)	10.0% (2)	0.0% (0)	
	Don't know	0.0% (0)	25.0% (1)	0.0% (0)	5.0% (1)	0.0% (0)	
		2	4	7	20	3	32
I view manure as a waste product that I have to get rid of	Yes	66.7% (2)	33.3% (1)	16.7% (1)	45.0% (9)	100.0% (2)	
	No	33.3% (1)	33.3% (1)	83.3% (5)	50.0% (10)	0.0% (0)	
	Don't know	0.0% (0)	33.3% (1)	0.0% (0)	5.0% (1)	0.0% (0)	
		3	3	6	20	2	31
The value of manure is a trade (equal value) for corn stalks	Yes	33.3% (1)	33.3% (1)	16.7% (1)	0.0% (0)	0.0% (0)	
	No	66.7% (2)	0.0% (0)	83.3% (5)	36.8% (7)	50.0% (1)	
	Don't know	0.0% (0)	66.7% (2)	0.0% (0)	63.2% (12)	50.0% (1)	
		3	3	6	19	2	30
The value of manure equals the cost of application	Yes	100.0% (2)	0.0% (0)	16.7% (1)	11.1% (2)	0.0% (0)	
	No	0.0% (0)	0.0% (0)	83.3% (5)	16.7% (3)	0.0% (0)	
	Don't know	0.0% (0)	100.0% (3)	0.0% (0)	72.2% (13)	100.0% (2)	
		2	3	6	18	2	29
The value of manure depends on the type and source of manure	Yes	100.0% (2)	100.0% (4)	87.5% (7)	55.0% (11)	100.0% (3)	
	No	0.0% (0)	0.0% (0)	12.5% (1)	10.0% (2)	0.0% (0)	
	Don't know	0.0% (0)	0.0% (0)	0.0% (0)	35.0% (7)	0.0% (0)	
		2	4	8	20	3	33

Take-away: While many respondents understand that manure has value, they simultaneously view it as a waste product that they need to get rid of. The majority of respondents are aware that the nutrient properties of manure depend on the type and source. Overall, the municipal staff respondents expressed virtually no uncertainty about the variables in this question, while the overall sample and some farmers were unsure about some variables (value of manure is a trade; value equals cost of application). In particular, the field crop producers had the highest "Don't know" responses. There may be an opportunity for some targeted educational messages on the value of manure.

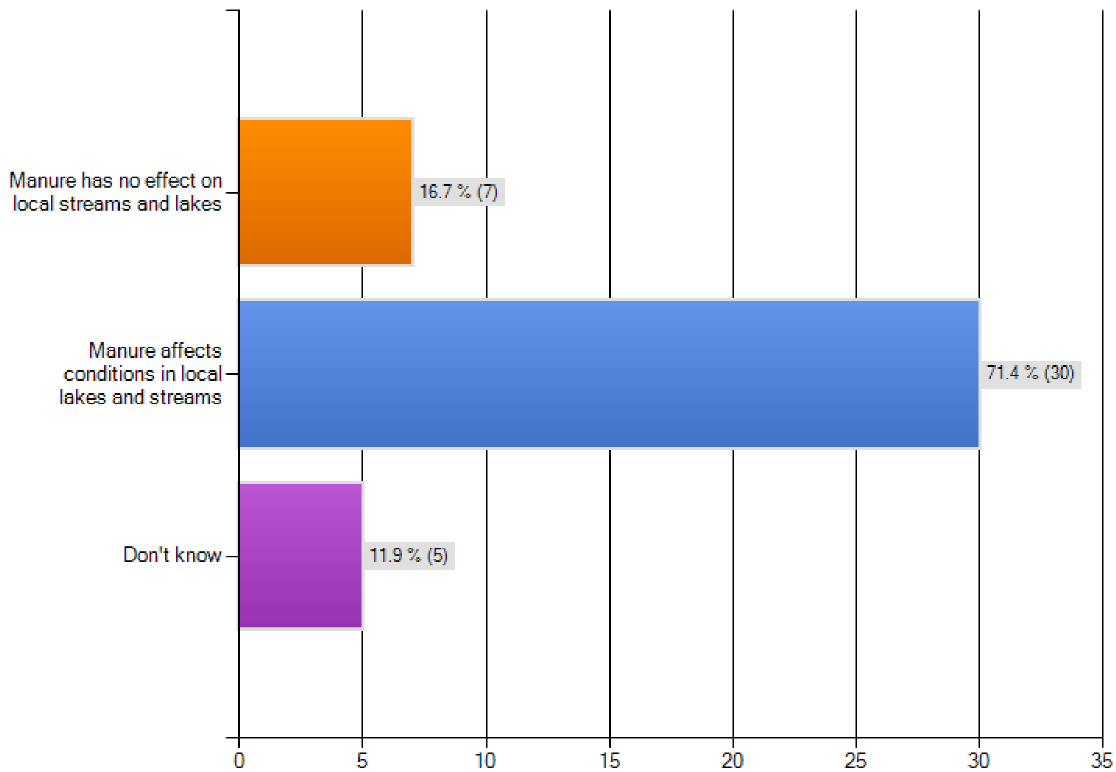
Impact of manure on local streams and lakes

Question 22 was a knowledge question about the impact of manure on local water bodies. Table 22.1 below gives responses for the entire sample. Table 22.2 shows results for municipal staff and officials. Table 23.3 gives results for agricultural respondents.

Q22: Does manure have any effect on the condition of local streams and lakes? Check only one response.

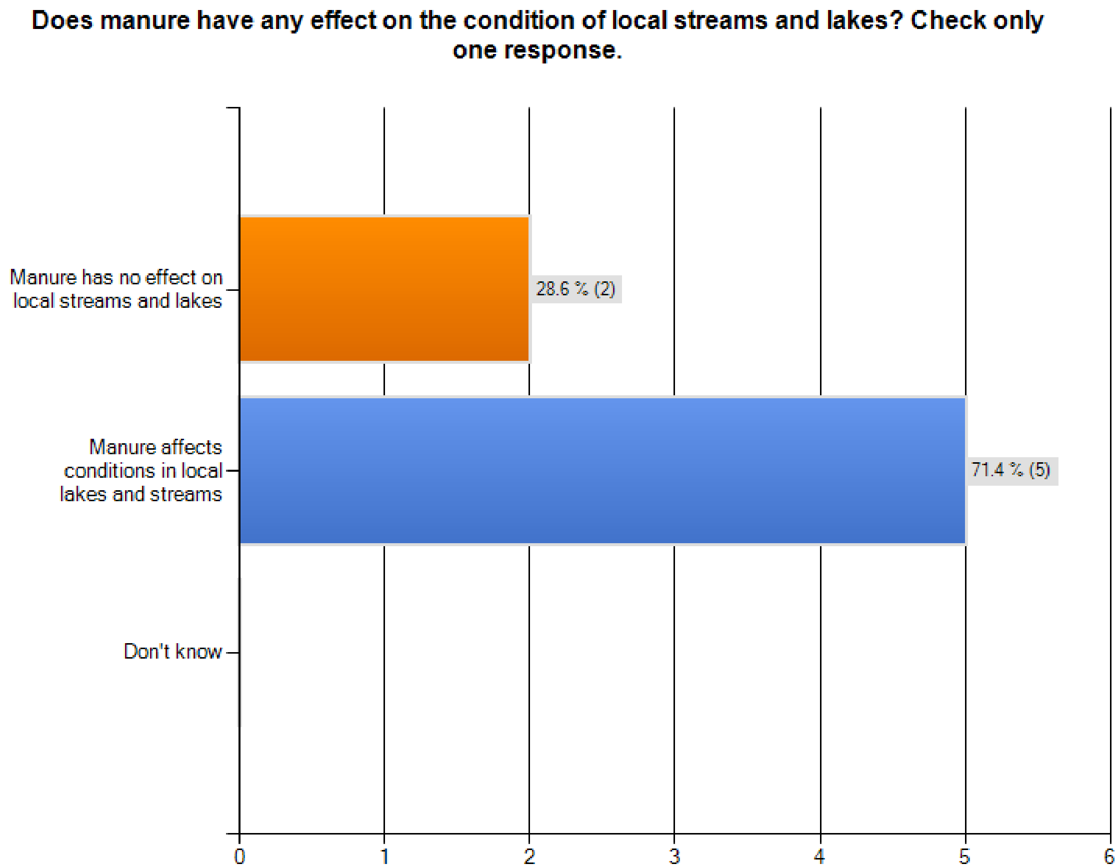
Table 22.1 All responses

Does manure have any effect on the condition of local streams and lakes? Check only one response.



Answered question: 42
Skipped question: 18

Table 22.2 Responses of municipal staff



Answered question: 7
Skipped question: 13

Table 22.3 Responses by agricultural subgroup – Crosstab Q22 x Q8

Elm Creek Water Survey

Does manure have any effect on the condition of local streams and lakes? Check only one response.						
	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	**Field crops**	**Both livestock and crops**	**Horses (hobby or personal use)**	**Horses (business such as breeding, boarding or training)**	**Response Totals**
Manure has no effect on local streams and lakes	**66.7% (2)**	0.0% (0)	37.5% (3)	9.5% (2)	0.0% (0)	20.0% (7)
Manure affects conditions in local lakes and streams	33.3% (1)	**80.0% (4)**	**50.0% (4)**	**85.7% (18)**	33.3% (1)	**65.7% (23)**
Don't know	0.0% (0)	20.0% (1)	12.5% (1)	4.8% (1)	**66.7% (2)**	14.3% (5)
Other (please specify)	1 reply	0 replies	1 reply	2 replies	0 replies	4
answered question	3	5	8	21	3	**35**
					skipped question	**2**

1 of 1

Responses to this question are very consistent. Around 71% of the entire sample, as well as municipal staff, understand that manure has an impact on local water bodies. For agricultural groups, the majority of field crop producers, crop and livestock producers, and horse owners understand this construct. However, two dairy/beef operators feel that manure has no effect on water bodies. Overall, seven respondents feel that manure has no impact on local streams. There is some uncertainty expressed by five individuals in the ag audience.

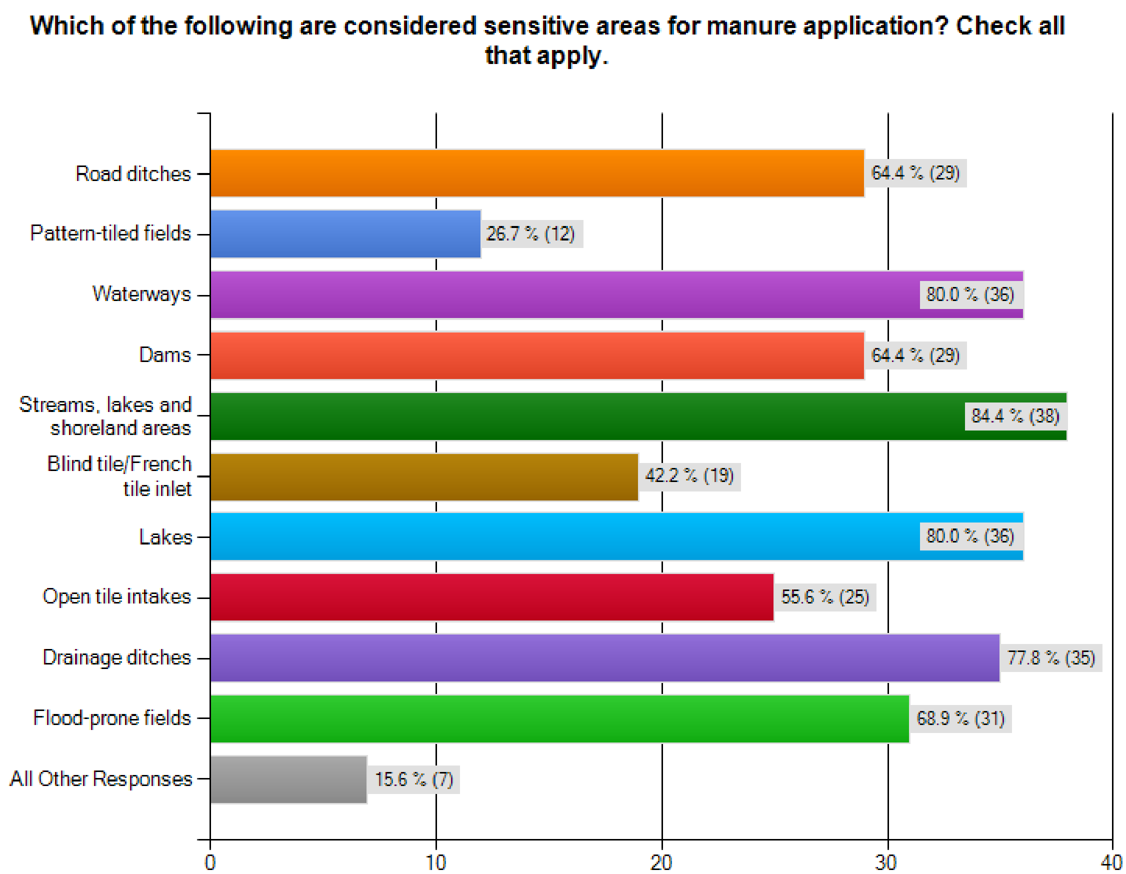
Take-away: While most people understand that there is a connection between human activities and water quality (Q5 above), there is less certainty about the impact of manure on water bodies. This should be a starting point upon which to build specific educational content and technical information, especially for agricultural producers.

Sensitive areas for manure application

Question 23 in the practices series explores how respondents manage manure. This question was also taken from the Rock County KAP study. Table 23.1 below gives responses for the entire sample. Table 23.2 shows results for municipal staff and officials. Table 23.3 gives results for agricultural respondents.

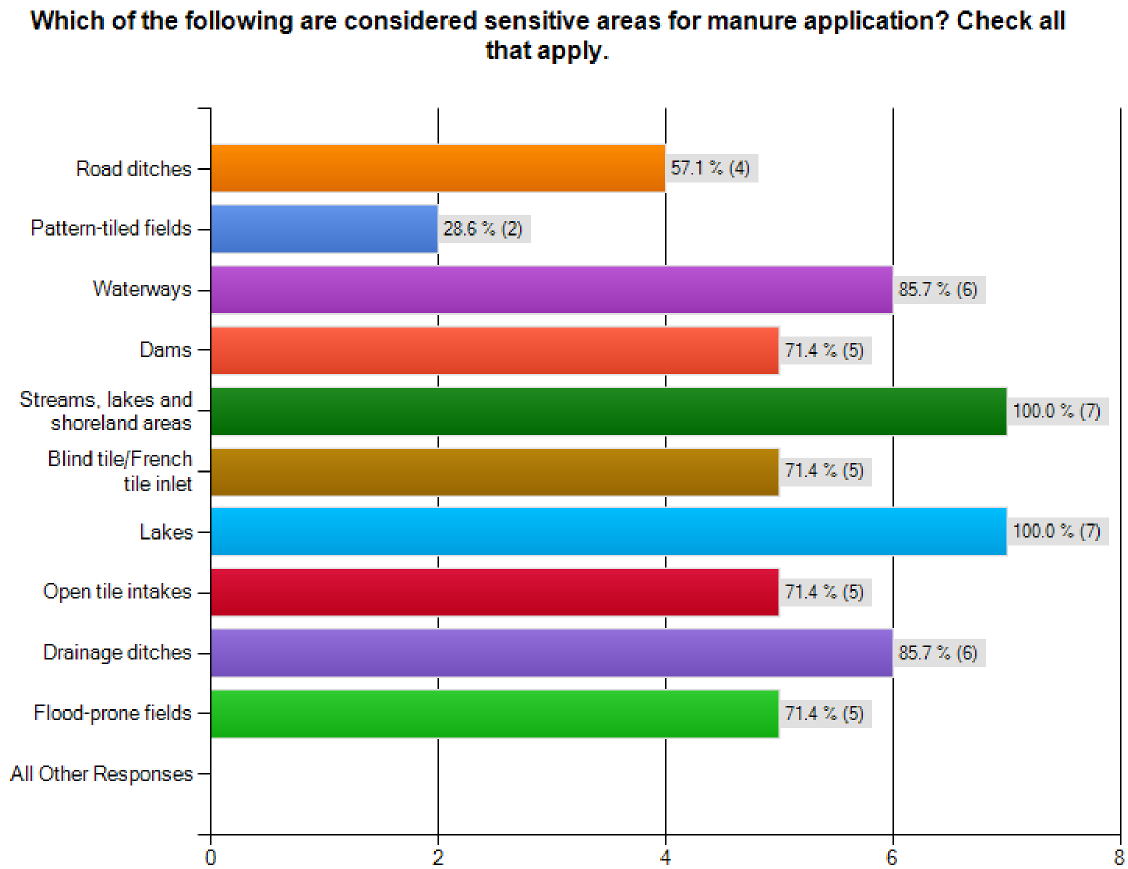
Q23: Which of the following are considered sensitive areas for manure application? Check all that apply.

Table 23.1 All responses



Answered question: 45
Skipped question: 15

Table 23.2 Responses of municipal staff



Answered question: 7
Skipped question: 13

Table 23.3 Responses of agricultural subgroups – Crosstab Q23 x Q 8

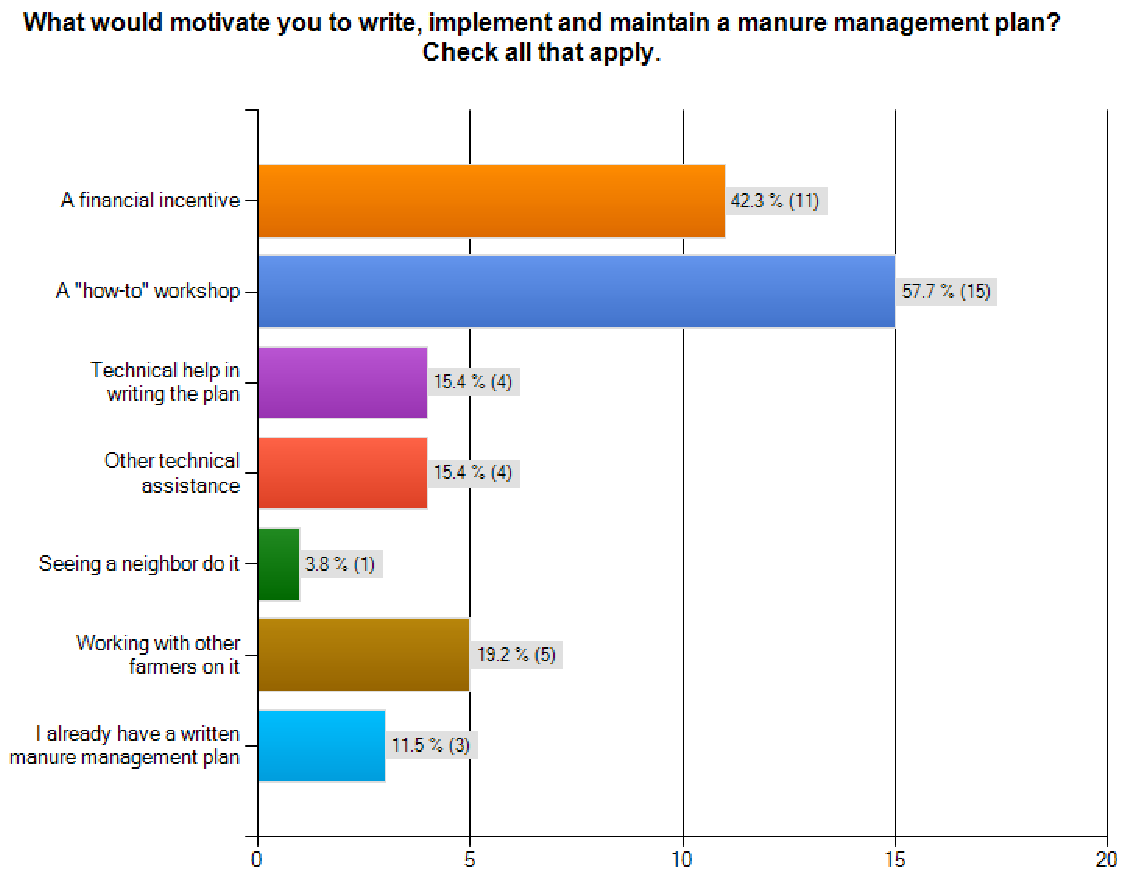
Two of the sample groups, agricultural producers and municipal staff, were highly aware that lakes, streams, waterways and other water bodies are sensitive areas for manure application. The sample overall was somewhat less aware. The results do not show any particular area where there is a need for heightened awareness.

Take-away: Awareness is quite high in the overall sample about what constitutes a sensitive area for manure management.

Options for manure management planning

This attitudes question was intended to find out what might encourage respondents to attempt manure management planning. Table 24.1 summarizes all responses; Table 24.2 shows responses for municipal staff and officials; and Table 24.3 summarizes the agricultural producers.

Table 24.1 All responses

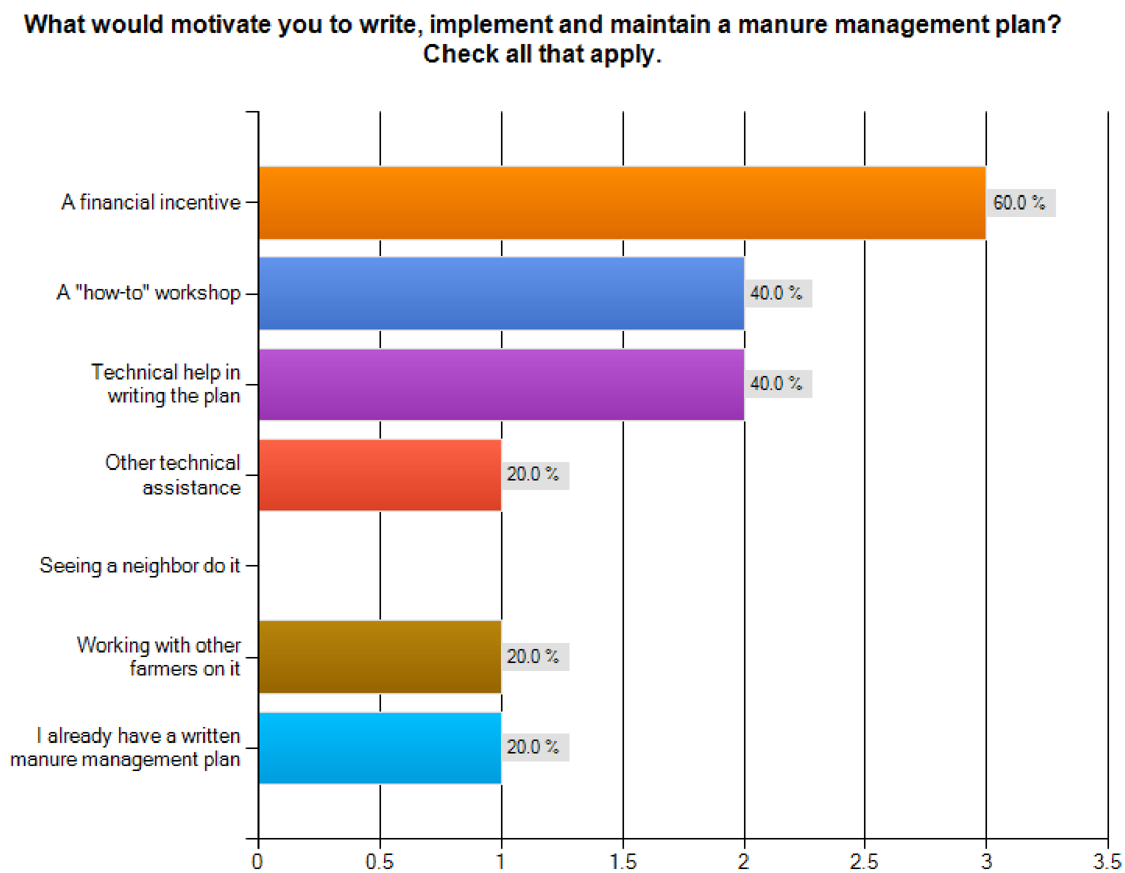


Answered question: 26
Skipped question: 34

Several respondents did not check an option on the questionnaire, but did provide the following comments:

- I am relying on my end user for final management.
- Nothing - government should leave me alone.
- I have my manure hauled away.
- I just own a little bit of land with a couple of horses. I have no manure management plans.
- NO horses anymore so not applicable
- We currently do not have large animals
- We compost and till in compost.
- We only have a few horses here so it doesn't seem to be an issue.

Table 24.2 Responses of municipal officials



Answered question: 5
Skipped question: 15

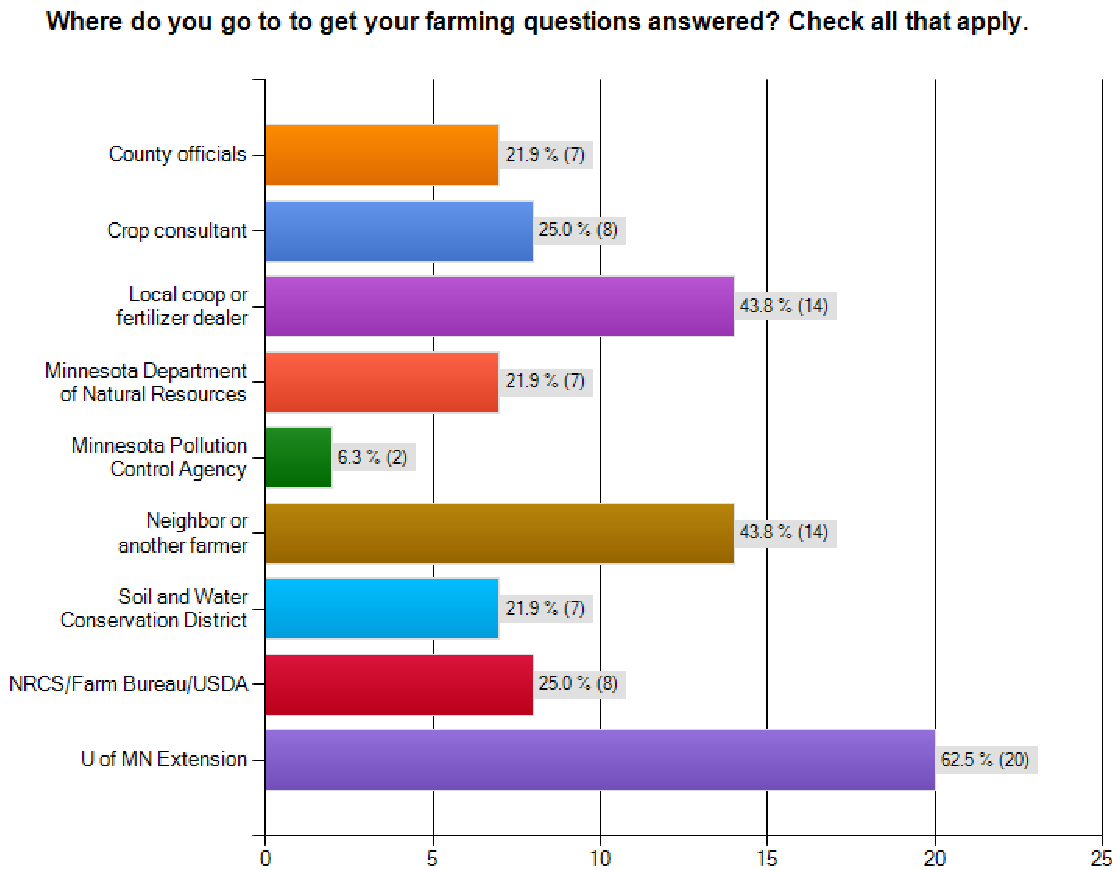
Table 24.3 Responses by subgroup – Crosstab Q 24 x Q 8

For the sample overall, and for the agricultural group, 58% preferred a "how-to" workshop. A financial incentive ranked second except for the municipal officials, which ranked this incentive highest at 60%. Municipal officials also ranked "technical help with writing the plan" as third. Half of all horse owners preferred a "how-to" workshop by a large margin.
Take-away: The majority of respondents prefer a how-to workshop on manure management planning, with many also opting for a financial incentive. Such options should be considered by the ECWMC.

Preferred sources of information

Q25: Where do you go to get your farming questions answered? Check all that apply

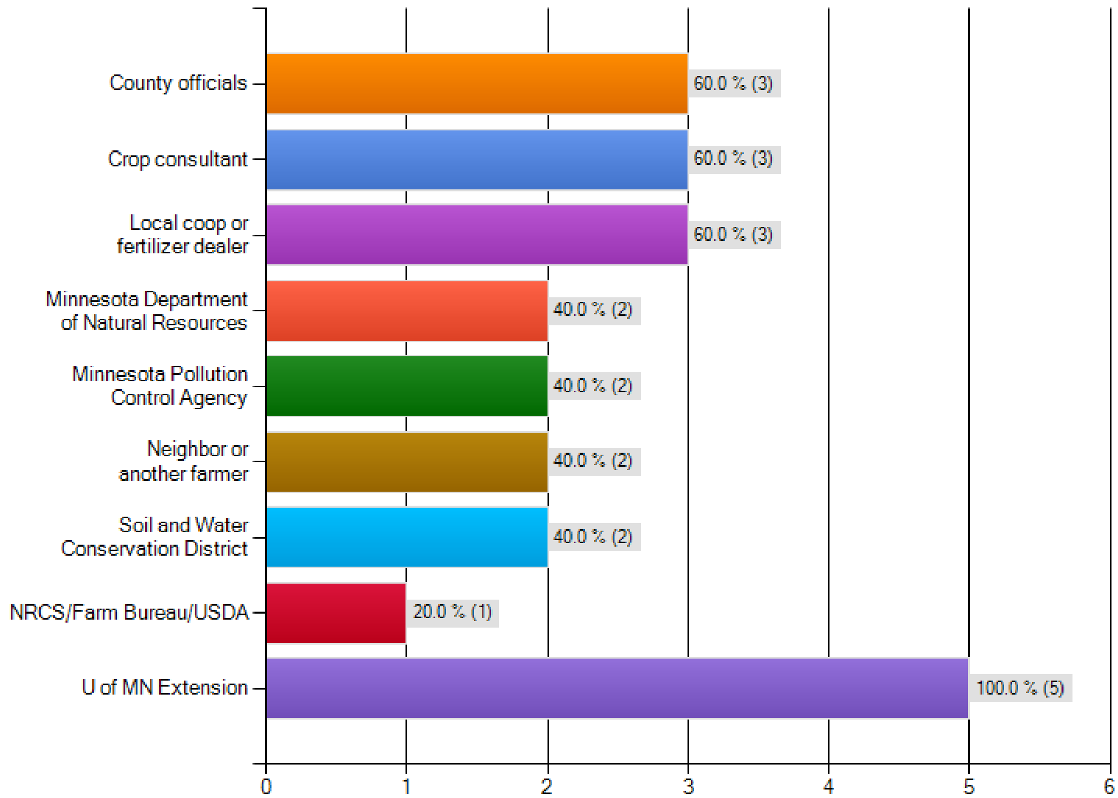
Table 25.1 All responses



Answered question: 32
Skipped question: 28

Table 25.2 Responses of municipal officials

Where do you go to to get your farming questions answered? Check all that apply.



Answered question: 5
Skipped question: 15

Table 25.3 Responses by agricultural subgroup – Crosstab Q25 x Q 8

Elm Creek Water Survey

Where do you go to to get your farming questions answered? Check all that apply.

	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	**Field crops**	**Both livestock and crops**	**Horses (hobby or personal use)**	**Horses (business such as breeding, boarding or training)**	**Response Totals**
County officials	33.3% (1)	25.0% (1)	50.0% (4)	23.5% (4)	33.3% (1)	23.3% (7)
Crop consultant	66.7% (2)	0.0% (0)	62.5% (5)	5.9% (1)	0.0% (0)	26.7% (8)
Local coop or fertilizer dealer	66.7% (2)	50.0% (2)	**75.0% (6)**	23.5% (4)	33.3% (1)	43.3% (13)
Minnesota Department of Natural Resources	**100.0% (3)**	25.0% (1)	12.5% (1)	23.5% (4)	33.3% (1)	20.0% (6)
Minnesota Pollution Control Agency	33.3% (1)	0.0% (0)	12.5% (1)	5.9% (1)	33.3% (1)	6.7% (2)
Neighbor or another farmer	33.3% (1)	0.0% (0)	25.0% (2)	47.1% (8)	**66.7% (2)**	43.3% (13)
Soil and Water Conservation District	**100.0% (3)**	0.0% (0)	37.5% (3)	17.6% (3)	33.3% (1)	23.3% (7)
NRCS/Farm Bureau/USDA	66.7% (2)	25.0% (1)	37.5% (3)	17.6% (3)	0.0% (0)	23.3% (7)
U of MN Extension	**100.0% (3)**	**100.0% (4)**	62.5% (5)	**64.7% (11)**	33.3% (1)	**63.3% (19)**
Other (please specify)	0 replies	0 replies	0 replies	3 replies	0 replies	3
answered question	3	4	8	17	3	**30**

1 of 2

skipped question	7

For the entire sample, most respondents (63%) see the University of Minnesota UM Extension as their primary source of information on agricultural questions. Municipal staff ranked UM Extension even higher at 100%, as did livestock operators and field crop producers. Local fertilizer dealers, crop consultants and neighbors were also sought out but not ranked as highly as UM Extension. Some comments implied that ECWMC was not well known to respondents.

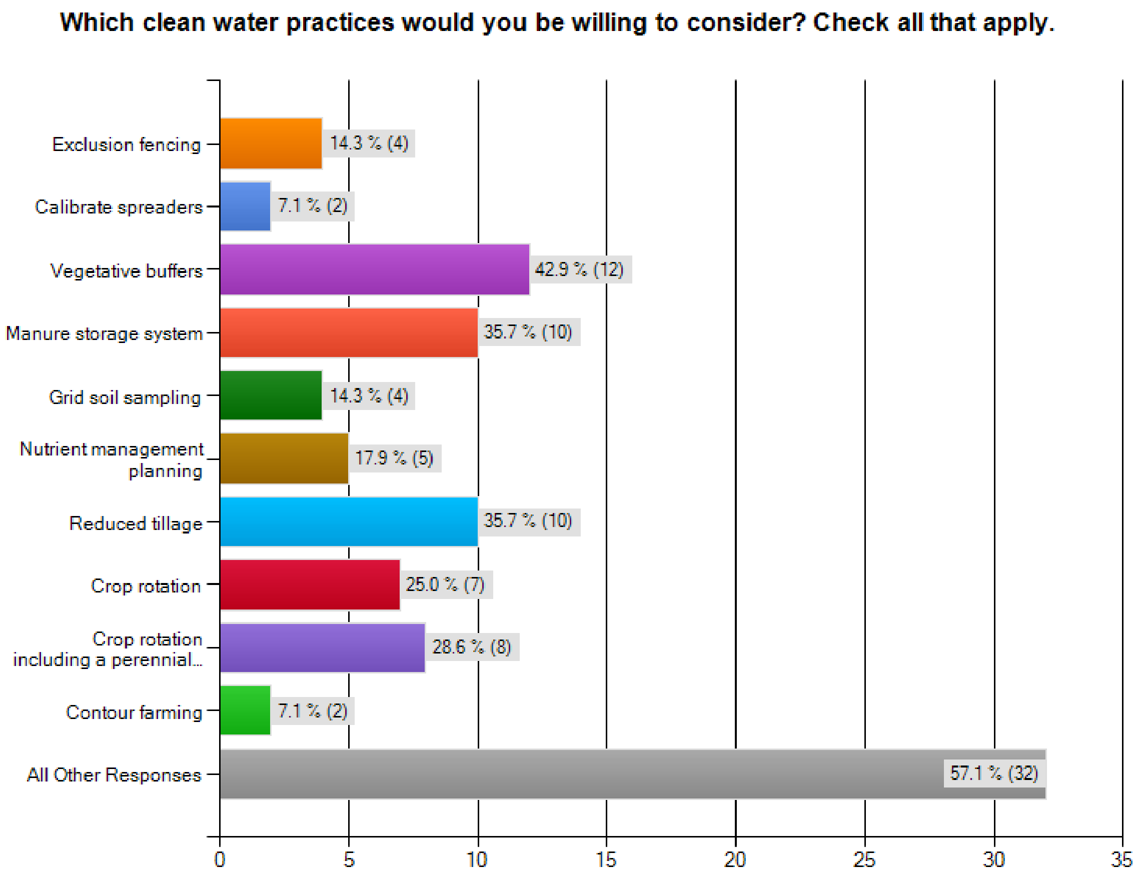
Take-away: ECWMC might consider partnering with Minnesota UM Extension staff (e.g. Betsy Wieland) are already known to respondents and appear to be trusted sources of information. ECWMC might consider heightening its visibility as a technical resource to local producers and residents, possibly by sponsoring (or co-sponsoring) environmental events, an open house, field days, workshops and other informational events.

Willingness to adopt a BMP

This question was posed to gauge the willingness of respondents to adopt a best management practice. Table 26.1 summarizes all responses. Table 26.2 shows the responses of municipal staff and officials. Table 26.3 summarizes responses of agricultural sub-groups.

Q26: Which clean water practices would you be willing to consider? Check all that apply.

Table 26.1 All responses

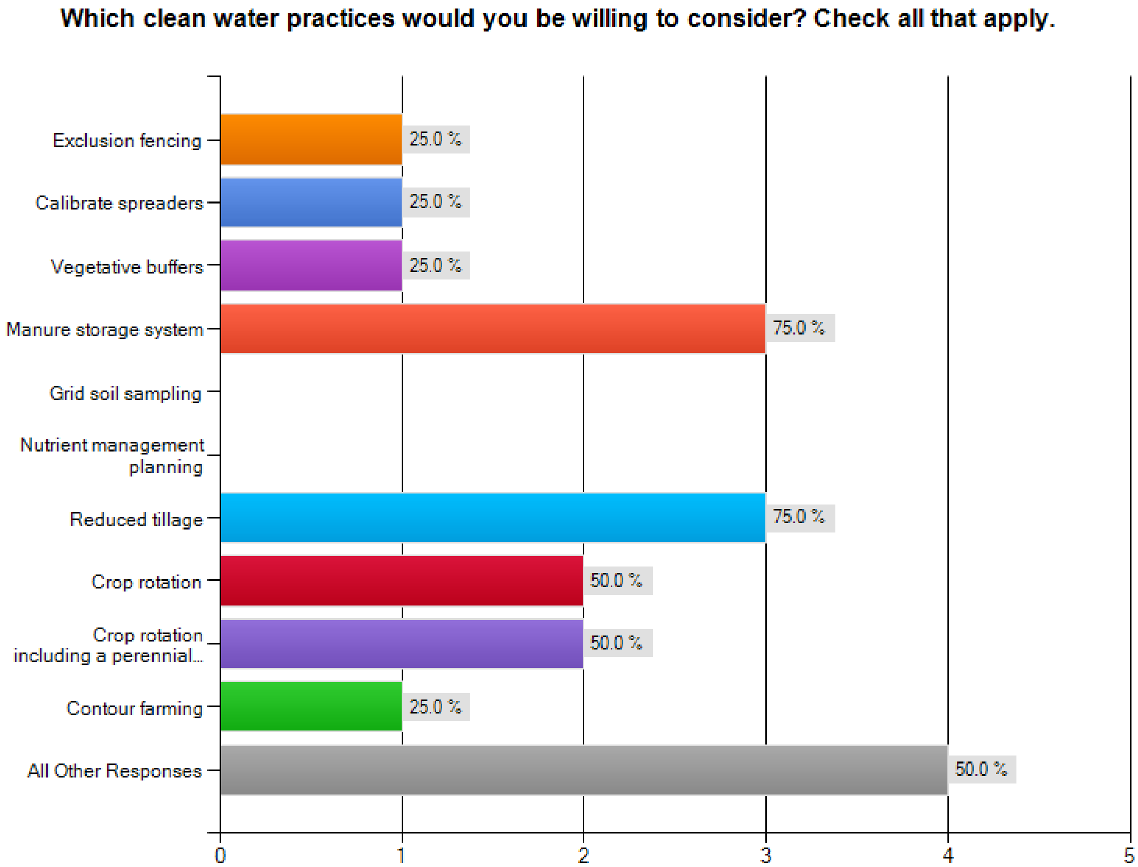


Answered question: 28
Skipped question: 32

Two respondents offered the following comments:

- I already store on concrete pad and have it hauled away
- Any, but without farm equipment or money to pay, very low motivation for our hobby

Table 26.2 Responses of municipal staff



Answered question: 4
Skipped question: 16

Table 26.3 Responses by agricultural subgroups – Crosstab Q26 x Q 8

Overall, respondents were most likely to try vegetative buffers (43%), followed by a manure storage system (36%) and reduced tillage (36%). Smaller numbers were willing to try other options (crop rotation with perennials). About 17% were willing to try nutrient management planning. Municipal officials were more willing to try reduced tillage and a manure storage system (75% each), followed by crop rotation and crop rotation with a perennial. Among all producer groups, there was highest willingness to try manure management, followed by reduced tillage.

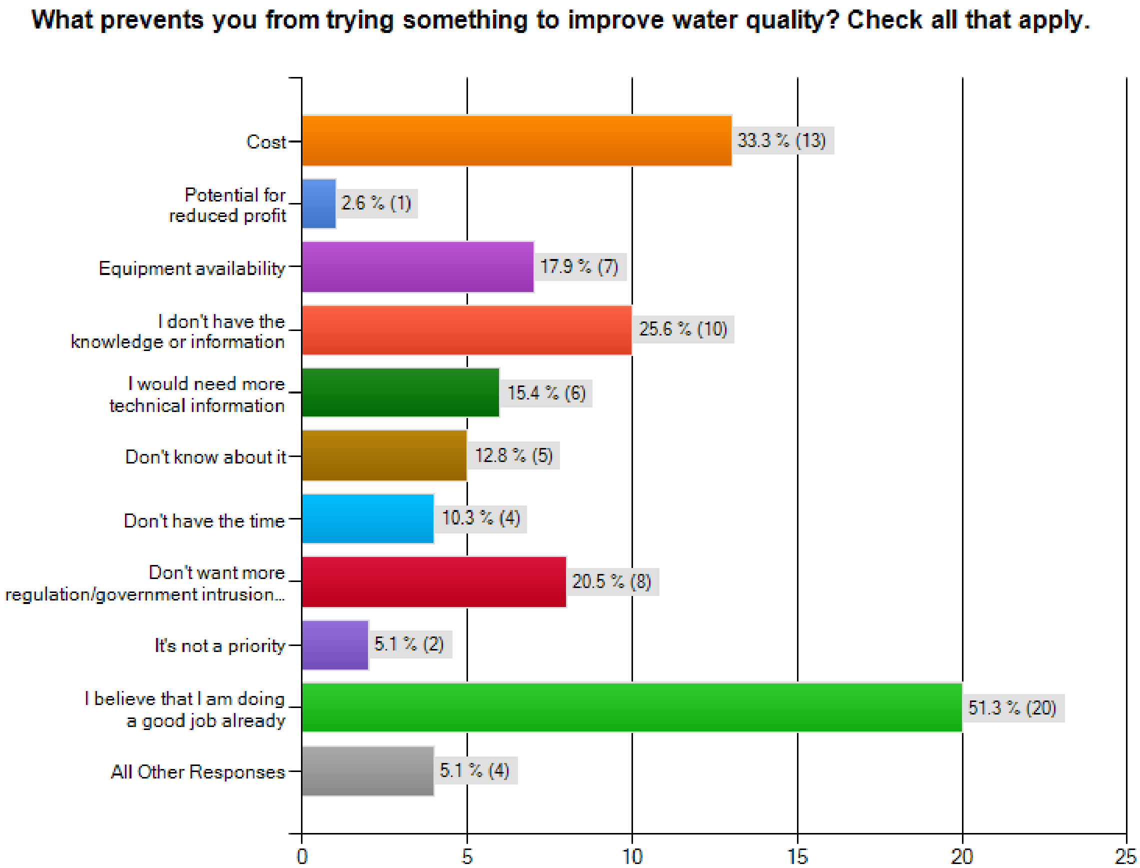
Take-away: All producer groups are willing to try something to improve water quality. This is very good news. However, different producer groups vary in their willingness to adopt different BMPs. It may be necessary to offer different "how-to" workshops or training in a variety of BMPs. Given the small sample size for the watershed, it can be expected that such workshops would be fairly small, and each would appeal to a different group of individuals depending on their interests and information needs.

Constraints to adoption

This question explored reasons why respondents might not adopt a BMP. Table 27.1 summarizes all responses. Table 27.2 presents responses of municipal officials. Table 27.3 shows responses of agricultural sub-groups.

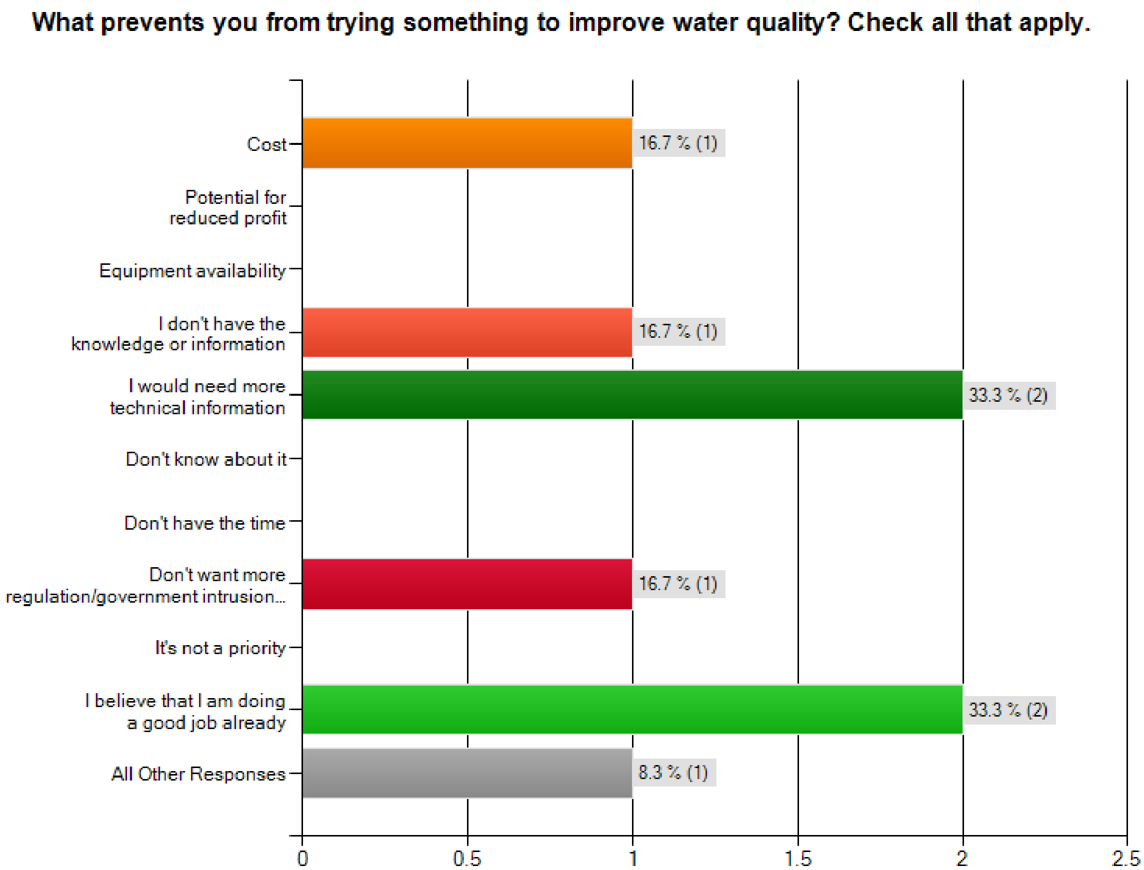
Q27: What prevents you from trying something to improve water quality? Check all that apply.

Table 27.1 All responses



Answered question: 39
Skipped question: 21

Table 27.2 Responses of municipal staff



Answered question: 6
Skipped question: 14

Table 27.3 Responses by agricultural subgroups – Crosstab Q 27 x Q 8

Elm Creek Water Survey

What prevents you from trying something to improve water quality? Check all that apply.

	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	**Field crops**	**Both livestock and crops**	**Horses (hobby or personal use)**	**Horses (business such as breeding, boarding or training)**	**Response Totals**
Cost	66.7% (2)	0.0% (0)	**37.5% (3)**	31.8% (7)	**100.0% (3)**	35.3% (12)
Potential for reduced profit	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	33.3% (1)	2.9% (1)
Equipment availability	0.0% (0)	0.0% (0)	12.5% (1)	18.2% (4)	66.7% (2)	20.6% (7)
I don't have the knowledge or information	0.0% (0)	**33.3% (1)**	12.5% (1)	27.3% (6)	33.3% (1)	26.5% (9)
I would need more technical information	0.0% (0)	0.0% (0)	25.0% (2)	18.2% (4)	66.7% (2)	17.6% (6)
Don't know about it	0.0% (0)	**33.3% (1)**	0.0% (0)	13.6% (3)	0.0% (0)	11.8% (4)
Don't have the time	33.3% (1)	0.0% (0)	0.0% (0)	13.6% (3)	33.3% (1)	11.8% (4)
Don't want more regulation/government intrusion into my operation	66.7% (2)	**33.3% (1)**	0.0% (0)	27.3% (6)	33.3% (1)	23.5% (8)
It's not a priority	0.0% (0)	0.0% (0)	0.0% (0)	4.5% (1)	0.0% (0)	2.9% (1)
I believe that I am doing a good job already	**100.0% (3)**	**33.3% (1)**	25.0% (2)	**59.1% (13)**	0.0% (0)	**50.0% (17)**
Neighbor doesn't want me to	0.0% (0)	0.0% (0)	0.0% (0)	4.5% (1)	0.0% (0)	2.9% (1)

1 of 2

Take-aways: For respondents overall, the most important finding is that people believe that they are already doing the right thing. Although this view may prevent them changing their practices, this is actually a very positive finding. It is likely that a communication strategy focusing on stewardship and “doing the right thing” will resonate with this worldview.

The second most important constraint for respondents is cost. In particular, agricultural groups (and especially horse business operators) seem to be more sensitive to cost concerns. A financial incentive could be of interest to some individuals (but not necessarily all) to better enable them to adopt a BMP. A third concern for all groups is the need for more information and not knowing about a BMP. There appears to be an unmet need for technical information across all groups.

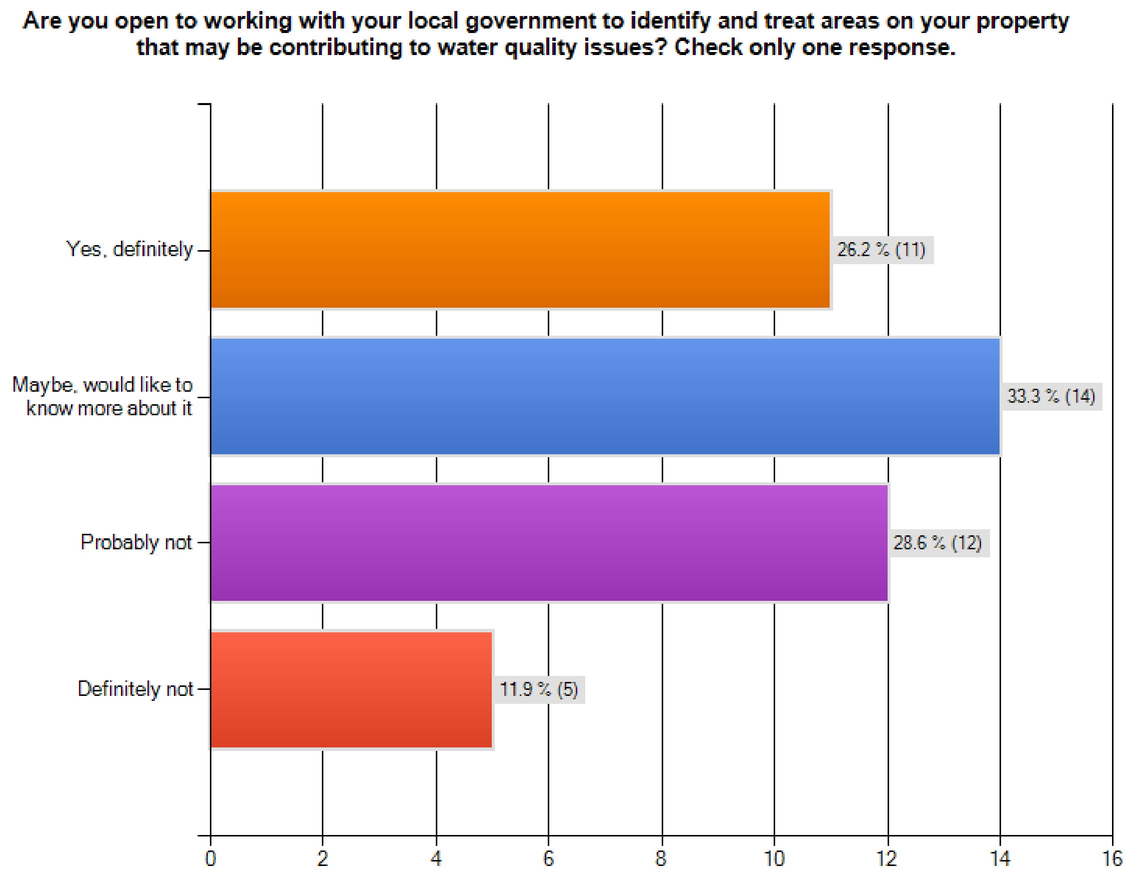
At least some respondents noted other constraints (lack of equipment, lack of time etc.). Eight respondents noted that they do not want government intrusion.

Willingness to working with local government

This attitudes question explored whether respondents would work with a local government entity on water quality issues. Table 28.1 presents all responses; Table 28.2 presents municipal officials' responses; and Table 28.3 gives responses from agricultural sub-groups.

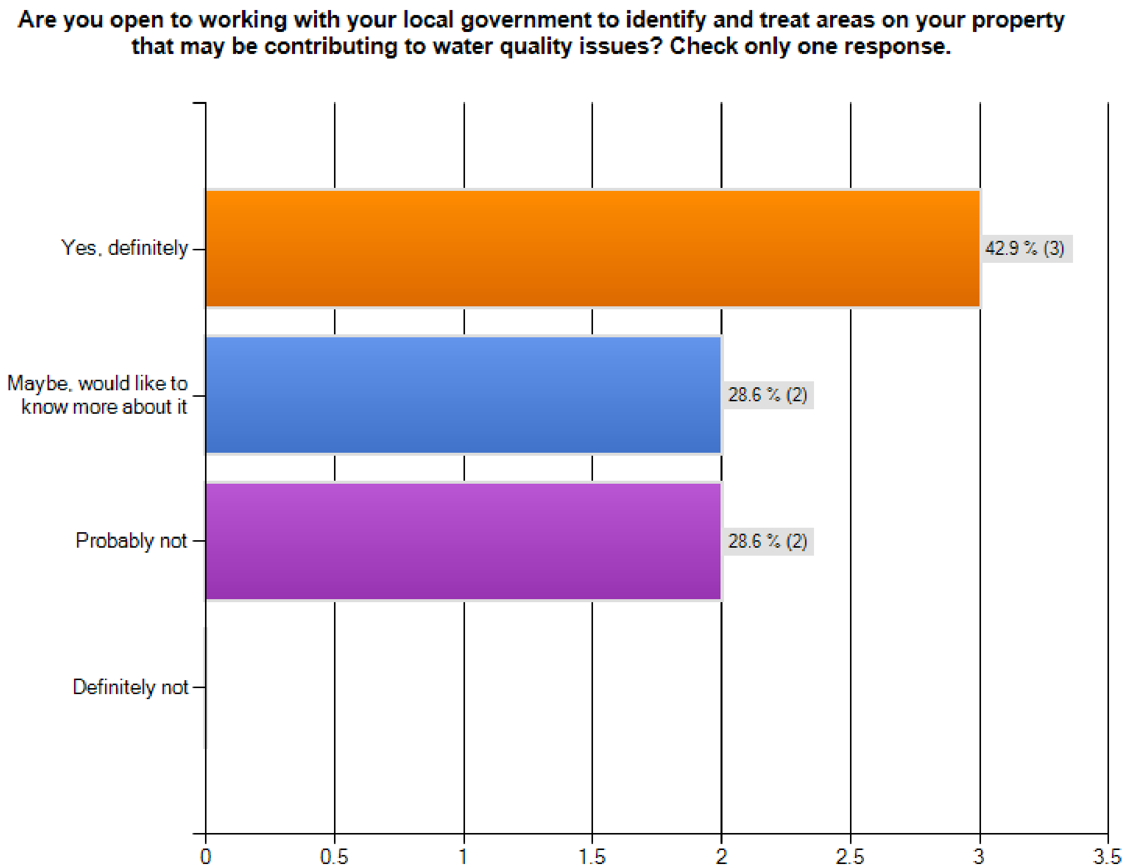
Q28: Are you open to working with your local government to identify and treat areas on your property that may be contributing to water quality issues? Check only one response.

Table 28.1 All responses



Answered question: 42
Skipped question: 18

Table 28.2 Responses of municipal officials



Answered question: 7
Skipped question: 13

Table 28.3 Responses by subgroup – Crosstab Q 28 x Q 8

Take-aways: For survey respondents overall, the majority (almost 60%) responded positively, with either a "yes" or "maybe – would like to learn more about it." About 40% answered in the negative, with 29% inclined not to work with local government, and 12% (*n* = 5) stating "definitely not." 72% of municipal staff were also more inclined to do so, with 42% responding "yes," and 29% responding "maybe." Another 29% said "probably not," but none said "definitely not."

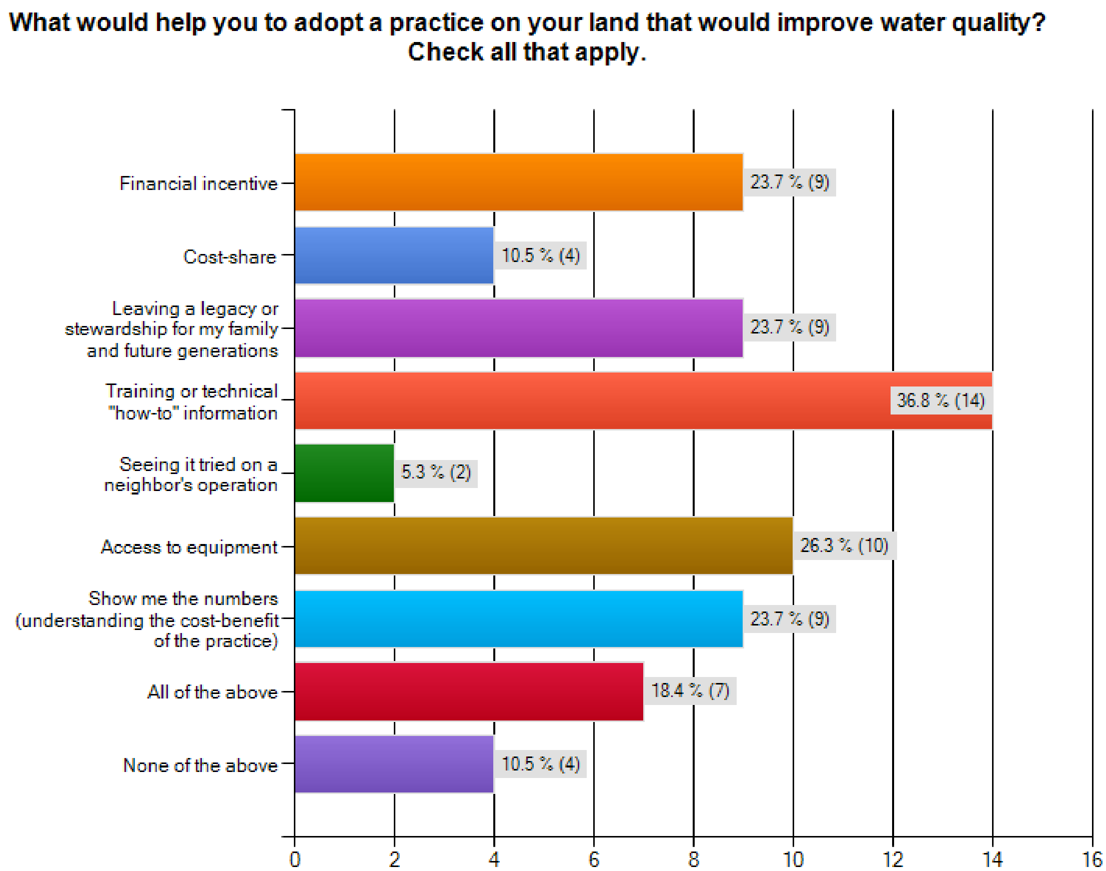
Among agricultural producer groups, only the livestock farmers (dairy/beef) were clearly uninterested in working with local government. The other groups have more mixed responses. Horse owners ranked next in terms of disinclination, although horse business owners showed more interest. Just over half (56%) of the agricultural groups were positively inclined.

Motivational mechanisms

The final attitudes question explored which mechanisms might help respondents to adopt a BMP. Table 29.1 summarizes responses for the entire sample. Table 29.2 gives responses of municipal staff and officials. Table 29.3 summarizes responses of agricultural producers.

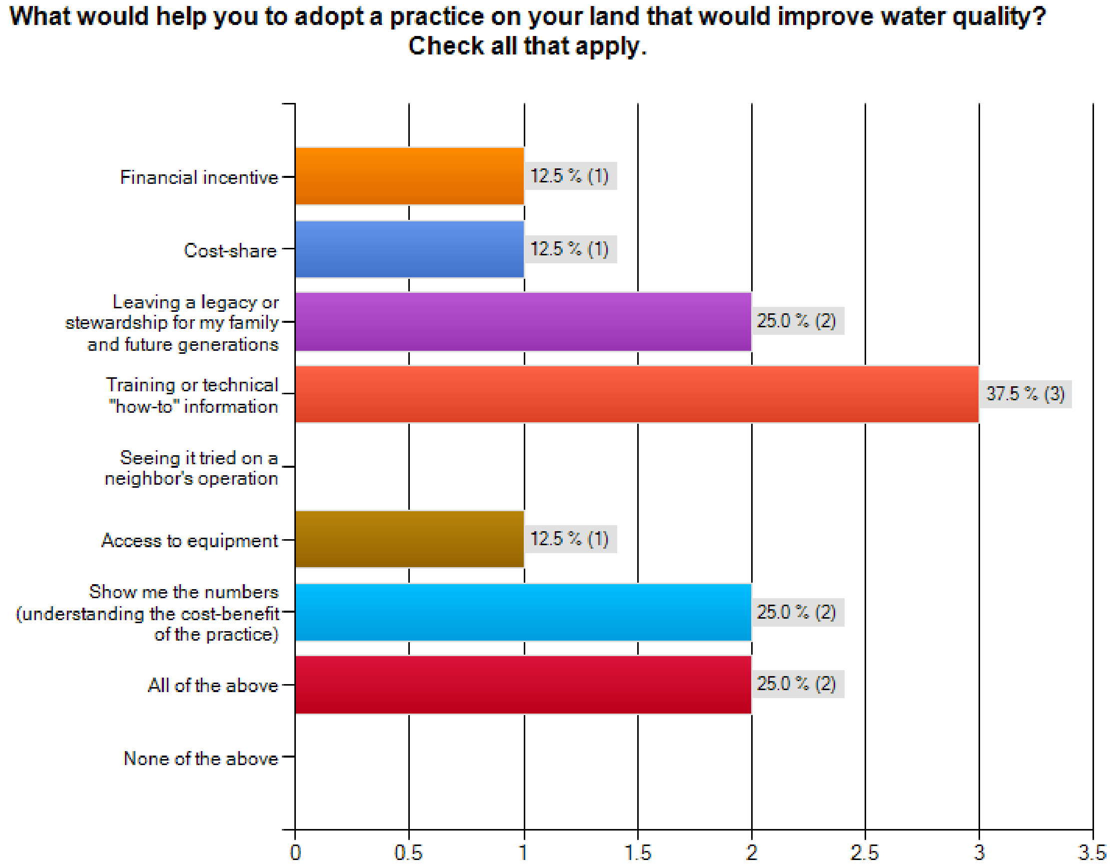
Q29: What would help you to adopt a practice on your land that would improve water quality? Check all that apply.

Table 29.1 All responses



Answered question: 38
Skipped question: 22

Table 29.2 Responses of municipal staff



Answered question: 8
Skipped question: 12

Table 29.3 Responses by agricultural subgroup – Crosstab Q 29 x Q 8

Elm Creek Water Survey

What would help you to adopt a practice on your land that would improve water quality? Check all that apply.

	What type of farming operation do you have? Check all that apply.					
	Dairy or beef	Field crops	Both livestock and crops	Horses (hobby or personal use)	Horses (business such as breeding, boarding or training)	Response Totals
Financial incentive	0.0% (0)	20.0% (1)	25.0% (2)	25.0% (5)	**66.7% (2)**	26.5% (9)
Cost-share	0.0% (0)	0.0% (0)	12.5% (1)	10.0% (2)	33.3% (1)	11.8% (4)
Leaving a legacy or stewardship for my family and future generations	33.3% (1)	**80.0% (4)**	12.5% (1)	20.0% (4)	33.3% (1)	26.5% (9)
Training or technical "how-to" information	33.3% (1)	60.0% (3)	25.0% (2)	**40.0% (8)**	33.3% (1)	**41.2% (14)**
Seeing it tried on a neighbor's operation	0.0% (0)	0.0% (0)	12.5% (1)	0.0% (0)	33.3% (1)	5.9% (2)
Access to equipment	33.3% (1)	40.0% (2)	12.5% (1)	25.0% (5)	33.3% (1)	26.5% (9)
Show me the numbers (understanding the cost-benefit of the practice)	**66.7% (2)**	0.0% (0)	12.5% (1)	20.0% (4)	33.3% (1)	20.6% (7)
All of the above	0.0% (0)	0.0% (0)	**37.5% (3)**	15.0% (3)	**66.7% (2)**	17.6% (6)
None of the above	0.0% (0)	0.0% (0)	0.0% (0)	20.0% (4)	0.0% (0)	11.8% (4)
Other (please specify)	0 replies	0 replies	1 reply	2 replies	0 replies	3
answered question	3	5	8	20	3	**34**

1 of 2

For the entire sample and for municipal respondents, the highest ranked mechanism was training or technical “how-to” information. Agricultural producers ranked “show me the numbers” as their highest mechanism. Next most important for the overall sample was access to equipment; leaving a legacy; and a financial incentive. Cost-sharing ranked somewhat lower than a financial incentive. A similar pattern held for the municipal employees, who also ranked “show me the numbers” highly. Among agricultural groups (including horse owners) access to training and technical information ranked highest, except for livestock producers who ranked “show me the numbers” highest.

Take-away: while all mechanisms generated some interest across respondent groups, providing training and technical information is the mostly likely option for most people. Offering a financial incentive, demonstrating “the numbers,” facilitating access to equipment, and leaving a legacy are also important to all groups.

Discussion

This section summarizes general findings and impressions from the KAP study data and comments provided by respondents.

As a whole, the sample population seems more polarized in their attitudes than other KAP study respondents elsewhere in Minnesota. While there is clearly a strong undercurrent of distrust of government agencies among certain respondents, there are also indications that many respondents have a strong stewardship ethic, believe in leaving a legacy, and are interested in partnering with ECWMC. This was seen in numerous comments entered by respondents expressing concern for water quality and willingness to adopt new practices.

There is an impression in this study that respondents and stakeholders are unaware of the potential of civic engagement in the watershed planning process. Civic engagement is a *requirement* of a TMDL, and is best described as a democratic process whereby local citizens become directly involved in watershed planning, activities, education, and determining outcomes. However, civic engagement takes time and cannot be rushed, and does not happen simply by holding a facilitated public meeting. Some respondents appear to be ready to take a more active role, and there is good potential to engage them in the TMDL process.

There seems to be a general lack of awareness and familiarity with local streams and rivers, with only a handful of respondents reporting that they visit any of the water bodies in the vicinity.

There appears to be a lack of familiarity about the role and functions of ECWMC among the respondents. As a relatively young watershed agency it is likely to be unfamiliar to many residents, especially to property owners who have recently moved to the area. ECWMC is not viewed as a resource for producers. However it could potentially be viewed as an agency that might regulate an agricultural operation.

While most respondents feel that everyone is responsible for water quality, the majority do not seem to feel that their own operation is responsible for water quality issues in local water bodies. Agricultural operators tend to attribute problems to runoff from residential developments. A major challenge will be to raise awareness among all respondents about the specific causes of water impairments, and convincing property owners to accept responsibility for their role in contributing to the impairments.

On the positive side, there are many findings upon which to develop mechanisms for civic engagement, outreach and education. Most respondents understand the linkage between people's actions and water quality, and have some basic knowledge about clean water. Most are generally interested in trying something new to improve water quality, and the various sampling groups express different preferences for ways to learn about and to adopt BMPs. It is likely that people will respond to communications that are positive in tone and content, and that recognize and reward stewardship and water conservation efforts. This study did not explore social networks or peer-to-peer communication, but there is no reason to believe that these strategies would not be successful.

Recommendations

The following recommendations for consideration by ECWMC commissioners and staff are based upon the study data as well as numerous comments provided by the respondents. They are intended to contribute to civic engagement efforts and an educational strategy and content for the ECWMC.

To foster civic engagement the following recommendations are made:

● Begin with the board. The ECWMC commissioners are effectively citizens engaged in and committed to watershed management. Board members and staff are already important civic actors by virtue of being at the table and making critical decisions about financial and natural resources. The general lack of awareness of the ECWMC might be alleviated by sponsoring an ECWMC open house, field days, and other events where board members could participate. Commissioners might consider talking with neighbors and colleagues in the watershed, inviting them to meetings and CAC meetings, and bringing them into the civic engagement process. As ECWMC becomes more active and visible in the TMDL process, it should consider creating opportunities for the public to "meet and greet" board members and staff.

● In light of the relative unfamiliarity of many residents with ECWMC it is suggested that ECWMC consider heightening its visibility and promote a positive image as an environmental resource with a focus on water quality. This may help to assuage distrust of ECWMC as a government entity, and enable the public to view ECWMC as a source of information and assistance.

● Build on the interest expressed by a number of KAP study respondents. Send out a "get involved" message to study respondents inviting them to watershed meetings and sponsored events.

● Communication with watershed residents should be built upon positive messages that reinforces fundamental self-images (doing the right thing), and encourages people to take incremental small steps to protect clean water. Communication that is based upon scolding or negative ("Don't…") messages will likely be tuned out. Moving forward, this should set the tone for future engagement and education. As noted, many respondents commented about wanting to do the right thing, and about their willingness to do something more to help the environment. There are respondents in all sample groups that are ready and willing to adopt new practices.

● Given the undercurrent of distrust in government among some residents, ECWMC should consider partnering with non-governmental entities that are locally popular with horse and livestock owners (for example, saddle clubs, YMCA/YWCA and scout camps, veterinary practices, tack shops, horse riding schools, ag coops). Such organizations could provide a valuable entry point and access to local residents. ECWMC could sponsor recreational events with these organizations, and in the process, enable the public to learn about the watershed.

● Local expertise on civic engagement is available from MPCA and other agencies. In particular, Lynne Kolze (MPCA) has deep knowledge of CE processes and has worked successfully in other rural and urban watersheds. Betsy Wieland (MN UM Extension) is already familiar with livestock and horse owners in the area, representing the agency which is already the most important source of information for watershed communities. It is strongly recommended that both experts be brought in to the CE process.

To foster the adoption and maintenance of clean water practices, the following actions are recommended:

● Respondents expressed a clear need and desire for technical information, training and education, and was respondents' top priority overall. It is strongly recommended that ECWMC consider developing and implementing a comprehensive, targeted education and outreach strategy. This should include multiple learning opportunities to meet the priorities and needs of diverse sub-groups in the watershed that impact local waters. Based upon the experience of other watershed districts and commissions in Minnesota, this is best done by recruiting an experienced staff member. Such watershed educators often work together on various initiatives and partnerships, and may be joined by MN UM Extension staff. However, there is no substitute for a water quality educator that is very familiar with local groups and individual property owners, and who can build trust and productive partnerships. A good education programmer can also complement the civic engagement efforts that are required by the TMDL process.

● Financial incentives and cost-shares may be helpful for some individuals to adopt a BMP. However, financial incentives may not appeal to everyone, especially in affluent communities. A 2011 KAP study of shoreland property owners in northern Minnesota found that most people didn't need or want a financial incentive to adopt a BMP. The audience adopted because they believed that was the right thing to do, and enabled them to act on their stewardship values ethics (often involving children and grandchildren in the process). The most important mechanism to them was direct access to a technical professional who could show them what to do. They needed a site visit by a watershed technician, and/or a hands-on workshop. The "human touch" (also called a "high touch" approach) can be much more important to property owners than a financial incentive, and more effective in fostering clean water actions. These options need not be mutually exclusive.

● Most of the possible mechanisms and incentives appealed to at least some sample sub-groups, but not necessarily to all. Results suggest that the best approach is to offer multiple opportunities to learn about different BMPs. Given the small sample size, and diverse nature of the sub-groups, ECWMC should consider offering small hands-on workshops or other learning opportunities for targeted groups. This will require developing content-specific workshop materials and curricula. Examples are given in Table 30 below.

Table 30: Examples of workshops for targeted sub-groups

Sub group	Content/subjects
Livestock owners (dairy/beef)	"Show me the numbers" (cost-benefit); Manure management planning; Nutrient management planning; Cost-share/incentive information; Reduced tillage; Vegetative buffers; Manure storage; Crop rotation
Field crop producers	Cost-share/incentive information; Nutrient management planning; Cost-share/incentive information; Reduced tillage; Vegetative buffers; Crop rotation
Both livestock and field crops	Manure management planning; Nutrient management planning; Cost-share/incentive information; Reduced tillage; Vegetative buffers; Manure storage; Crop rotation
Horse owners	Cost-share/incentive information; Manure management planning; Vegetative buffers; Manure storage; Managed grazing/exclusion fencing
Horse-related businesses	Manure management planning; Cost-share/incentive information; Vegetative buffers; Manure storage; Managed grazing/exclusion fencing
All respondents and the general public	Field days/trips to local water bodies; Residential stormwater management; Basic watershed planning for citizens;
Municipal officials and staff	NEMO curricula; The Watershed Game; Civic engagement processes and practices

● Finally, evaluation of outcomes is essential to determine whether investments in water quality activities have reaped benefits in this watershed. The ECWMC monitoring program will be able to determine whether impairments have been diminished.

Evaluating the “people” aspects will also be needed, e.g. did people actually become engaged in watershed planning through the CE process, and how will that be measured? Did people actually adopt and maintain recommended practices? Did they acquire new knowledge and awareness of the condition of local water bodies? It is recommended that a repeat (summative) KAP study be conducted in approximately two years (depending on the TMDL/WRAPP implementation schedule) to collect evidence of program outcomes.

Acknowledgements

The author thanks the Elm Creek Watershed Management Commission for funding to carry out this research. Funding originated with Environmental Protection Agency's 319 grant program, administered by the Minnesota Pollution Control Agency. Special thanks to Lynne Kolze at MPCA for continued support for the KAP study and civic engagement work, and to Barb Peichel as the project manager. The author is grateful to Judie Anderson and Rich Brasch of the ECWMC for their involvement in the gap exercise and for support to the KAP process throughout. Marylee Murphy of Three Rivers Park District prepared the survey sample list.

In addition, several local stakeholders and officials took part in the gap exercise that was the basis for this KAP study, and contributed valuable comments that helped to shape the study**. These included Elizabeth Weir, Cindy Patnode, Dan Patnode, Bill Kidder, James Kujawa, Ali Durgunoglu, Betsy Wieland, Rich Brasch and Judie Anderson**

Finally, the participation of sixty individual respondents in taking part in this study is gratefully acknowledged.

References

Eckman, Karlyn. 2013. *Training Modules for Evaluating the Social Outcomes of Water Quality Projects.* Saint Paul: Minnesota Pollution Control Agency.

Wieland, Betsy. Undated. *Medina Livestock Water Quality BMP Survey Highlights*. University of Minnesota UM Extension.

Elm Creek Watershed TMDL Implementation Cost Estimate

Project Element Description	Average Unit Cost Range	Total Cost Range
25,000 feet of stream channel rehabilitation/habitat improvement[3]	$150-$300/ft. of channel	$3.75 - $7.5 million
20 large urban stormwater retro-fit projects[1]	$80,000-$160,000/project	$1.6 - $3.2 million
50 small urban stormwater retro-fit projects[1]	$15,000 - $30,000/project	$750,000 - $1,500,000
20 wetland restoration projects[3]	$40,000 - $80,000/project	$800,000-$1.6 million
10 livestock feedlot/pasture improvement projects[2]	$25,000-$50,000/project	$250,000 - $500,000
50,000 feet of row crop field buffers [2]	$10-$20/foot	$500,000-$1,000,000
300 development reviews for compliance w/ ECWMC standards[1]	$200-$400/review	$60,000-$120,000
Curly leaf pondweed control in lakes (5 lakes/1200 ac. for 7 years)[2]	$200-$300/ac./yr.	$1.68 - $2.52 million
Immobilization of phosphorus release from enriched lake sediments (4 lakes/550 ac.)[2]	$1,500-$2,500/ac.	$825,000 - $1.375 million
50 septic system upgrades[2]	$4,000 - $8,000/system	$200,000 - $400,000
1 NPDES point source compliance (Maple Hills Estates WWTP)[1]	$400,000 - $800,000/system	$400,000-$800,000
Urban/rural-agricultural education efforts (20 years)[3]	$10,000-$20,000/year	$200,000 - $400,00
Sub-total		$10,815,000-$20,550,000
20% contingency		$2,163,000 - $3,810,000
TOTAL		$12,078,000 - $24,660,000

[1] Applies to permitted sources

[2] Applies to non-permitted source

[3] Applies to both permitted and non-permitted sources

Appendix I

Affected MS4s By Impaired Water

Stream/Lake Name (ID #)[1]	Impairment	MS4s with WLAs	MS4 Permit #	Type
Diamond Creek (-525)	*E. coli*	Dayton	MS400083	City
	Biota (TSS)	Dayton	MS400083	City
		Rogers	Not assigned	City
		Hennepin County	MS400138	Non-traditional
		MnDOT Metro District	MS400170	Non-traditional
	Biota (TP)	Dayton	MS400083	City
		Rogers	Not assigned	City
		Hennepin County	MS400138	Non-traditional
Rush Creek, South Fork (-760)	Biota (TP)	Corcoran	MS400081	City
		Medina	MS400105	City
Rush Creek, South Fork (-732)	*E. coli* and Biota (TP)	Corcoran	MS400081	City
		Maple Grove	MS400102	City
		Medina	MS400105	City
		Hennepin County	MS400138	Non-traditional
Rush Creek, Mainstem (-528)	*E. coli*	Corcoran	MS400081	City
		Dayton	MS400083	City
		Maple Grove	MS400102	City
		Rogers	Not assigned	City
		Hennepin County	MS400138	Non-traditional
	Biota (TP)	Corcoran	MS400081	City
		Dayton	MS400083	City
		Maple Grove	MS400102	City
		Medina	MS400105	City
		Rogers	Not assigned	City
		Hennepin County	MS400138	Non-traditional
		MnDOT Metro District	MS400170	Non-traditional
Elm Creek (-508)	E. coli	Corcoran	MS400081	City
		Champlin	MS400008	City
		Dayton	MS400083	City
		Maple Grove	MS400102	City
		Medina	MS400105	City
		Plymouth	MS400112	City
		Hennepin County	MS400138	Non-traditional
		MnDOT Metro District	MS400170	Non-traditional

	Biota (TSS)	Champlin	MS400008	City
		Corcoran	MS400081	City
		Dayton	MS400083	City
		Maple Grove	MS400102	City
		Medina	MS400105	City
		Plymouth	MS400112	City
		Hennepin County	MS400138	Non-traditional
		MnDOT Metro District	MS400170	Non-traditional
	Biota (TP)	Champlin	MS400008	City
		Corcoran	MS400081	City
		Dayton	MS400083	City
		Maple Grove	MS400102	City
		Medina	MS400105	City
		Rogers	Not assigned	City
		Hennepin County	MS400138	Non-traditional
		MnDOT Metro District	MS400170	Non-traditional
Fish Lake (ID # 27-0118)	Nutrients	None	N/A	N/A
Rice Lake (ID # 27-0116-01)	Nutrients	Corcoran	MS400081	City
		Maple Grove	MS400102	City
		Medina	MS400105	City
		Plymouth	MS400112	City
		Hennepin County	MS400138	Non-traditional
		MnDOT Metro District	MS400170	Non-traditional
Diamond Lake (ID # 27-0125)	Nutrients	Dayton	MS400083	City
		Rogers	Not assigned	City
		Hennepin County	MS400138	Non-traditional
		MnDOT Metro District	MS400170	Non-traditional
Goose Lake (ID # 27-0122)	Nutrients	Champlin	MS400008	City
		Dayton	MS400083	City
		Hennepin County	MS400138	Non-traditional
		MnDOT Metro District	MS400170	Non-traditional
Cowley Lake (ID # 27-0169)	Nutrients	Rogers	Not assigned	City
		Hennepin County	MS400138	Non-traditional
Sylvan Lake (ID # 27-0171)	Nutrients	Rogers	Not assigned	City
Henry Lake (ID # 27-0175)	Nutrients	None	N/A	N/A

[1] 8-digit HUC for all AUID stream reaches is 07010206