Sunrise River Watershed

Total Maximum Daily Load Study

2013

Chisago Soil & Water Conservation District
Emmons & Olivier Resources, Inc.

wq-iw6-06e

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<tr><td>Second Lake
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(13-0030-00)</td><td>2B, 3C</td><td>2012</td><td>2019/2023</td></tr>
<tr><td>White Stone Lake
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<tr><th>Standard</th><th>Units</th><th>Notes</th></tr>
<tr><td>E. coli</td><td>126 orgs per 100 ml</td><td>Geometric mean of ≥ 5 samples per month (April – October)</td></tr>
<tr><td>E. coli</td><td>1,260 orgs per 100 ml</td><td>< 10% of all samples per month (April – October) that individually exceed</td></tr>
</table>
Total phosphorus was identified as the stressor for the aquatic life impairment, with an in-stream concentration goal of 100 µg TP/L.

Lake Eutrophication Standards, MN Rule 7050.0222, Subpart 4, Northern Central Hardwood Forests Ecoregion
<table>
<tr><th>Lake Type</th><th>TP (ppb)</th><th>Chl-a (ppb)</th><th>Secchi (m)</th></tr>
<tr><td>NCHF – Aquatic Recreation – General
Including: Linwood Lake</td><td><40</td><td><14</td><td>>1.4</td></tr>
<tr><td>NCHF – Aquatic Recreation – Shallow Lakes
Including: Second, Vibo, and White Stone Lakes</td><td><60</td><td><20</td><td>>1.0</td></tr>
</table>
</td><td>16-17</td></tr>
</table>

Loading Capacity (expressed as daily load)		
Loading Capacity (expressed as daily load)	see table below	49, 66

Waterbody Name (AUID or Lake ID)	Loading Capacity				
	High	Wet	Mid	Dry	Low
Phosphorus	**(lb/day)**				
Sunrise River, West Branch (07030005-529)	76.0	33.2	18.4	10.7	6.82
Linwood Lake (02-0026-00)	3.979				
Second Lake (13-0025-00)	0.334				
Vibo Lake (13-0030-00)	2.270				
White Stone Lake (13-0048-00)	0.167				
E. coli	**(Billion organisms/day)**				
Sunrise River (07030005-543)	1551.1	678.2	375.0	218.9	139.1
Hay Creek (07030005-545)	62.0	27.1	15.0	8.75	5.56

Wasteload Allocation		
Wasteload Allocation	see table below	54, 68

Source (Permit #)	Waterbody Name (AUID or Lake ID)	Wasteload Allocation				
		High	Wet	Mid	Dry	Low
Phosphorus		**(lb/day)**				
City of E Bethel (MS400087)	**Linwood Lake** (02-0026-00)	0.058				
Industrial Stormwater (MNR50000)	**Linwood Lake** (02-0026-00)	0.010				
	Second Lake (13-0025-00)	0.0002				
	Vibo Lake (13-0030-00)	0.001				
	White Stone Lake (13-0048-00)	0.0001				
	Sunrise River, West Branch (07030005-529)	4.10	1.79	0.99	0.58	0.37
Construction Stormwater (MNR100001)	**Linwood Lake** (02-0026-00)	0.010				
	Second Lake (13-0025-00)	0.0002				
	Vibo Lake (13-0030-00)	0.001				
	White Stone Lake (13-0048-00)	0.0001				
	Sunrise River, West Branch (07030005-529)	4.10	1.79	0.99	0.58	0.37
E. coli		**(Billion organisms/day)**				
City of N Branch (MS400260)	**Hay Creek** (07030005-545)	1.40	0.61	0.34	0.20	0.13
Chisago Lakes Joint STC (MN0055808)	**Sunrise River** (07030005-543)	11.7				

<table>
<tr>
<td>Load Allocation</td>
<td>The load allocation is based on the following sources of phosphorous and E. coli that do not require NPDES coverage, as applicable to each waterbody:

Watershed runoff
Loading from upstream waters
Atmospheric deposition
Subsurface sewage treatment systems (SSTS)
Groundwater
Internal Loading

<table>
<tr><th rowspan="2">Waterbody Name
(AUID or Lake ID)</th><th colspan="5">Load Allocation</th></tr>
<tr><th>High</th><th>Wet</th><th>Mid</th><th>Dry</th><th>Low</th></tr>
<tr><td>Phosphorus</td><td colspan="5">(lb/day)</td></tr>
<tr><td>Sunrise River, West Branch
(07030005-529)</td><td>60.2</td><td>26.3</td><td>14.6</td><td>8.47</td><td>5.40</td></tr>
<tr><td>Linwood Lake
(02-0026-00)</td><td colspan="5">3.503</td></tr>
<tr><td>Second Lake
(13-0025-00)</td><td colspan="5">0.301</td></tr>
<tr><td>Vibo Lake
(13-0030-00)</td><td colspan="5">2.041</td></tr>
<tr><td>White Stone Lake
(13-0048-00)</td><td colspan="5">0.150</td></tr>
<tr><td>E. coli</td><td colspan="5">(Billion organisms/day)</td></tr>
<tr><td>Sunrise River
(07030005-543)</td><td>1384.3</td><td>598.7</td><td>325.8</td><td>185.3</td><td>113.5</td></tr>
<tr><td>Hay Creek
(07030005-545)</td><td>54.4</td><td>23.8</td><td>13.2</td><td>7.67</td><td>4.87</td></tr>
</table>
</td>
<td>54, 68</td>
</tr>
<tr>
<td>Margin of Safety</td>
<td><u>Lakes</u>: A 10% explicit margin of safety (MOS) was accounted for in the TMDL for each lake. This MOS is sufficient to account for uncertainties in predicting loads to the lake and predicting how the lake responds to changes in phosphorus loading.

<u>Streams</u>: An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

Since the TMDL is developed for each of five flow regimes, most of the uncertainty in flow is a result of extrapolating (area-weighting) flows from the hydrologically-nearest stream gage. The explicit MOS, in part, accounts for this.
Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.
With respect to the E. coli TMDLs, the load duration analysis does not address bacteria re-growth in sediments, die-off, and natural background levels. The MOS helps to account for the variability associated with these conditions.

</td>
<td>58, 72</td>
</tr>
</table>

Seasonal Variation	**<u>Lakes</u>**: Critical conditions in the impaired lakes and stream occur during the growing season, which is when they are used for aquatic recreation. Similar to the manner in which the standards take into account seasonal variation, since the TMDL is based on growing season averages, the critical condition is covered by the TMDL. **<u>Streams</u>**: Critical conditions and seasonal variation are addressed in this TMDL through several mechanisms. The *E. coli* standard applies during the recreational period, and data was collected throughout this period. The water quality analysis conducted on these data evaluated variability in flow through the use of five flow regimes: from high flows, such as flood events, to low flows, such as baseflow. Through the use of load duration curves and monthly summary figures, *E. coli* loading was evaluated at actual flow conditions at the time of sampling (and by month), and monthly *E. coli* concentrations were evaluated against precipitation and streamflow.	58, 72
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EXECUTIVE SUMMARY

The Clean Water Act (1972) requires that each State develop a plan to identify and restore any waterbody that is deemed impaired by state regulations. A Total Maximum Daily Load Study (TMDL) is required by the Environmental Protection Agency (EPA) as a result of the federal Clean Water Act. A TMDL identifies the pollutant that is causing the impairment and how much of that pollutant can enter the water body and still meet water quality standards.

Four lakes within the Sunrise River Watershed are currently on the EPA's 303(d) Impaired Waters List for Excess Nutrients: Linwood, Second, Vibo, and White Stone (see Table 1 for impairment listing). Three stream reaches will also be addressed: the West Branch of the Sunrise River (Aquatic Life – Fish and Macroinvertebrate Bioassessments and Turbidity), Lower Sunrise River (Aquatic Recreation – E. coli), and Hay Creek (Aquatic Recreation – E. coli). This TMDL report will only address impairments that are not addressed in another nested TMDL report (for example: Chisago Lakes Chain of Lakes Watershed TMDL, Comfort Lake Forest Lake Impaired Lakes TMDL, North Branch of the Sunrise River Fecal Coliform TMDL, and Martin and Typo Lakes TMDL).

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

- All available in-lake water quality data over the past ten years
- Sediment phosphorus concentrations
- Fisheries surveys
- Plant surveys
- Water chemistry data from streams
- All available stream flow data

The following phosphorus sources were evaluated for each lake: watershed runoff, feedlots, subsurface sewage treatment systems (SSTS), loading from upstream lakes, atmospheric deposition, and internal loading. An inventory of phosphorus sources was then used to develop a lake response model for each lake and these models were used to determine the phosphorus reductions needed for the lakes to meet water quality standards. A summary of the necessary reductions is below.

Lake	Loading Capacity (TMDL) (lb/day)	Wasteload Allocation (lb/day)	Load Allocation (lb/day)	Margin of Safety (lb/day)	Reduction Needed (lb/yr)	Reduction Needed (%)
Linwood	3.98	0.078	3.50	0.398	341.3	21%
Second	0.334	0.0004	0.301	0.0334	72.0	40%
Vibo	2.27	0.002	2.04	0.227	9,718	93%
White Stone	0.167	0.0002	0.150	0.0167	80.0	59%

The West Branch of the Sunrise River is currently impaired for Fish and Macroinvertebrate Bioassessments and Turbidity. These impairments are all due to the high amounts of phosphorus in the water, based on the MPCA stressor identification work that is currently being completed. To meet the TMDL, the total load to the Sunrise River West Branch from the direct drainage area (downstream of Martin Lake) needs to be reduced by 12-18% under mid-range to dry flow conditions. In addition, the total load from the upstream contributing drainage area (i.e., Martin Lake) also needs to be reduced by 2,973 lb/yr (41%) to meet water quality goals. A TMDL for Excess Nutrients was completed for Martin Lake in 2011

Both Hay Creek and the Lower Sunrise River are impaired for E. coli bacteria. E. coli bacteria in the water column can be traced to a variety of sources including: wildlife, livestock, humans, septic system discharges, and land application of septage. To meet the TMDL for Hay Creek, E. coli needs to be reduced 44% in wet conditions, 67% in mid flow conditions, 87% in dry conditions, and 67% in low flow conditions. To meet the TMDL for the Lower Sunrise River from the direct drainage area (downstream of the North Branch of the Sunrise River and Carlos Avery Pools), E. coli needs to be reduced by 19% in wet conditions and 38% during dry conditions. A TMDL for Fecal Coliform was completed for the North Branch of the Sunrise River in 2006.

The implementation approach will include education and outreach, technical assistance, and partnerships with landowners, cities, landowners, lake and river associations, and watershed groups. After the completion of the Sunrise River Watershed TMDL Study a Watershed Restoration and Protection Strategy (WRAPS) will be completed.

1 PROJECT OVERVIEW

1.1 Purpose

This Total Maximum Daily Load (TMDL) study addresses excess nutrients (phosphorus) and *E. coli* impairments in several lakes and streams in the Sunrise River watershed. The goal of this TMDL is to provide wasteload allocations (WLAs) and load allocations (LAs) and quantify the pollutant reductions needed to meet the state water quality standards. These TMDLs are being established in accordance with section 303(d) of the Clean Water Act, because the State of Minnesota has determined that these lakes exceed the state established standards.

1.2 Identification of Waterbodies

The Sunrise River Watershed TMDL is somewhat unique in that the waterbodies to be addressed by this study (see Table 1) are four lake impairments and three stream impairments within the Sunrise River Watershed (*HUC 0703000504*) that have NOT previously been included in other TMDL studies (Typo Lake and Martin Lake TMDL, Chisago Lakes Chain of Lakes Watershed TMDL, Comfort Lake-Forest Lake Watershed District Six Lakes TMDL, or the North Branch of the Sunrise River Fecal Coliform TMDL). There are other impaired waterbodies in the watershed that did not warrant a TMDL due to work completed through a stressor identification process conducted by the Minnesota Pollution Control Agency (MPCA). Actions to address these impairments will be included in the Watershed Restoration and Protection Strategies report. These waterbodies were found to have non-load based stressors (e.g., habitat) or will be addressed through NPDES permit updates. Refer to the Lower St. Croix River Watershed Biotic Stressor Identification for further details. The waterbodies listed in Table 1 are all currently on the 2012 EPA 303(d) Impaired Waters List.

Table 1. Sunrise River watershed impairments addressed by this report

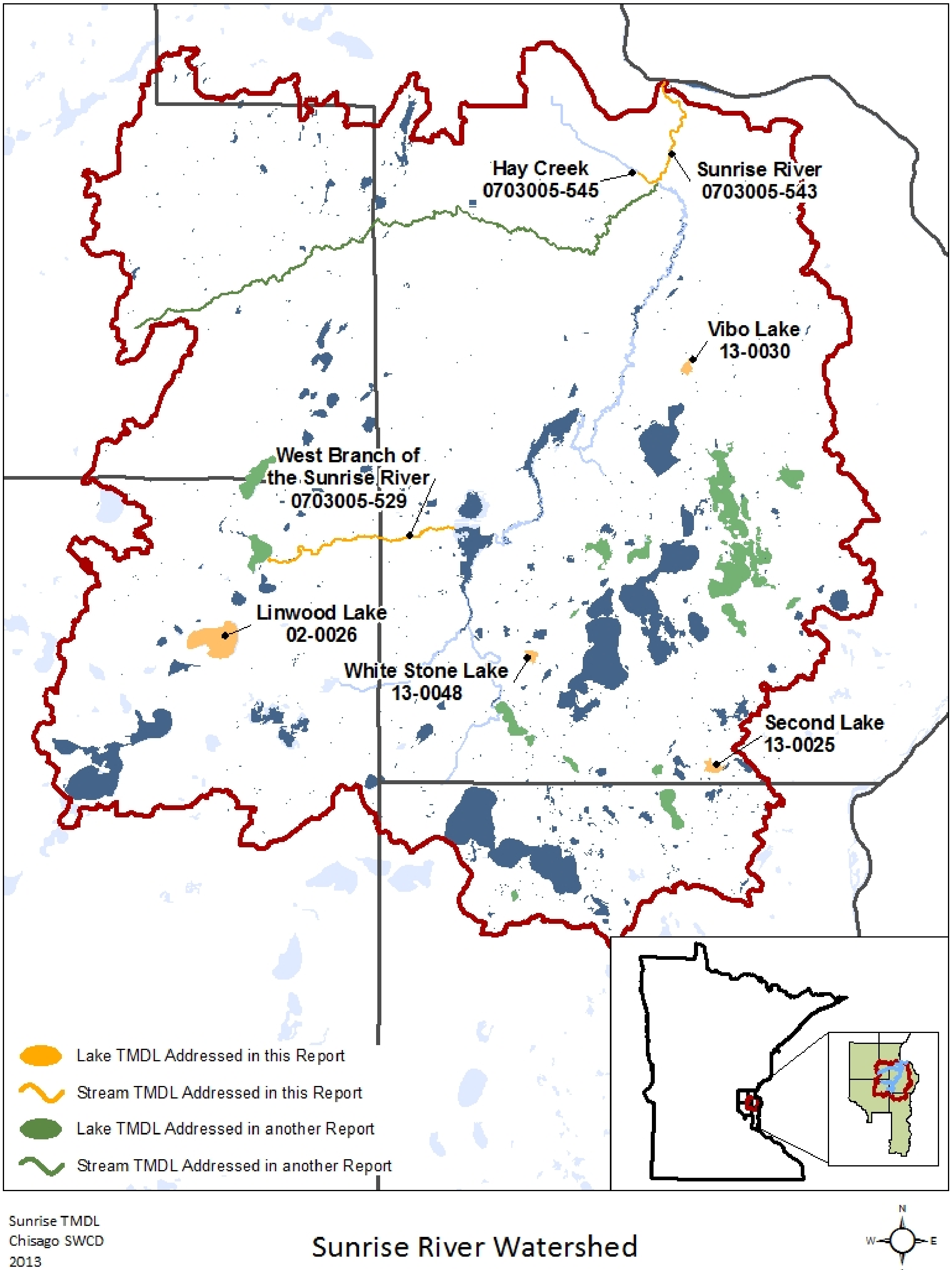
Waterbody Name (AUID or Lake ID)	Reach Description	Designated Use Class	Listing Year	TMDL Completion	Affected Use: Pollutant/Stressor
Sunrise River, West Branch (07030005-529)	Martin L to Sunrise R (Pool 1)	1B, 2Bd, 3C	2012 2004 2008	2009/2014 2010/2015 2010/2015	*Aquatic Life:* - Macroinvertebrate Bioassessments - Fish Bioassessments - Turbidity
Sunrise River (07030005-543)	North Branch Sunrise R to St Croix R	2B, 3C	2012	2009/2014	*Aquatic Recreation:* - *Escherichia Coli*
Hay Creek (07030005-545)	CD 3 (Beaver Cr) to Sunrise R	1B, 2A, 3B	2008	2009/2013	
Linwood Lake (02-0026-00)	NA (lake)	2B, 3C	2010	2010/2015	*Aquatic Recreation*: - Nutrient/ Eutrophication Biological Indicators
Second Lake (13-0025-00)	NA (lake)	2B, 3C	2012	2019/2023	
Vibo Lake (13-0030-00)	NA (lake)	2B, 3C	2012	2019/2023	
White Stone Lake (13-0048-00)	NA (lake)	2B, 3C	2012	2019/2023	

1.3 Priority Ranking

MPCA's projected schedule for TMDL completions (Table 1), as indicated on the 2012 EPA 303(d) list of impaired waters, implicitly reflects Minnesota's priority ranking of 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 with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

The project area is part of the Lower St. Croix River Watershed. The MPCA intensive monitoring of this watershed began in 2009. Refer to the following website for more details: http://www.pca.state.mn.us/index.php?option=com_k2&layout=item&view=item&Itemid=2893&id=2788

Figure 1. Impaired waters in the Sunrise River Watershed addressed by this TMDL report



2 APPLICABLE WATER QUALITY STANDARDS

Each stream reach and lake has a Designated Use Classification defined by the MPCA which defines the optimal purpose for that waterbody (see Table 1). Class 2 waters are protected for aquatic life and aquatic recreation by Minnesota Rules Chapter 7050.0140. The West Branch of the Sunrise River and Hay Creek are also protected for aquatic consumption under Class 1B. However, water bodies are not currently being assessed by the MPCA for the beneficial use of domestic consumption; therefore standards for the Class 1B waters are not presented here.

2.1 Stream Standards

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

Through the stressor identification process, MPCA has identified stream eutrophication/algal-turbidity due to excess phosphorus as the primary cause of impaired aquatic life in the West Branch of the Sunrise River (Lower St. Croix River Watershed Biotic Stressor Identification). Stream eutrophication standards are under development based on several studies and data collection efforts that have demonstrated significant and predictable relationships among summer nutrients, sestonic chlorophyll-a, and biochemical oxygen demand in several medium to large Minnesota rivers (Heiskary & Markus 2001, 2003). Consistent with EPA guidance, criteria are being developed for three "River Nutrient Regions (RNR)". The draft phosphorus standard for Central Region streams is 0.1 mg/L as a growing season (June-September) mean (for more information, refer to the draft *Minnesota Nutrient Criteria Development for Rivers* report online: http://www.pca.state.mn.us/index.php?option=com_k2&Itemid=131&id=3312&layout=item&view=item#draft-water-quality-standards-technical-support-documents) – which will be used as the water quality target for the West Branch of the Sunrise River Biota TMDL.

Numeric water quality standards have also been developed for bacteria (Minnesota Rule 7050.0222), in this case Escherichia coli (*E. coli*), which are protective concentrations for short- and long-term exposure to this pollutant in water. The past fecal coliform and current *E. coli* numeric water quality standards for Class 2 waters are shown in Table 2. *E. coli* and fecal coliform are fecal bacteria used as indicators for waterborne pathogens that have the potential to cause human illness. Although most are harmless themselves, fecal indicator bacteria are used as an easy-to-measure surrogate to evaluate the suitability of recreational and drinking waters, specifically, the presence of pathogens and probability of illness. Pathogenic bacteria, viruses, and protozoa pose a health risk to humans, potentially causing illnesses with gastrointestinal symptoms (nausea, vomiting, fever, headache, and diarrhea), skin irritations, or other symptoms. Pathogen types and quantities vary among fecal sources; therefore, human health risk varies based on the source of fecal contamination.

This Total Maximum Daily Load (TMDL) study and protection plan will use the standard for *E. coli*. The change in the water quality standard from fecal coliform to *E. coli* is supported by an EPA guidance document on bacteriological criteria (USEPA 1986). As of March 17, 2008, Minnesota Rules Chapter 7050 water quality standards for *E. coli* are:

> *Escherichia (E.) coli - Not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31.*

Although surface water quality standards are now based on *E. coli*, wastewater treatment facilities are permitted based on fecal coliform (not *E. coli*) concentrations.

Geometric mean is used in place of arithmetic mean in order to measure the central tendency of the data, dampening the effect that very high or very low values have on arithmetic means. The MPCA's *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* provides details regarding how waters are assessed for conformance to the *E. coli* standard (MPCA 2012a).

Table 2. Past and current numeric water quality standards of bacteria (fecal coliform and *E. coli*) for the beneficial use of aquatic recreation (primary and secondary body contact).

Past Standard	Units	Current Standard	Units	Notes
Fecal coliform	200 orgs per 100 ml	*E. coli*	126 orgs per 100 ml	Geometric mean of ≥5 samples per month (April - October)
Fecal coliform	2,000 orgs per 100 ml	*E. coli*	1,260 orgs per 100 ml	<10% of all samples per month (April - October) that individually exceed

2.2 Lake Standards

Lake eutrophication standards (Minnesota Rule 7050.0222, subp 4) were developed for each state ecoregion by the MPCA from an evaluation of a large cross-section of lakes (Heiskary and Wilson 2005). Clear relationships were established between the causal factor total phosphorus and the response variables chlorophyll-a (a pigment found in algal cells) and Secchi transparency. Regression equations developed by the MPCA (2005) suggest that the two response variables, Secchi depth and chlorophyll-a, should also meet state standards when the necessary phosphorus reductions are made. Total phosphorus is often the limiting factor controlling primary production in freshwater lakes: as in-lake phosphorus concentrations increase, algal growth increases resulting in higher chlorophyll-a concentrations and lower water transparency. The impaired lakes within the Sunrise River Watershed are located within the Northern Central Hardwood Forests Ecoregion. The applicable water quality standards are listed in Table 3.

To be listed as impaired (Minnesota Rule 7050.0150 subp 5), the summer growing season (June-September) monitoring data must show that the standards for both total phosphorus (the causal factor) and either chlorophyll-a or Secchi transparency (the response variables) were violated. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if it will be listed as impaired. For more details regarding the listing process, see the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* (MPCA 2012a).

Table 3. Lake Eutrophication Standards for Northern Central Hardwood Forest (NCHF) Ecoregion

Lake Type	TP (ppb)	Chl-a (ppb)	Secchi (m)
General Including: Linwood Lake	< 40	< 14	> 1.4
Shallow Lakes Including: Second, Vibo, and White Stone Lakes	< 60	< 20	> 1.0

3 WATERSHED DESCRIPTION

The Sunrise River Watershed is approximately 388 square miles and is located in parts of four counties (Anoka, Chisago, Isanti, and Washington) with the largest area in Chisago County. The area includes eight incorporated cities (North Branch, Stacy, Wyoming, Forest Lake, East Bethel, Chisago City, Lindstrom, and Center City) and covers portions of nineteen townships. The northern branch of the river is designated as the North Branch, which begins in Isanti County and flows east to its confluence with the main branch in Sunrise Township. The West Branch of the Sunrise River begins in Anoka County and flows east to the confluence with the main stem in Stacy, MN. The headwater of the main branch of the Sunrise River is located in northern Washington County. The main branch flows north and east to its confluence with the St. Croix River at Sunrise Township.

The Sunrise River Watershed is a high priority subwatershed of the St. Croix River. The waters within the Sunrise River Watershed boundary outlet to the St. Croix River near the town of Sunrise in Wild River State Park. This project will not only address the impairments within the Sunrise River Watershed, but will also aid in understanding the phosphorus loading to Lake St. Croix. Lake St. Croix was listed on the 2008 303(d) Impaired Waters List for excess phosphorus. The Sunrise River was identified as one of the greatest contributors of phosphorus and sediment to the St. Croix River (U.S. Geological Survey, 1999) and was allocated a 33% reduction in phosphorus loading by the Lake St. Croix Total Maximum Daily Load Study.

3.1 Lakes

The physical characteristics of the impaired lakes are listed in Table 4. Lake surface areas were digitized from 2010 aerial photography; lake volumes, mean depths, and littoral areas (< 15 feet) were calculated using MN DNR 1992 depth contours (Linwood) or bathymetric data collected in 2012 (Second, Vibo, White Stone) and 2010 digitized surface areas; maximum depths were reported from the MN DNR Lake Finder website (Linwood) or 2012 field measurements (Second, Vibo, White Stone); and watershed areas were delineated from SWAT subbasins (Almendinger and Ulrich 2010b) and 2 foot elevation contours.

Table 4. Impaired lake physical characteristics

Parameter	Linwood Lake	Second Lake	Vibo Lake	White Stone Lake
Surface area (ac)	569	85	57	49
Littoral area (% total area)	85%	100%	100%	100%
Volume (ac-ft)	5,252	446	265	244
Mean depth (feet)	9.2	5.3	4.6	5.0
Maximum depth (feet)	42	11	12	8
Watershed area (ac)	7,366	605	7,733	268
Watershed area: surface area	13:1	7:1	136:1	5.5:1

3.2 Streams

The physical characteristics of the impaired streams are listed in Table 5. Watershed and direct drainage areas were delineated from SWAT subbasins (Almendinger and Ulrich 2010b) and 2 foot elevation contours.

Table 5. Impaired stream physical characteristics

Parameter	Sunrise River (07030005-543)	Hay Creek (07030005-545)	Sunrise River, West Branch (07030005-529)
Entire watershed area (ac)	248,951	8,929	33,694
Direct drainage area (ac)	46,209	8,928	8,851

3.3 Subwatersheds

Several other impaired lakes and streams are located upstream of the impaired waters addressed in this study: the North Branch of the Sunrise River, the Chisago Lakes Chain of Lakes, and Comfort Lake (upstream of the Sunrise River from the North Branch to the St. Croix River, and Hay Creek) and Martin Lake (upstream of the West Branch of the Sunrise River). LA and WLA have already been assigned for the watersheds of these upstream impaired waters in previous TMDL studies. These upstream areas were included in the watersheds of the impaired waters addressed in this study for the determination of the existing load and loading capacity (TMDL), but were excluded from the watersheds of the impaired waters addressed in this study for the determination of:

- Pollutant sources,
- Modified existing load,
- Estimated load reductions,
- WLAs, and
- Unallocated LAs;

In addition, the watershed area upstream of Carlos Avery Pool 3 was also excluded from the watershed of the Sunrise River from the North Branch to the St. Croix River (07030005-543) because *E. coli* is not readily transported through lake and reservoir systems and therefore the watershed area located upstream of Pool 3 is not expected to contribute to downstream *E. coli* impairments. For the purposes of this TMDL, the water quality at the Pool 3 outlet will be considered background conditions. Figure 2 identifies the subwatersheds or direct drainage areas to each of the impaired stream systems.

Figure 2. Direct drainage areas to impaired lakes

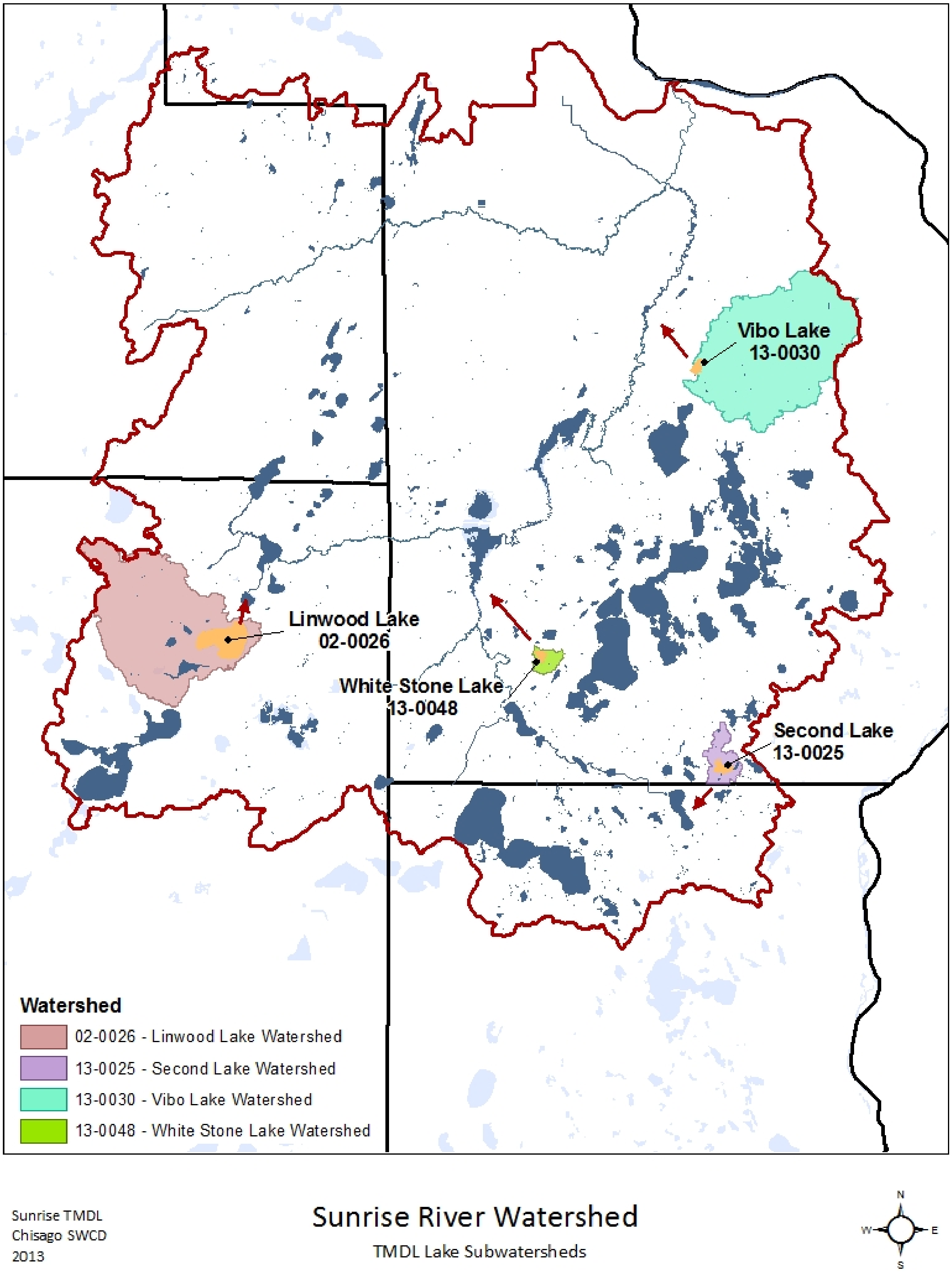
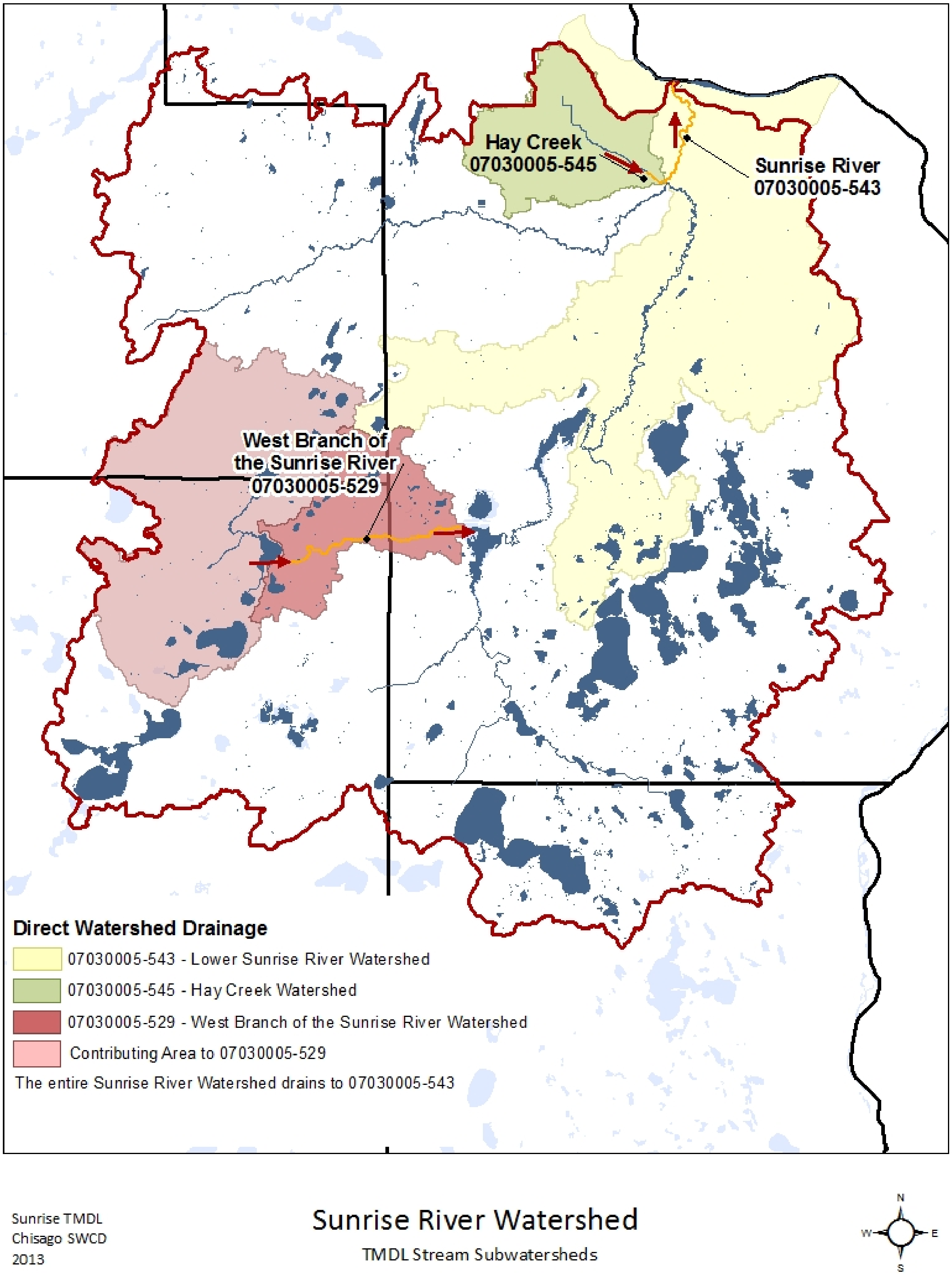


Figure 3. Direct drainage and upstream contributing areas to impaired streams



3.4 Land Cover

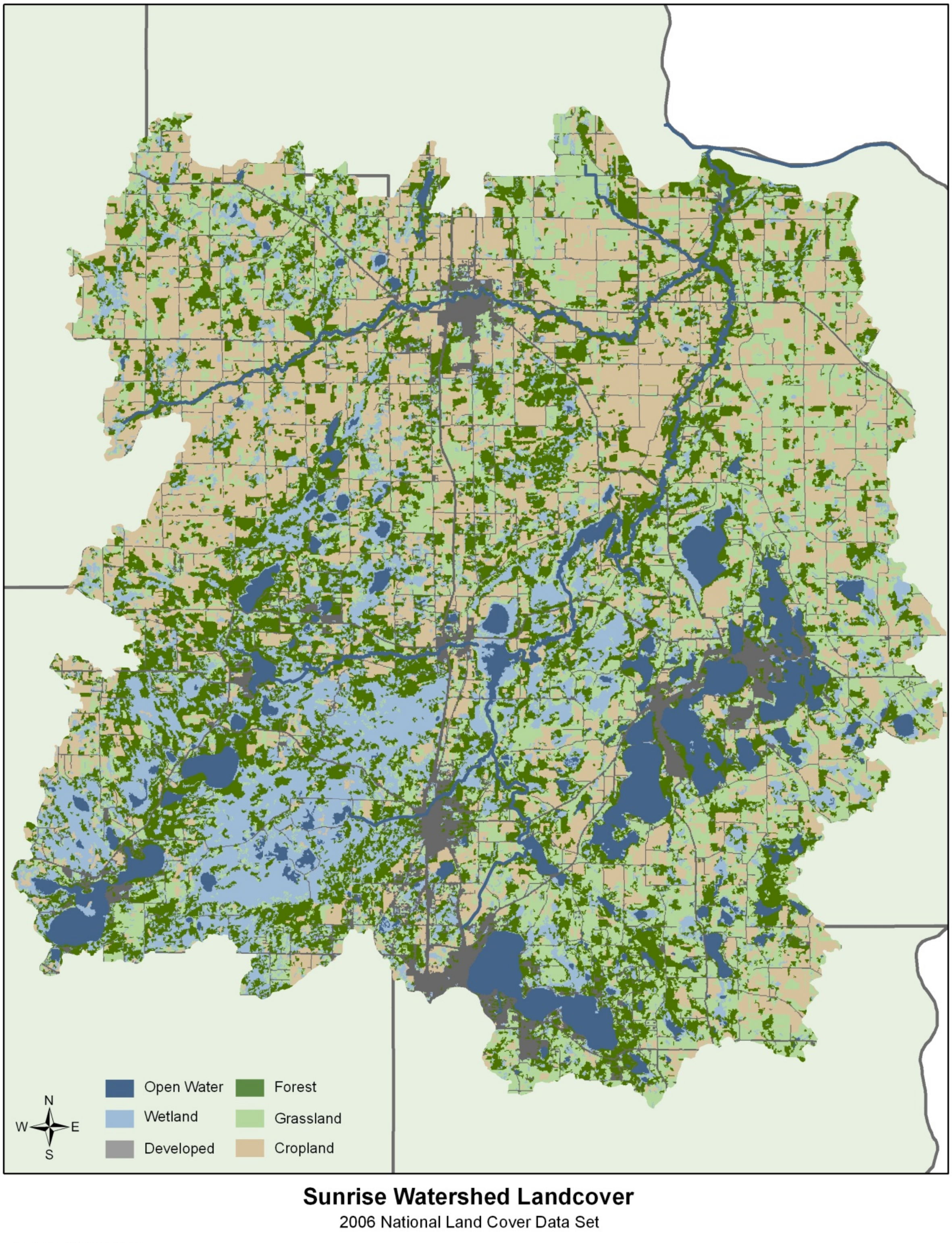
Land cover data for the entire Sunrise River Watershed was simplified from the 2006 National Land Cover Dataset from the United States Geological Survey (USGS). This information is necessary to draw conclusions about pollutant sources and best management practices that may be applicable within each subwatershed. The land cover distribution within impaired lake and stream watersheds is listed in Table 6. This data was simplified to reduce the overall number of categories. Forest includes: evergreen forests, deciduous forests, and mixed forests. Developed includes: developed open space, and low, medium and high density developed areas. Grassland includes: native grass stands, alfalfa, clover, long term hay, and pasture. Cropland includes: all annually planted row crops (corn, soybeans, wheat, oats, barley, etc.), and fallow crop fields. Wetland includes: wetlands, and marshes. Open water includes: all lakes and rivers.

Table 6. Land cover distribution within impaired lake and stream watersheds

Waterbody Name (AUID or Lake ID)	Forest	Developed	Grassland	Cropland	Wetland	Open Water	Total Area
	Acres (% total area)						
Sunrise River, West Branch (07030005-529)	4,179 (47%)	817 (9.2%)	964 (11%)	551 (6.2%)	1,901 (21%)	439 (5.0%)	8,851
Sunrise River (07030005-543)	4,019 (26%)	736 (4.7%)	5,983 (38%)	4,389 (28%)	474 (3.0%)	51 (0.3%)	15,653[1]
Hay Creek (07030005-545)	1,727 (19%)	397 (4.0%)	3,275 (37%)	3,229 (36%)	300 (3%)	0 (0%)	8,928
Linwood Lake (02-0026-00)	2,390 (32%)	323 (4%)	812 (11%)	1,115 (15%)	1,969 (27%)	757 (10%)	7,366
Second Lake (13-0025-00)	282 (47%)	8 (1%)	169 (28%)	22 (4%)	41 (7%)	84 (14%)	605
Vibo Lake (13-0030-00)	867 (11%)	383 (5%)	3,420 (44%)	2,845 (37%)	181 (2%)	37 (<1%)	7,733
White Stone Lake (13-0048-00)	72 (27%)	24 (9%)	68 (25%)	38 (14%)	21 (8%)	45 (17%)	268

[1] This calculation includes only the most downstream portion of the Sunrise River Watershed.

Figure 4. Land Cover of the Sunrise River Watershed



3.5 Historic Water Quality Conditions

3.5.1 Lakes

Lake conditions were summarized for each lake based on available in-lake water quality, fisheries, and macrophyte data. The existing in-lake water quality conditions were quantified using data downloaded from the MPCA EQuIS database in April 2012. Ten year growing season (June-September) means were calculated for total phosphorus, chlorophyll-*a*, and Secchi depth for the most recent ten-year (2002-2011) time period. This corresponds to the time period that the MPCA used to assess these lakes for nutrient impairments in the 2012 assessment cycle (MPCA, 2012a). Information on the species and abundance of macrophyte and fish present within the lakes was compiled from MN DNR fisheries surveys and information from volunteer lake monitors. Historic and recent (2002-2011) water quality trends and macrophyte and fish communities are summarized in the individual lake summary appendices included at the end of this report. The 10-year growing season mean TP, Chl-*a*, and Secchi for each impaired lake is listed in Table 7.

Table 7. 10-year growing season mean TP, Chl-*a*, and Secchi, 2002-2011

Lake Name	10-year Growing Season Mean (June – September)					
	TP		Chl-*a*		Secchi	
	(µg/L)	CV	(µg/L)	CV	(m)	CV
NCHF – General Standard	**< 40**	**--**	**< 14**	**--**	**> 1.4**	**--**
Linwood Lake	44	5%	27	5%	0.90	3%
NCHF – Shallow Lakes Standard	**< 60**	**--**	**< 20**	**--**	**> 1.0**	**--**
Second Lake	77	7%	30	13%	0.64	12%
Vibo Lake	516	8%	91	19%	0.36	9%
White Stone Lake	97	8%	75	20%	0.62	12%

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

3.5.2 Streams

The existing in-stream water quality conditions were quantified using data downloaded from the MPCA EQuIS database in April 2012. Ten year growing season means were calculated for total phosphorus and *E. coli* from the most recent ten-year (2002-2011) time period. This corresponds to the time period that the MPCA used to assess these streams for impairments in the 2012 assessment cycle (MPCA, 2012a). In-stream phosphorus concentrations in the Sunrise River West Branch exceeded the draft water quality standard in all years (Figure 7). In-stream *E. coli* concentrations exceeded the water quality standard during the growing season in the Sunrise River from the North Branch to the St. Croix River (Figure 5) and Hay Creek (Figure 6).

Figure 5. ***E. coli*** **geometric mean and standard deviation by month, Lower Sunrise 07030005-543 (2006-2010)**

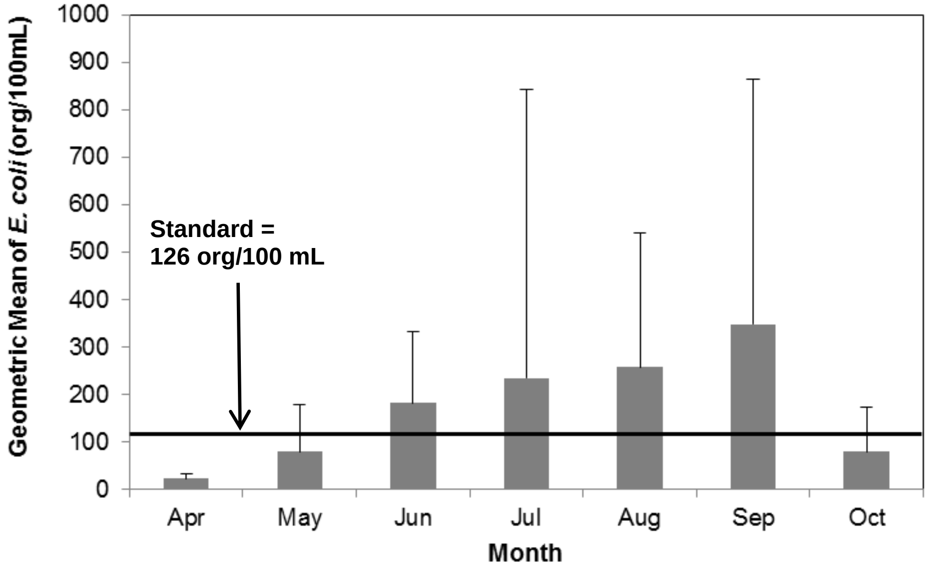


Figure 6. ***E. coli*** **geometric mean and standard deviation by month, Hay Creek 07030005-545 (2009-2010)**

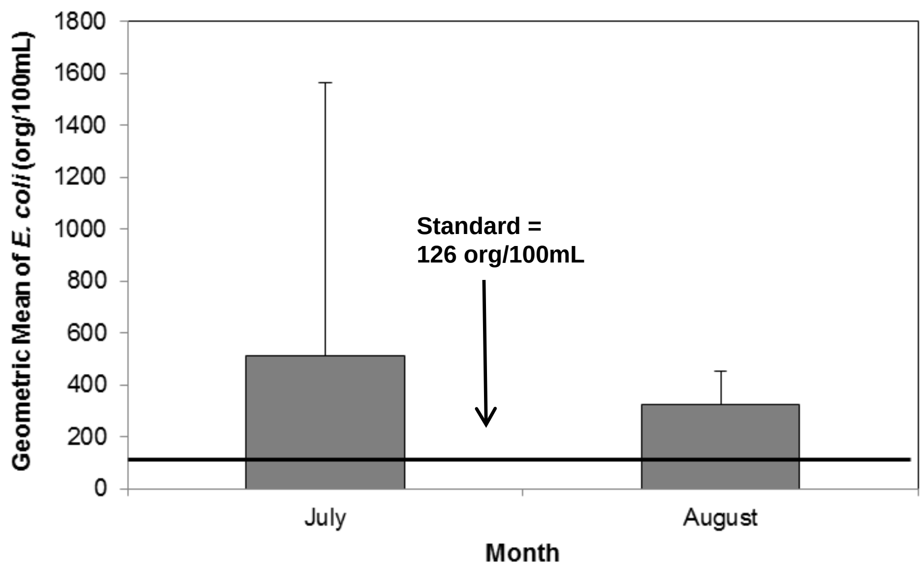
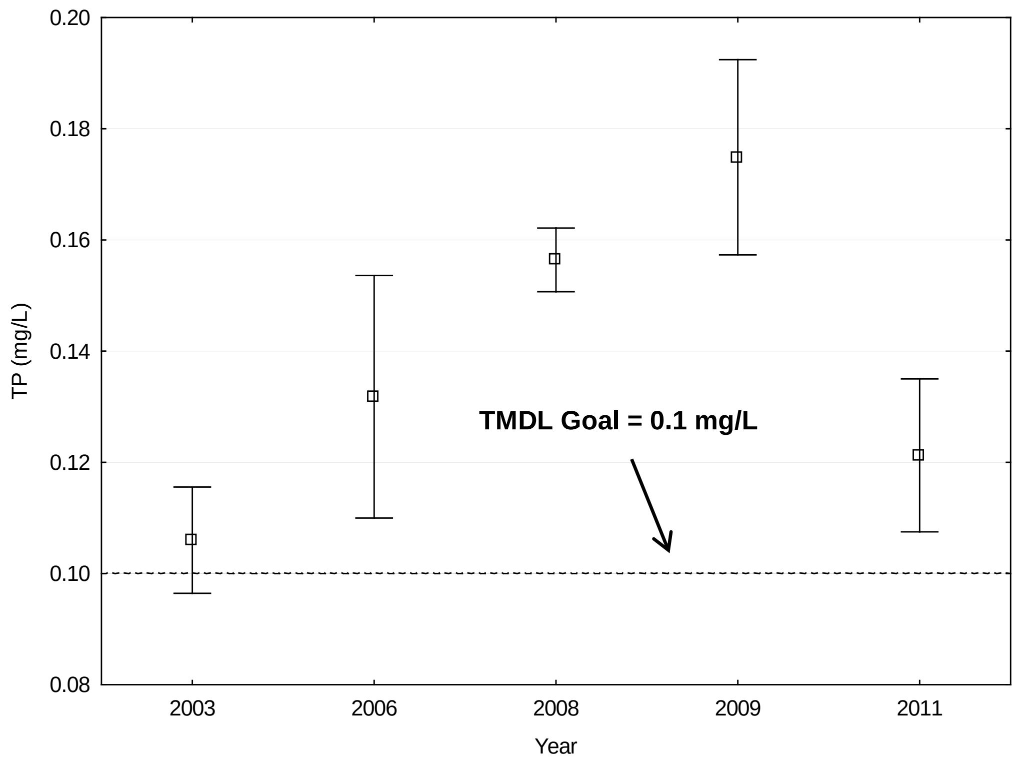


Figure 7. Total phosphorus growing season mean and standard error, West Branch Sunrise River 07030005-529 (2003-2011)



3.6 Pollutant Source Summary

3.6.1 Phosphorus

3.6.1.1 Permitted Sources of Phosphorus

Regulated surface water discharge of phosphorus is permitted through the National Pollutant Discharge Elimination System (NPDES) and State Disposal System (SDS) permits. Section 4.1.3 describes the various permitted sources and the methods used to assign the wasteload allocations. The regulated sources of phosphorus within the watersheds of the eutrophication impairments addressed in this TMDL study include regulated stormwater from municipal separate storm sewer systems (MS4), construction sites, and industrial sites. Phosphorus loads from regulated MS4, construction, and industrial stormwater runoff were accounted for in the loading capacity using the existing Sunrise River SWAT model as described in Section 3.6.1.2 below.

3.6.1.2 Non-permitted Sources of Phosphorus

The following are the sources of phosphorus not requiring NPDES permit coverage that were evaluated:

- Watershed runoff
- Loading from upstream waters
- Runoff from feedlots not requiring NPDES permit coverage
- Atmospheric deposition
- Septic systems
- Groundwater
- Internal loading

Watershed Runoff

The Sunrise River Soil and Water Assessment Tool (SWAT) Model was constructed in 2010 by Almendinger and Ulrich with funding provided by the National Park Service and the MPCA (Almendinger and Ulrich 2010b). Results from this model were used for determination of average annual watershed runoff and phosphorus load from subwatersheds of impaired lakes and streams except for the Sunrise River West Branch upstream of Martin Lake that had water quality monitoring data. Sunrise River SWAT model results represent the average annual water and phosphorus loading for the 20-year period from 1990 through 2009. SWAT model results include water and phosphorus loads derived from both watershed runoff and shallow groundwater. These two constituents were not disaggregated in water and phosphorus loading estimates to the impaired lakes and streams (see *Groundwater* for further discussion).

SWAT was developed by the United States Department of Agriculture (USDA) Agricultural Research Service to predict water, sediment, and agricultural chemical yields in large watersheds based on soils, land use, and management conditions over long periods. SWAT is a continuous simulation model that simulates hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch et al. 2002 as referenced in Borah et al. 2006). Simulations are performed on a daily time step (typically) on hydrologic response units (HRUs), which are unique combinations of soils and land uses throughout the modeled watershed. Results are summarized by subwatersheds as defined by the user. Simulated variables (e.g. water and phosphorus) are routed through the stream network to the overall watershed outlet. SWAT is a physically-based, parameter-intensive model. SWAT simulates the physical processes related to water and sediment movement, crop growth, and nutrient cycling using model inputs associated with weather, soils, topography, vegetation, and land management practices.

The Sunrise River SWAT model watershed study area (Figure 8) was divided into 142 subwatersheds based on topographic and hydrographic data. Land cover data were taken from the 2007 USDA Crop Data Layer. Soils data were generated based on available USDA Soil Survey Geographic data. Land cover, soils, and slopes were spatially intersected to create HRUs within each subwatershed. A total of 1,642 HRUs were created, about 11 to 12 per subbasin on average. In addition, topographic data were analyzed to identify depressional storage on the landscape, which was entered into SWAT in order to account for the impact of such depressions both on the hydraulics of rainfall-runoff response and on transport of nonpoint-source pollutant loads. The Sunrise River SWAT model was calibrated to crop yield, flow, sediment, and phosphorus data. For a full description of model construction of the Sunrise River SWAT Model refer to *Constructing a SWAT model of the Sunrise River watershed, Eastern Minnesota* (Almendinger and Ulrich 2010a).

Subwatersheds of the Sunrise River SWAT model were delineated based on a USGS 10-meter digital elevation model from the USGS and a high-density flow network from the MN DNR. Annual water and phosphorus loading from the subwatersheds of impaired waterbodies were derived based on areal loading rates from the respective Sunrise River SWAT model subwatersheds, which were applied to the TMDL subwatersheds. Rice Lake and Boot Lake are located upstream of Linwood Lake, however water quality monitoring data are not available for these lakes to independently estimate their contributing phosphorus load to Linwood Lake. Martin Lake is impaired and is located upstream of the Sunrise River, West Branch. The load from Martin Lake to the Sunrise River West Branch was based on the assumption that the lake will meet shallow lake water quality standards in the future (60 ppb).

Table 8. SWAT watershed phosphorus runoff to impaired waters

	Linwood Lake	Second Lake	Vibo Lake	White Stone Lake
Lake watershed load (lb/yr)	1,079	167	9,239	41

Note: These loads do not include the unknown/internal load added during BATHTUB model calibration.

<u>Feedlots</u>

Runoff during precipitation and snow melt can carry phosphorus from uncovered feedlots to nearby surface waters. For the purpose of this study, non-permitted feedlots are defined as being all registered feedlots without an NPDES/SDS permit that house under 1,000 animal units. While these feedlots do not fall under NPDES regulation, other regulations still apply.

Phosphorus loading from feedlots was accounted for within the SWAT model. County-wide feedlot numbers for Chisago County were obtained from the National Agricultural Statistics Service (NASS) and adjusted with advice from Chisago SWCD personnel. Livestock numbers were converted to manure quantities and the model simulated the location, timing, and spreading rate (mass per area) of manure applications on the landscape. Refer to Almendinger and Ulrich (2010a) for additional information.

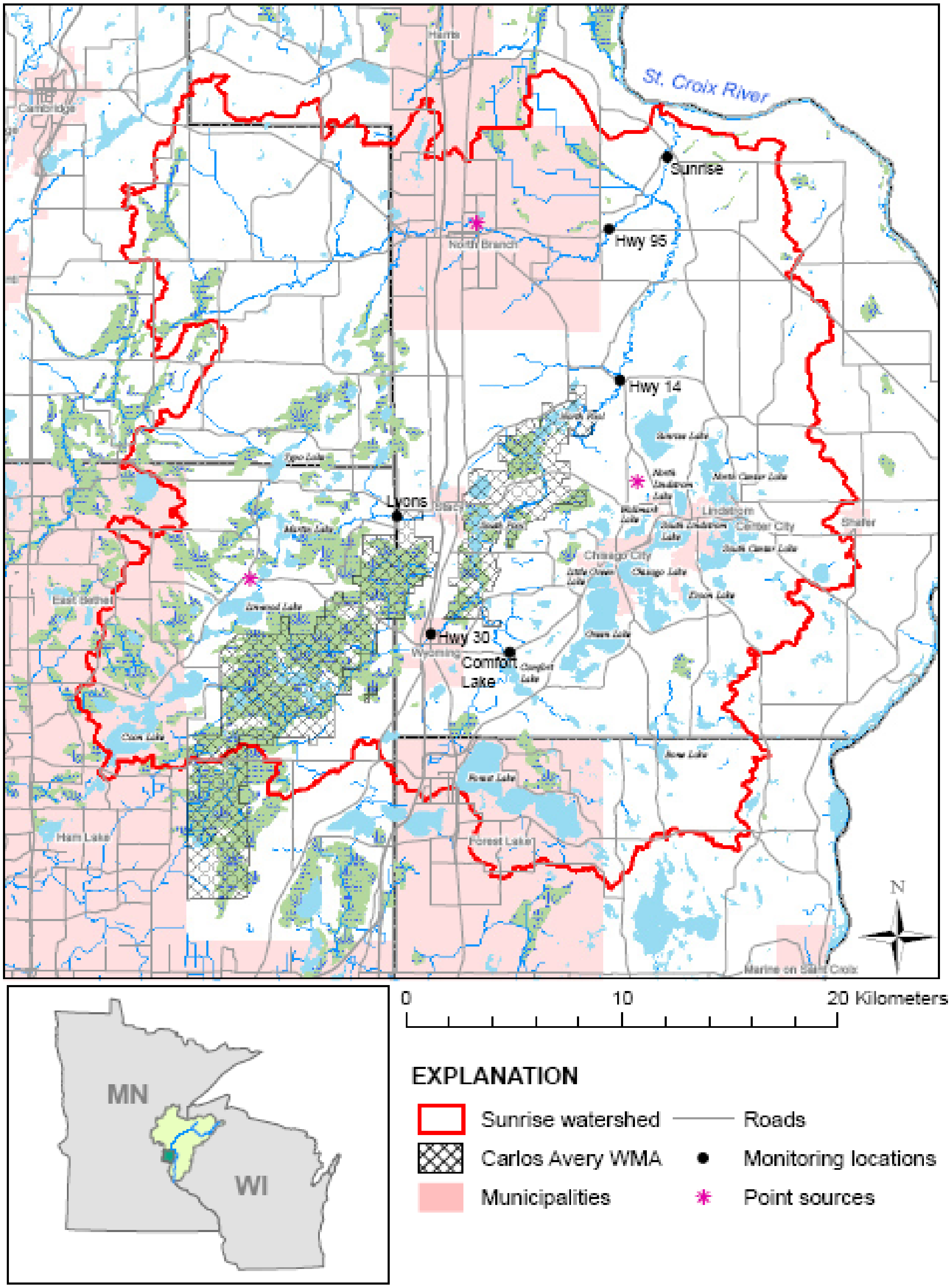
Atmospheric Deposition

Atmospheric deposition represents the phosphorus that is bound to particulates in the atmosphere and is deposited directly onto surface waters as the particulates settle out of the atmosphere. Average phosphorus atmospheric deposition loading rates were calculated for the St. Croix River Basin (MPCA 2004). The report determined that atmospheric deposition equaled 0.27 lb/ac of TP per year. This rate was applied to each impaired lake surface area to determine the total pounds per year of atmospheric phosphorus deposition (Table 9).

Table 9. Atmospheric phosphorus load summary

	Linwood Lake	Second Lake	Vibo Lake	White Stone Lake
Atmospheric Deposition (lb/yr)	152	23	15	13

Figure 8. Sunrise River Watershed SWAT Model Study Area
Source: Almendinger and Ulrich (2010a)



Septic Systems
Phosphorus loads attributed to septic systems were accounted for within the SWAT model by assigning a phosphorus concentration of 0.3-120 µg/l to shallow groundwater to calibrate the SWAT watershed phosphorus loads (Almendinger and Ulrich 2010a). The groundwater P concentrations used to calibrate the SWAT model were similar to groundwater phosphorus concentrations typically found below agricultural and urban settings (10-20 µg/l; Nolan and Stoner 2000).

Independent estimates of the shoreline individual septic treatment system (ISTS) phosphorus loads to the impaired lakes were made using data from the 2004 MPCA *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* according the input table below (Table 10).

Table 10. ISTS phosphorus load assumptions and summary

Parameter	Linwood Lake	Second Lake	Vibo Lake	White Stone Lake
Shoreline parcels	114	8	5	13
County	Anoka	Chisago	Chisago	Chisago
% seasonal residence (4 months)	28%	0%	0%	0%
% permanent residence	72%	100%	100%	100%
% conforming systems	88.6%	75%	75%	75%
% failing systems [a]	11.4%	25%	25%	25%
Capita per residence [b]	2.70	2.63	2.63	2.63
P production/ capita/ year (lbs) [c]	1.95	1.95	1.95	1.95
Conforming % P passing [d]	0.20%	0.20%	0.20%	0.20%
Non-conforming % P passing [d]	0.43%	0.43%	0.43%	0.43%
P load conforming ISTS (lb/year)	86	6	4	10
P load non-conforming ISTS (lb/year)	24	4	3	7
Total P load ISTS (lb/year)	**110**	**11**	**7**	**17**

[a] Chisago County estimated that 25% of septic systems are failing in a recent survey; for all other counties, the MPCA 2004 estimate of 11.4% failing septic systems in the St. Croix Basin was used.
[b] County estimates for 2007-2011 from the U.S. Census Bureau
[c] Barr Technical Memorandum (page 4)
[d] Barr Technical Memorandum (page 15)

Groundwater
SWAT model results include water and phosphorus loads derived from both watershed runoff and shallow groundwater. Therefore, phosphorus contributions from shallow groundwater are accounted for in this TMDL study. Contributions from watershed runoff and shallow groundwater were not disaggregated in water and phosphorus loading estimates to impaired lakes. Due to the scale of the original Sunrise River SWAT model and the significantly smaller scale of the subwatersheds to the impaired lakes in this TMDL study, there is enough uncertainty

in extracting the groundwater contribution from the SWAT model to warrant leaving groundwater and surface water contributions coupled for this study.

Internal Loading

Internal loading in lakes refers to the phosphorus load that originates in the bottom sediments or macrophytes and is released back into the water column. Internal loading can occur via:

1. *Chemical release from the sediments* – caused by anoxic (lack of oxygen) conditions in the overlying waters or high pH (>9). If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be mixed throughout the water column when the lake loses its stratification at the time of fall mixing. In shallow lakes, the periods of anoxia can last for short periods of time and occur frequently.
2. *Physical disturbance of the sediments* – caused by bottom-feeding fish behaviors (such as carp and bullhead), motorized boat activity, and wind mixing. This is more common in shallow lakes than in deeper lakes.
3. *Decaying plant matter* – specifically curly-leaf pondweed (*Potamogeton crispus*) which is an invasive plant that dies back mid-summer which is during the season to which the TMDL will apply and when water temperatures can accelerate algal growth.

Internal loading due to the anoxic release from the sediments of each lake was estimated in this study based on the expected release rate (RR) of phosphorus from the lakebed sediment, the lake anoxic factor (AF), and the lake area. Lake sediment samples were taken and tested for concentration of total phosphorus (TP) and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound phosphorus. Phosphorus release rates were calculated using statistical regression equations developed using measured release rates and sediment P concentrations from a large set of North American lakes (Nürnberg 1988; Nürnberg 1996; Table 11). Internal loading due to physical disturbance and decaying curly-leaf pondweed is difficult to estimate reliably and was therefore not included in the lake phosphorus analyses.

These internal loading estimates were not used as direct inputs to the Bathtub lake models, since the Bathtub model includes an implicit but unknown amount of internal loading. The independent estimate of internal loading will be used to determine what proportion of load allocation reductions should be distributed between watershed versus internal phosphorus sources in the restoration plan.

Table 11. Internal TP loads calculated from sediment TP concentrations (Nurnberg 1988, 1996)

Lake	Sediment Total P Concentration (mg/kg dry)	Anoxic Factor (days)	Release Rate NA Lakes Dataset (mg/m2-day)	Internal Load (lb/yr)
Linwood Lake	1,700	48	2.23	**538**
Second Lake	1,300	60	0.72	**33**
Vibo Lake	2,400	102	4.87	**254**
White Stone Lake	1,200	66	0.34	**10**

3.6.2 Escherichia Coli

Potential sources of bacteria to surface waters were investigated at two different scales: 1) six large subwatersheds constituting the project area downstream of Comfort Lake and the North Branch of the Sunrise River, and 2) 29 small subwatersheds (Target Subwatersheds) discharging more directly to the reaches impaired due to bacteria (Sunrise River, North Branch Sunrise River to St Croix River (07030005-543), and Hay Creek, Beaver Creek to Sunrise River (07030006-545)). Figure 9 and Figure 10 illustrates these two areas. The bacteria source assessment for the large subwatersheds provides guidance for protection, but it is less detailed than that of the 29 Target Subwatersheds discharging more directly to the reaches impaired due to bacteria. Methods and results for the six large subwatersheds can be found in Appendix B. The following provides a general discussion of bacteria sources and delivery mechanisms including details applicable to the 29 Target Subwatersheds. Also included is a description of the approach used in the bacteria source assessment for the estimation of potential bacteria sources for the 29 Target Subwatersheds as well as the findings of the bacteria source assessment.

3.6.2.1 Permitted Sources of Escherichia Coli

<u>Humans: Wastewater Treatment Facilities (WWTFs) and Collection Systems</u>
WWTFs are required to test fecal coliform bacteria levels in effluent on a weekly basis. Dischargers to Class 2 waters are required to disinfect from April through October, and dischargers to Class 7 waters are required to disinfect from May through October. Wastewater disinfection is required during all months for dischargers within 25 miles of a water intake for a potable water supply system (Min. Rules Ch. 7053.0215, subp. 1). The geometric mean for all samples collected in a month must not exceed 200 cfu/100 ml fecal coliform bacteria. Table 12 identifies the WWTFs in the 29 Target Subwatersheds and includes design flows and bacteria loads. The WWTF locations are shown in Figure 9.

Table 12. WWTFs, Design Flows, and Bacteria Loads in the 29 Target Subwatersheds

Subwatershed ID	Name of WWTF	Permit No.	Design Flow [mgd]	Permitted Bacteria Load as *E. coli* at 126 org / 100 ml[1] [billion org/day]
66	Chisago Lakes Joint STC	MN0055808	2.46	11.7

[1] WWTF permits are regulated for fecal coliform, not *E. coli*. The MPCA surface water quality standard for *E. coli* (126 org / 100 ml) was used in place of the fecal coliform permitted limit of 200 org / 100 ml, which was also the MPCA surface water quality standard prior to the March 2008 revisions to Minnesota Rules Chapter 7050. Loads are reported with three significant figures.

<u>Humans: Land Application of Biosolids</u>
Application of biosolids from WWTFs follows the same regulations as septage application from SSTSs (see *Land Application of Septage*). However, whereas septage application is not highly tracked, the application of biosolids from WWTFs is highly regulated, monitored, and tracked. Biosolids disposal methods that inject or incorporate within 24-hours of land application result in minimal possibility for mobilization to downstream surface waters. Surface application presents a conceivable risk to surface waters. However, the restrictions in Table 13 apply.

Figure 9. Bacteria Source Assessment – 29 Target Subwatersheds for 07030005-543 and 07030006-545

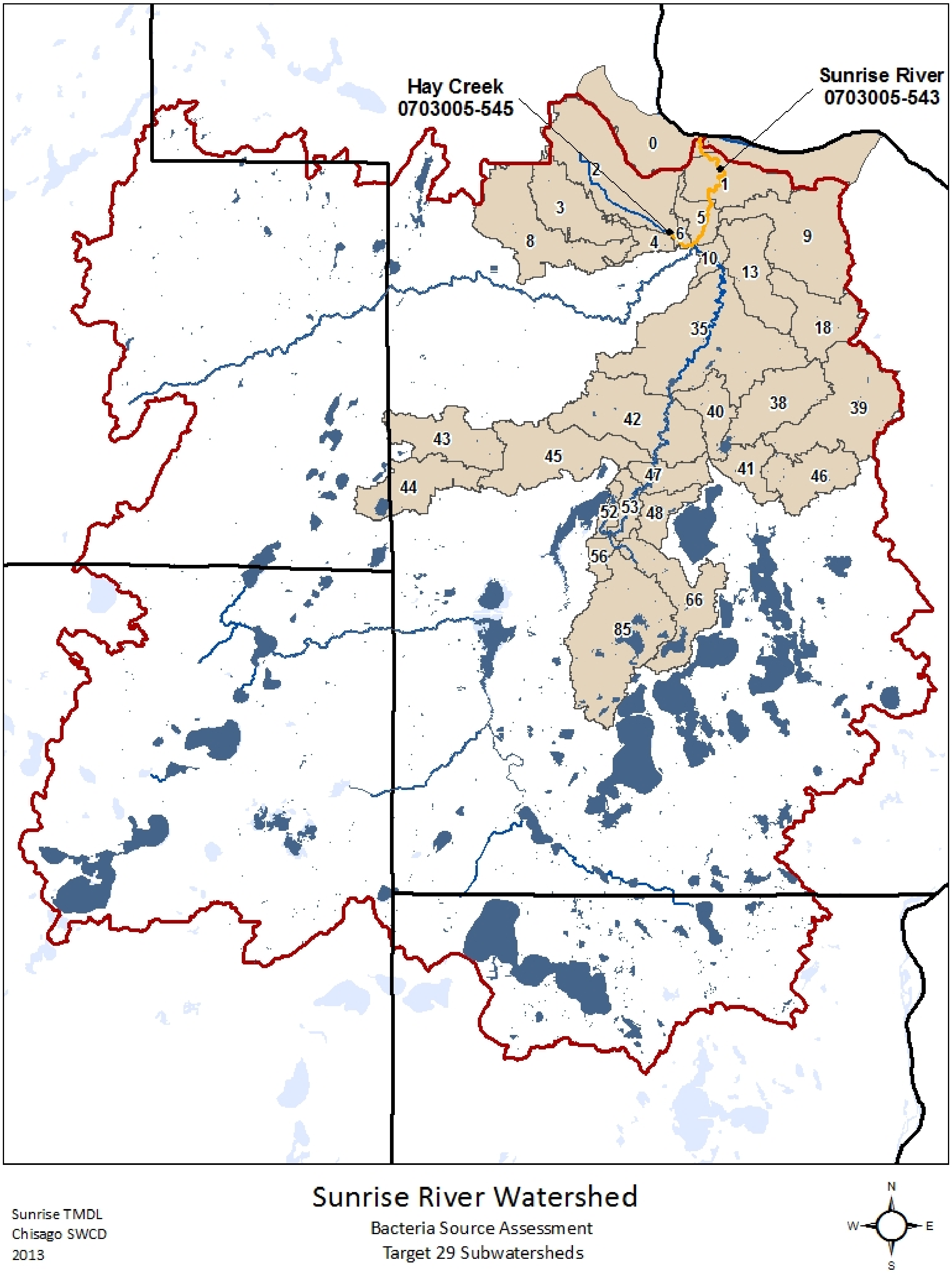
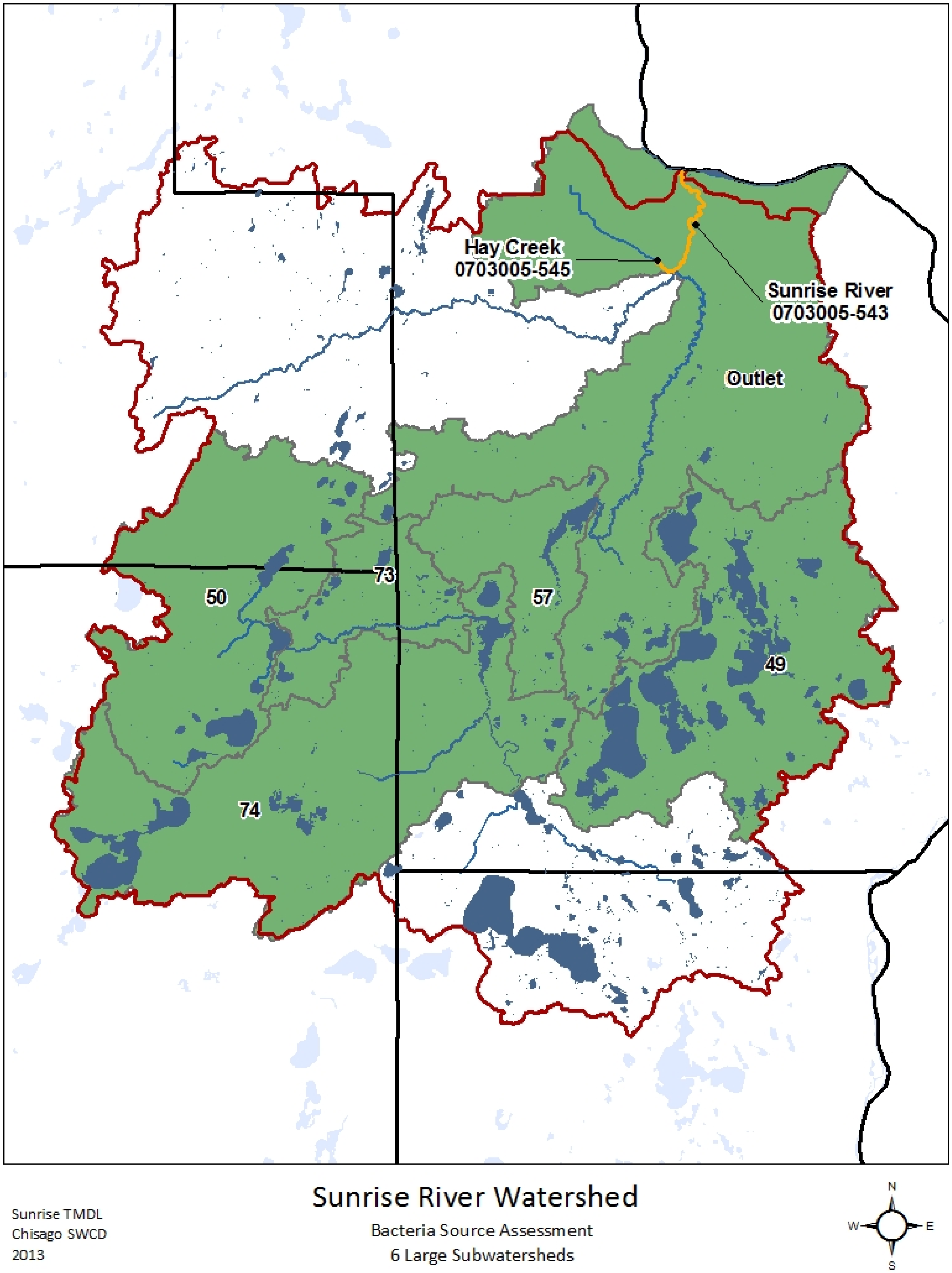


Figure 10. Bacteria Source Assessment – 6 Large Subwatersheds for 07030005-543 and 07030006-545



3.6.2.2 Non-permitted Sources of Escherichia Coli

Humans: Combined Sewer Overflows

Combined sewer systems are designed to collect sanitary sewage and stormwater runoff in a single pipe system. These systems overflow occasionally when heavy rain or melting snow causes the wastewater volume to exceed the capacity of the sewer system or treatment plant. An overflow event is called a combined sewer overflow or CSO, which entails a mix of raw sewage and stormwater runoff (from buildings, parking lots, and streets) flowing untreated into surface waters. The occurrence of CSOs is not known to be an issue in the Sunrise River Watershed.

Humans: Illicit Discharges from Unsewered Communities

In many cases, onsite or small community cluster systems to treat wastewater are installed and forgotten until problems arise. Residential lots in small communities throughout Minnesota cannot accommodate modern septic systems that meet the requirements of current codes due to small lot size and/or inadequate soils. Development pressures in lake communities add to the problem as well as cabins that occupy a large footprint on small lake lots. In addition, many small communities are characterized by outdated, malfunctioning septic systems serving older residences. Small lots, poor soils, and inadequate septic system designs and installations may be implicated in bacterial contamination of groundwater but the link to surface water contamination is tenuous. Community septic systems that discharge greater than 10,000 gallons per day are required to obtain an NPDES discharge permit.

“Failing” subsurface sewage treatment systems (SSTS) are specifically defined as systems that are failing to protect groundwater from contamination, while those systems which discharge partially treated sewage to the ground surface, road ditches, tile lines, and directly into streams, rivers and lakes are considered an imminent threat to public health and safety (ITPHS).

ITPHS systems also include illicit discharges from unsewered communities (sometimes called “straight-pipes”). Straight pipes are illegal and pose an imminent threat to public health as they convey raw sewage from homes and businesses directly to surface water. Community straight pipes are more commonly found in small rural communities.

MPCA’s 2011 report to the legislature, *Recommendations and Planning for Statewide Inventories, Inspections of Subsurface Sewage Treatment System*, identifies percent of systems in unsewered communities that are ITPHS for each county in Minnesota (MPCA 2011). An estimated 4% of systems in unsewered communities in Chisago County are estimated to be ITPHS.

Humans: Land Application of Septage

A state subsurface sewage treatment system (SSTS) license applicable to the type of work being performed is required for any business that conducts work to design, install, repair, maintain, operate, or inspect all or part of an SSTS. A license is also required to land spread septage and operate a sewage collection system discharging to an SSTS. Disposal contractors are required to properly treat and disinfect septage through processing or lime stabilization. Treated septage may then be disposed of onto agricultural and forest lands. EPA Standards Section 503 provides general requirements, pollutant limits, management practices, and operational standards for the final use or disposal of septage generated during the treatment of domestic sewage in a treatment works.

MPCA does not directly regulate the land application of septage, but management guidelines entail site suitability requirements with respect to soil conditions, slope, and minimum separation distances (MPCA 2002). Notable requirements include 3 foot minimum depth to bedrock and seasonally saturated soils, restrictions on 6-12% slopes, no application on slopes greater than 12%, and horizontal separation distances as shown in Table 13. Chisago County has an SSTS septage ordinance (County Ordinance Number 10-1), but site suitability guidance does not appear to differ significantly from MPCA guidance. Some cities and townships have SSTS septage ordinances (a list is available at http://www.pca.state.mn.us/index.php/view-document.html?gid=10139); these were not reviewed as a part of this study.

Table 13. Minimum Separation Distances for Septage Land Application
Table adapted from Table 3 of Chisago County Ordinance Number 10-1, Section 14.06,

Feature		Surface Application	Incorporated within 48 hours	Injected
Private drinking water supply wells		200’		
Public drinking water supply wells[1]		1000’		
Irrigation wells		50’	25’	25’
Residences		300’	200’	100’
Residential developments		600’	600’	300’
Public contact sites		600’	600’	300’
Down gradient lakes, rivers, streams, wetlands, intermittent streams[2], or tile inlets connected to these surface water features, and sinkholes	0 to 6% slope	200’	50’	50’
	6 to 12% slope	Not Allowed	100’	100’
	Winter (0 to 2% slope)	600’	Not Applicable	Not Applicable
Grassed Water Ways	0 to 6% slope	100’	33’	33’
	6 to 12% slope	Not Allowed	33’	33’
Shoreland		Not Allowed		

[1]There may be special requirements if the land application site is within the boundaries of a wellhead protection area.
[2] Intermittent stream means a drainage channel that provides for runoff flow to any surface water during snow melt or rainfall events.

Companion Animals

Companion animals (dogs and cats) can contribute bacteria to a watershed when their waste is not properly managed. When this occurs, bacteria can be introduced to waterways from:

- Dog parks
- Residential yard runoff (spring runoff after winter accumulation)
- Rural areas where there are no pet cleanup ordinances
- Animal elimination of excrement directly into waterbodies

Dog waste can be a significant source of pathogen contamination of water resources (Geldreich 1996). Dog waste in the immediate vicinity of a waterway could be a significant local source with local water quality impacts. However, it is generally thought that these sources may be only minor contributors of fecal contamination on a watershed scale. Cats may contribute significantly to bacteria levels in urban streams and rivers (Ram et al. 2007). Feral cats are accounted for separately in this study as wildlife.

Livestock: Animal Feeding Operations

Animal waste containing fecal bacteria can be transported in watershed runoff to surface waters. The MPCA regulates animal feedlots in Minnesota though counties may be delegated by the MPCA to administer the program for feedlots that are not under federal regulation. The primary goal of the state program for animal feeding operations is to ensure that surface waters are not contaminated by the runoff from feeding facilities, manure storage or stockpiles, and cropland with improperly applied manure. Refer to Section 3.6.2.1 for a description of registration and permitting thresholds for AFOs (also known as feedlots).

Livestock also occur at hobby farms, small-scale farms that are not large enough to require registration but may have small-scale feeding operations and associated manure application or stockpiles.

Livestock: Land Application of Manure

Livestock manure is often either surface applied or incorporated into farm fields as a fertilizer and soil amendment. This land application of manure has the potential to be a substantial source of fecal contamination, entering waterways from overland runoff and drain tile intakes. Research being conducted in southern MN shows high concentrations of fecal bacteria leaving fields with incorporated manure and open tile intakes (Scott Matteson, personal communication).

MN Rules Chapter 7020 contains manure application setback requirements (Table 14). These setback requirements are largely based on research related to phosphorus transport, and not bacterial transport, and the effectiveness of these current setbacks on bacterial transport to surface waters is not known.

Table 14. Manure Application Setback Distances for Minnesota
Minimum setbacks near waters (counties can be more restrictive than MN Rule 7020).
Table adapted from "Fecal Coliform TMDL Assessment for 21 Impaired Streams in the Blue Earth River Basin" (Minnesota State University, Mankato, Water Resources Center, June 2007).

Waterbody Type	Surface Application	Incorporation within 24 hrs.
Lake, stream	300'*	25'**
Wetlands (10+ ac.)	300'*	25'**
Ditches (without berms)	300'*	25'**
Open tile intakes	300'	0
Well, quarry	50'	50'
Sinkhole (w/o berms)		
Downslope	50'	50'
Upslope	300'	50'

*100' vegetated buffer can be used instead of 300' setback for non-winter applications (50' buffer for wetlands/ditches).
**No long-term phosphorus build-up within 300'

Livestock: Grazing

Pastured areas are those where grass or other growing plants are used for grazing and where the concentration of animals allows a vegetative cover to be maintained during the growing season. Pastures are neither permitted nor registered with the state.

Wildlife

Bacteria can be contributed to surface water by wildlife (e.g. raccoons, deer, geese, waterfowl, and feral cats) from dwelling in waterbodies, within conveyances to waterbodies, or when their waste is carried to stormwater inlets, creeks, ditches, and lakes during stormwater runoff events. Areas such as DNR designated wildlife management areas, State Parks, National Parks, National Wildlife Refuges, golf courses, state forest, and for some animals, urban areas (e.g. raccoons) provide wildlife habitat encouraging congregation and could be potential sources of higher fecal coliform due to the high densities of animals. There are likely many other areas within the project area where wildlife congregates.

3.6.2.3 Bacteria Sources and Delivery Mechanisms

Humans, companion animals, livestock, and wildlife contribute bacteria to the environment. These bacteria, after appearing in animal waste, are dispersed throughout the environment by an array of natural and man-made mechanisms. Bacteria fate and transport is affected by disposal and treatment mechanisms, methods of manure reuse, imperviousness of land surfaces, and natural decay and die-off due to environmental factors such as UV exposure and detention time in the landscape. The following discussion highlights sources of bacteria in the environment and mechanisms that drive the delivery of bacteria to surface waters. Details specific to the 29 Target Subwatersheds discharging more directly to the impaired reaches informed the approach to the bacteria source assessment, which is discussed in the section titled *Approach*.

The fate and transport of bacteria after it leaves the animal is widely variable. The landscape onto which the bacteria is excreted, applied, stored, or discharged affects the level of risk of contamination of downstream surface waters. Mechanisms that drive the fate and transport of bacteria in pervious landscapes significantly differ from that of impervious landscapes.

Certainly agricultural activities and septic systems are unique to pervious, if not rural, landscapes. In addition, expansive pervious landscapes are characterized by natural and ditched drainage ways, agricultural draintile, and large tracts of natural landscapes. These factors affect the movement to surface waters of watershed runoff and its associated pollutants. Draintile can accelerate transport of pollutants, but pervious surfaces and natural landscapes can slow transport.

Absent of stormwater BMPs, fecal bacteria and associated pathogen loads in urban stormwater are directly conveyed to lakes, streams, and rivers via impervious surfaces, storm drains, and storm sewer system networks. As a result of aging infrastructure, impervious landscapes can also be characterized by chronic contamination of storm sewer systems that convey raw sewage originating from breeches in sanitary sewers (Sauer et al. 2011; Sercu et al. 2009; Sercu et al. 2011). Fecal bacteria concentrations in stormwater runoff from urban areas can be as great as or greater than those found in cropland runoff, grazed pasture runoff, and feedlot runoff (EPA 2001).

Approach

The following series of tables describes the methodologies used to estimate the delivery of bacteria to surface waters in the 29 Target Subwatersheds. Where applicable in this approach, bacteria production estimates are based on the bacteria content in feces and an average excretion rate [with units of cfu/day-head; where 'head' implies an individual animal]. Bacteria content and excretion rates vary by animal type (a.k.a. *producer*). The EPA's *Protocol for developing pathogen TMDLs* provides estimates for bacteria production by producer for most producers shown in Table 15 (EPA 2001); values for deer and raccoons were obtained from other sources (Zeckoski et al. 2005; Yagow 1999). *E. coli* production rates are based on fecal coliform production rates and a conversion factor. All production rates obtained from the literature are for fecal coliform rather than *E. coli* due to the availability of fecal coliform data. The production rate was multiplied by 0.5 to estimate the *E. coli* production rate, which is based on the rule of thumb that 50% of fecal coliform are *E. coli* (Doyle and Erikson 2006).

Bacteria delivery to surface waters was calculated for each subwatershed for each source. However, for this study results are reported in relative terms [low, medium-low, medium-high, high]. The relative rankings relate multiple sources in a single Target Subwatershed.

Table 15. Bacteria Production by Source

Source Category	Producer	*E. coli* Production Rate [cfu/day-head]	Literature Source[1]
Humans	Humans	1×10^{9}	Metcalf and Eddy 1991
Companion Animals	Dogs and Cats	2.5×10^{9}	Horsley and Witten 1996
Livestock	Horses	2.1×10^{8}	ASAE 1998
	Cattle	2.7×10^{9}	Metcalf and Eddy 1991
	Hogs	4.5×10^{9}	Metcalf and Eddy 1991
	Sheep and Goats	9×10^{9}	Metcalf and Eddy 1991
	Poultry	1.3×10^{8}	Metcalf and Eddy 1991
Wildlife	Deer	1.8×10^{8}	Zeckoski et al. 2005
	Geese	2.5×10^{10}	LIRPB 1978
	Breeding Ducks	5.5×10^{9}	Metcalf and Eddy 1991
	Raccoons	5.7×10^{7}	Yagow 1999
	Pigeons	8.0×10^{7}	Oshiro and Fujioka 1995

[1] Literature sources provide fecal coliform production rates, which were converted to *E. coli* by applying a conversion factor of 0.5 based on Doyle and Erikson (2006). Therefore, *E. coli* production rate = 0.5 x fecal coliform production rate

Table 16. Data Sources and Assumptions for Estimates of Potential Bacteria Sources: Humans.

Bacteria Sources			Data Sources and Assumptions
Sewered Community	WWTF	WWTF Effluent	Based on WWTF design flow and NPDES permit limits; refer to Table 12 on Page 34
		Land Application of Biosolids	Delivery assumed to be low based on regulations; refer to *Humans: Land Application* of Biosolids on Page 34.
Unsewered Community	Compliant SSTS	SSTS Discharge to Groundwater	Neglected because discharge is not to surface water
		Land Application of Septage	Delivery assumed to be low based on regulations; refer to *Humans: Land Application* of Septage on Page 37.
	Non-Compliant SSTS	ITPHS SSTS including Illicit Discharges	The population in unsewered communities was estimated based on 2010 Census block groups[1] (U.S. Census Bureau 2011) for those areas outside of the WWTF service area. The WWTF service area was estimated as applicable 2006 NLCD *Developed* land covers in Subwatersheds 66 and 85. SSTS flow was estimated to be 265 L/person-day (Metcalf and Eddy 1991). The estimated fraction of flow from unsewered communities that is classified as ITPHS was applied based on MPCA (2011) (4%). Raw sewage *E. coli* concentration was estimated at 3.15×10^{6} org/100ml, which is equal to half the fecal coliform concentration [(as suggested by Doyle and Erikson (2006)] provided in Overcash and Davidson (1980) as referenced in EPA (2011).

[1] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g. a municipality or a portion of a large city). There could be hundreds of census tracts in large cities like Chicago.

Table 17. Data Sources and Assumptions for Estimates of Potential Bacteria Sources: Livestock. NOTE: This table is read from left-to-right, demonstrating the progressive breakdown into increasing numbers of categories of fate and transport mechanisms. For example, first livestock populations were categorized into grazing and AFO populations. The fate of bacteria from AFOs was further categorized into ‘Partially Housed or Open Log without Runoff Controls’ or ‘Land Application of Manure’. In all cases, bacteria production by animal type was used based on references cited by EPA (2011), refer to Table 15.

<table>
<tr><th colspan="3">Bacteria Sources
Data Sources and Assumptions</th><th>Delivery Factor</th></tr>
<tr><td colspan="3">Grazing
Grazing populations were estimated for cattle, goats, sheep, and horses based on a fall 2012 windshield survey by Chisago SWCD. All horses were considered to be pastured.</td><td>Ultimately, a delivery factor was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46). The applicable geographic area for grazing animals is based on 2006 NLCD Pasture/Hay and Grassland/Herbaceous land covers.</td></tr>
<tr><td rowspan="3">Animal Feeding Operations (AFO)
AFO populations were estimated for cattle, poultry, goats, sheep and hogs based on a fall 2012 windshield survey by Chisago SWCD.</td><td colspan="2">Partially Housed or Open Lot without Runoff Controls
The proportion of AFO animals that are partially housed or in open lots without runoff controls was based on Mulla et al. (2001):
- Cattle 50%
- Poultry 8%
- Goats 42%
- Sheep 42%
- Hogs 15%</td><td>Ultimately, a delivery factor was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46). The applicable geographic area for AFOs is based on 2006 NLCD Barren, Pasture/Hay, Grassland/Herbaceous, and Scrub/Shrub land covers.</td></tr>
<tr><td rowspan="2">Land Application of Manure
Mulla et al. (2001):
- Cattle 50%
- Poultry 92%
- Goats 58%
- Sheep 58%
- Hogs 85%</td><td>Surface Application without Incorporation
Mulla et al. (2001):
- Cattle 86%
- Poultry 91%
- Goats 89%
- Sheep 89%
- Hogs 65%</td><td>Ultimately, a delivery factor was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46). The applicable geographic area for land application of manure is based on 2006 NLCD Cultivated Crops land cover.</td></tr>
<tr><td>Incorporated or Injected
Mulla et al. (2001):
- Cattle 14%
- Poultry 9%
- Goats 11%
- Sheep 11%
- Hogs 35%</td><td>Delivery was assumed to be low based on regulations; refer to Livestock: Land Application of Manure on Page 39.</td></tr>
</table>

Table 18. Data Sources and Assumptions for Estimates of Companion Animal Populations

Animal	Basis for Estimates of Animal Population
Dogs	American Veterinary Medical Association's (AVMA) 2006 data for % of households that own dogs and mean number of dogs in each household (AVMA 2007); 2010 Census block group data[1] for number of households (U.S. Census Bureau 2011) in the applicable geographic areas as described in Table 19.
Cats	AVMA's 2006 data for % of households that own cats and mean number of cats in each household (AVMA 2007); 2010 Census block group data[1] for number of households (U.S. Census Bureau 2011) in the applicable geographic areas as described in Table 19.

[1] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g. a municipality or a portion of a large city). There could be hundreds of census tracts in large cities like Chicago.

Table 19. Data Sources and Assumptions for Estimates of Potential Bacteria Sources: Companion Animals

NOTE: In all cases, bacteria production by animal type was used based on references cited by EPA (2001), refer to Table 15.

Bacteria Source Categories Data Sources and Assumptions		Delivery Factor
Waste Not Collected by Owners - Dogs 38% (TBEP 2012)	**Pervious Areas** Cats and dogs belonging to households within all 2006 NLCD land covers *except Open Water* and *Developed*.	Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46).
	Impervious Areas Cats and dogs belonging to households within 2006 NLCD *Developed* land covers.	Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46).
Waste Collected by Owners - Dogs 62% - Cats 100%		Zero delivery to downstream surface waters.

Table 20. Data Sources and Assumptions for Estimates of Wildlife Populations

Animal	Basis for Estimates of Animal Population
Breeding Ducks	State-wide estimate between the years 2005-2009 in a presentation by the Minnesota DNR Wetland Wildlife Population and Research Group at the 2010 Minnesota DNR Roundtable (http://files.dnr.state.mn.us/fish_wildlife/roundtable/2010/wildlife/wf_pop-harvest.pdf), distributed equally among areas of open water; annual *E. coli* production estimates include only the seven-month residence period (April through October)
Deer	DNR report Status of Wildlife Populations, Fall 2009, which entails pre-fawn densities by DNR deer permit area based on field surveys and modeling as reported in Population Trends of White-Tailed Deer in Minnesota's Farmland/Transition Zone, 2009 by Marrett Grund and Population Trends Of White-Tailed Deer In The Forest Zone, 2009 by Mark Lenarz (see Dexter 2009); missing data for the metro area (Permit Area 601) and three additional small permit areas were estimated based on the average density of surrounding permit areas.
Feral Cats	AVMA's 2006 data for % of households that own cats and mean number of cats in each household (AVMA 2007); 2010 Census block group data for number of households (U.S. Census Bureau 2011). Feral cat populations are unknown, but are suspected to be comparable to that of pet cats (AVMA 2010).
Geese	DNR report Status of Wildlife Populations, Fall 2009, estimates by Minnesota ecoregion based on a spring helicopter survey and modeling and reported in the Minnesota Spring Canada Goose Survey, 2009 by David Rave (see Dexter 2009).
Pigeons	New York City population estimate Innolytics (2012), applied as an aerial rate to applicable geographic areas (only *Developed, High Intensity* 2006 NLCD land cover).
Raccoons	A state-wide DNR estimate (DNR 2011).

Table 21. Data Sources and Assumptions for Estimates of Potential Bacteria Sources: Wildlife
NOTE: In all cases, bacteria production by animal type was used based on references cited by EPA (2001), refer to Table 15.

Bacteria Source Categories Data Sources and Assumptions	Delivery Factor
Open Water Areas All geese and ducks were considered to reside on and within a 100 foot buffer of 2006 NLCD *Open Water* and wetland land covers.	Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46).
Impervious Areas Deer, feral cats, and raccoons within 2006 NLCD *Developed* land covers.	Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46).
Pervious Areas Deer, feral cats, and raccoons within all 2006 NLCD land covers *except Open Water* and *Developed*.	Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46).
High Intensity Development Pigeons within 2006 NLCD *Developed, High Intensity* land covers.	Ultimately, a delivery factor from the applicable geographic area was applied to estimate the amount of bacteria delivered to downstream surface waters (refer to Page 46).

Bacteria Delivery Factor to Surface Waters

A bacteria delivery factor was applied to bacteria sources that do not directly discharge to surface waters (e.g. land application of manure or wildlife excrement) nor have overriding assumptions as to the relative delivery potential (e.g. land application of biosolids having low delivery potential). The bacteria delivery factor accounts for fate and transport factors such as proximity to surface waters, slope, imperviousness, and discharge to lakes prior to discharge to stream networks. The basis for the delivery factors was the state-wide GIS layers of Water Quality Risk, as recently developed by a Minnesota multi-Agency effort and published under the name Conservation Targeting Tools (www.bwsr.state.mn.us/ecological_ranking/, *Maps & GIS Data*). The original Water Quality Risk GIS layer is a 30 meter gridded dataset. Each grid cell has a risk score on a 0-100 basis for its potential contribution to surface water quality degradation, 100 being the highest risk. Half (50 points) of the risk score was determined by Stream Power Index (SPI) values, which account for the likelihood of overland erosion based on slope and soil type. Half of the risk score was determined based on the proximity to the nearest surface water feature; the highest risk score was given to the grid cells closest to water features.

The original Water Quality Risk layer does not account for imperviousness. In addition lakes that are not part of a stream network (i.e. not flow-through lakes), are weighed equally with streams and flow-through lakes in the proximity scoring. Since imperviousness increases risk of surface water contamination of bacteria and since streams are the impaired surface waters of interest (not lakes), the 0-100 water quality risk layer was revised to account for these elements. Non-flow-through-lakes (including a quarter mile buffer) were reduced by 50 points, to a minimum possible value of zero. In addition, a third 50-point scale for imperviousness was added to the water quality risk score. Areas having imperviousness of 50% or more (2006 NLCD *Developed, Medium Intensity* and *Developed, High Intensity* land covers) were given an additional 50 points. Areas having imperviousness of 25 to 49% (2006 NLCD *Developed, Low Intensity* land cover) were given an additional 25 points. Finally, the project-wide GIS layer was re-scaled to a range of 0-100, resulting in the delivery factor GIS layer for use in the estimates of potential bacteria sources.

The delivery factor GIS layer was used wherever described in the tables in this section (*Approach*), which define bacteria source estimation approaches. The mean delivery factor across the applicable geographic areas for each of the 29 Target Subwatersheds was calculated. This value was interpreted and applied as the percent of the bacteria that ultimately reaches downstream surface waters. The delivery factor is not specific to the individual impaired reaches, but accounts for all stream reaches in the subwatershed.

Results

Table 22 identifies the potential bacteria sources of the 29 Target Subwatersheds. Results are presented by source categories rather than animal type. A more detailed breakdown of these results, and implications associated with implementation, will be discussed when the more detailed implementation plan is developed. The actual estimated amount of bacteria delivered to surface waters is not presented in this report due to the large spatial and temporal variability of bacteria found in the environment and uncertainties associated with the ranking inputs. Rather, study results are reported in relative terms [low, medium-low, medium-high, high] for all sources within a single Target Subwatershed to guide BMP selection and implementation.

Table 22. Bacteria Source Assessment Results for the 29 Target Subwatersheds.
Comparison across source categories of relative amounts of each subwatershed. For example, the “0” row presents a comparison of the *E. coli* delivered to surface waters by one source category vs. another source category (within the same Subwatershed 0). (Symbols are viewed relative to other symbols within the same row.) **• - low (0-25th percentile), ž - medium-low (26th-50th percentile), œ - medium-high (51st-75th percentile), ˜ - high (76th-100th percentile), blank – zero bacteria**

	Humans				Livestock					Companion Animals		Wildlife		
Subwatershed	WWTF Effluent	ITPHS Septics	Land Application of Biosolids	Land Application of Septage	Grazing	Partially Housed or OL w/o Runoff Controls	Land Application w/o Incorporation	Land Application w/ Incorporation or Injection	Pastured Horses	Impervious	Pervious	Impervious	Pervious	Water and Wetlands
0		•		•						•	•	•	•	˜
1		•		•					•	•	•	•	•	˜
2		ž		•		•	•	•	•	•	•	•	ž	˜
3		˜		•						•	•	•	˜	›
4		ž		•						•	•	•	ž	˜
5		•		•	•				•	•	•	•	•	˜
6		•		•						•	•	•	ž	˜
8		•		•	•	•	˜		•	•	•	•	•	•
9		•		•	ž				•	•	•	•	ž	˜
10		•		•						•	•	•	•	˜
13		ž		•	›				•	•	•	•	›	˜
18		ž		•	ž	ž	•	•	•	•	•	•	›	˜
35		•		•	ž	•	•	•	•	•	•	•	ž	˜
38		ž		•	ž	›	ž	•	•	•	•	•	›	˜
39		›		•	ž	›	›	•	•	•	•	•	˜	˜
40		ž		•					•	•	•	•	ž	˜
41		•		•	ž	•	•	•	•	•	•	•	ž	˜
42		ž		•					•	•	•	•	›	˜
43		ž		•	•				•	•	•	•	ž	˜
44		•		•					•	•	•	•	•	˜
45		ž		•	•				•	•	•	•	ž	˜
46		›		•	›	ž	ž	•	•	•	•	•	›	˜
47		•		•					•	•	•	•	•	˜
48		•		•					•	•	•	•	•	˜
52		•		•						•	•	•	•	˜
53		•		•					•	•	•	•	•	˜

Subwatershed	Humans				Livestock					Companion Animals		Wildlife		
	WWTF Effluent	ITPHS Septics	Land Application of Biosolids	Land Application of Septage	Grazing	Partially Housed or OL w/o Runoff Controls	Land Application w/o Incorporation	Land Application w/ Incorporation or Injection	Pastured Horses	Impervious	Pervious	Impervious	Pervious	Water and Wetlands
56		ž		•						•	•	•	ž	~
66	•	ž	•	•						•	•	•	ž	~
85		•		•						•	•	•	ž	~

4 TMDL DEVELOPMENT

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

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

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 wastewater treatment facilities, regulated construction stormwater, and regulated industrial stormwater, all covered under NPDES permits for a current or future permitted pollutant source;
- **Load allocation (LA):** the pollutant load that is allocated to sources not requiring NPDES permit coverage, including non-regulated stormwater runoff, atmospheric deposition, and internal loading;
- **Margin of Safety (MOS):** an accounting of uncertainty about the relationship between pollutant loads and receiving water quality;
- **Reserve Capacity (RC):** the portion of the loading capacity attributed to the growth of existing and future load sources.

4.1 Phosphorus

4.1.1 Loading Capacity

4.1.1.1 Summary of Model Applications

For the lake TMDL derivations, results from the Sunrise River SWAT model [modeling conducted under a separate project, refer to Almendinger and Ulrich (2010b)] were used to estimate existing phosphorus loading to lakes. Phosphorus loading from the Sunrise River SWAT model includes loading from watershed runoff, shallow groundwater (including septic systems), and feedlots and were combined with phosphorus loading from atmospheric deposition. The SWAT phosphorus loading served as input to the Bathtub model, which estimates in-lake water quality. The Bathtub models were calibrated to existing in-lake water quality data (10-year growing season means) and were then used to identify the phosphorus load reductions needed to meet State in-lake water quality standards.

For the stream TMDL derivations, streamflow results from the Sunrise River SWAT model (Almendinger and Ulrich 2010b) were used, indirectly, to develop the flow for the individual impaired reaches. A coefficient of modeled flows was calculated, representing the flow contribution of the impaired reach relative to the flow at the location of the monitoring station at the mouth of the Sunrise River. This coefficient was applied to the monitored flows during the period of record (2006-2011); the resulting daily flows were used for the development of load duration curves.

4.1.1.2 Lakes: Bathtub Modeling

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

Long-term averages were used as input data to the models, due to the lack of detailed annual loading and water balance data for each of the lakes. The outputs from the phosphorus source assessment (*Section 3.6.1*) were used as inputs to the Bathtub lake models. The models were calibrated to existing phosphorus concentrations (2002-2011), and then were used to determine the phosphorus reductions needed to meet each lake's phosphorus standard. The phosphorus reduction needed to meet the phosphorus standard, calculated from the Bathtub model, was subtracted from the total existing phosphorus load to determine each lake's loading capacity. The loading capacity of each lake is the TMDL; the TMDL is then split into Wasteload Allocations (WLAs), Load Allocations (LAs), and a margin of safety (MOS). Regression equations developed by the MPCA (2005) suggest that the two response variables, Secchi depth and chlorophyll-a, should also meet state standards when the necessary phosphorus reductions are made.

The TMDL (or loading capacity) was first determined in terms of annual loads. In-lake water quality models predict annual averages of water quality parameters based on annual loads. Symptoms of nutrient enrichment normally are the most severe during the summer months; the state eutrophication standards (and, therefore, the TMDL goals) were established with this seasonal variability in mind. The annual loads were then converted to daily loads by dividing the annual loads by 365 days. *Appendix C: Supporting Data for Bathtub Models* contains for all lakes Bathtub modeling case data (inputs), diagnostics (results), and segment balances (water and phosphorus budgets) for both the calibrated (benchmark/existing) models and the TMDL scenarios.

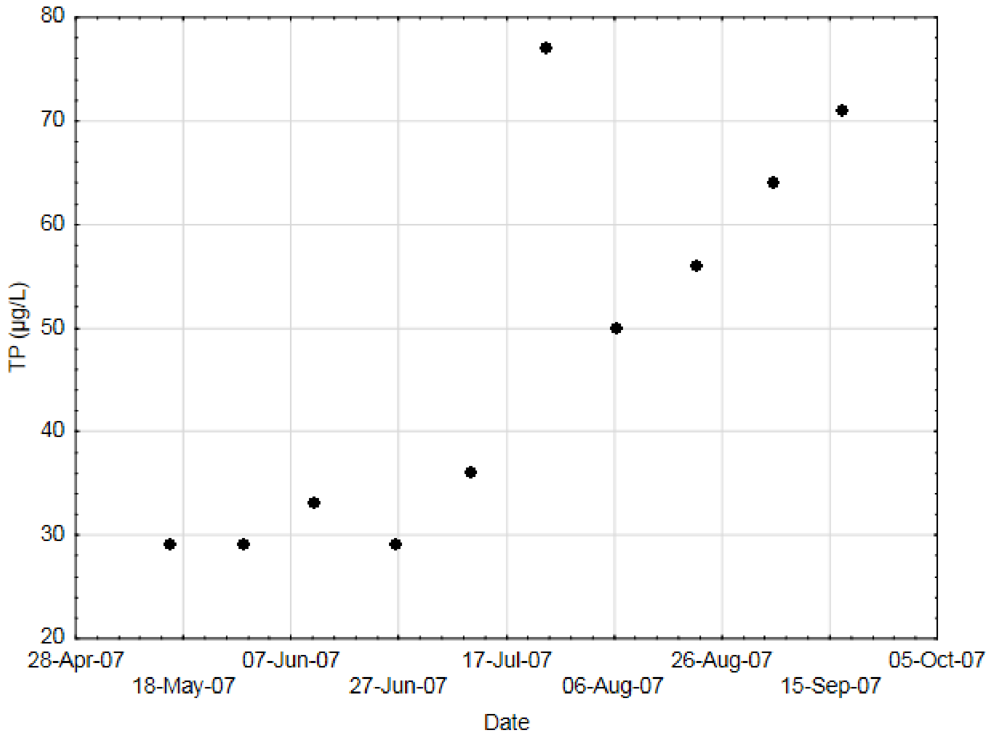
System Representation in Model

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

Internal Load
Under normal use, internal loading is not represented explicitly in Bathtub. An average rate of internal loading is implicit in Bathtub since the model is based on empirical data. For all lakes except Second, an explicit load was added during model calibration. This added load is likely from a mix of internal and external sources. A portion of the added load was attributed to failing shoreline septic system loads estimated in Section 3.6.1.2: Septic Systems. The remainder of the added load was attributed to internal loading according to the discussion below.

In Linwood Lake, there is a clear signature of internal TP loading in the seasonal in-lake TP concentrations which increase linearly with time (Figure 11). The average internal load estimated from phosphorus concentration increases during the growing season was 467 lb/yr, which is similar in magnitude to the added load in BATHTUB (417 lb/yr) and the load estimated from sediment P concentrations (538 lb/yr). In Vibo and White Stone Lakes, the added load in BATHTUB was much greater than the internal load estimated from sediment P concentrations. In addition, these lakes did not exhibit a linear increase in phosphorus during the growing season. Vibo and White Stone Lakes are shallow and mix frequently during the growing season and their internal loading rates are likely closely tied to watershed TP loading and oxic sediment P release (not included in the Nurnberg internal load estimates). Therefore, it is reasonable to assume that the internal load in these lakes is underrepresented by sediment P concentration estimates and likely much greater.

Figure 11. Seasonal TP concentration increase in Linwood Lake, 2007



Model Input
The input required to run the Bathtub model includes lake geometry, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data are also entered into the Bathtub program in order to facilitate model verification and calibration. Table 23 lists the key input values used in the simulations.

Table 23. Bathtub model input data

Input Parameter		Linwood	Second	Vibo	White Stone
Surface area (sq km)		2.302	0.343	0.232	0.198
Lake fetch (km)		2.286	0.808	0.762	0.678
Mean depth (m)		2.81	1.61	1.41	1.52
Growing Season Mean Surface Water Quality (%CV)	TP (µg/L)	44 (5%)	77 (7%)	516 (8%)	97 (8%)
	Chl-*a* (µg/L)	27 (5%)	30 (13%)	91 (19%)	75 (20%)
	Secchi (m)	0.9 (3%)	0.6 (12)	0.4 (9%)	0.6 (12%)
Watershed Runoff and Shallow Groundwater	Watershed area (sq km)	27.51	2.11	31.06	0.89
	Flow (hm^3/ yr)	8.08	0.23	4.96	0.10
	TP (µg/L)	84	314	955.5	552
Precipitation (m)		0.75	0.75	0.75	0.75
Evaporation (m)		0.89	0.88	0.88	0.88

Precipitation and Evaporation
Estimates of annual precipitation and evaporation rates were based on data from the MN Hydrology Guide (SCS 1992). Precipitation and evaporation rates apply only to the lake surface areas.

Atmospheric Deposition
Average phosphorus atmospheric deposition loading rates were estimated to be 0.27 lb/ac-yr for the St. Croix River Basin (MPCA 2004), applied over each lake's surface area. See discussion titled *Atmospheric Deposition* in *Section 3.6.1.2* for more details.

Segment Data: Lake Morphometry and Observed Water Quality
Lake morphometry data were gathered primarily from the MN DNR and aerial photography or were data collected for this study. Data sources are provided in the individual lake TMDL chapters. Observed water quality averages are from the lake assessments (*Section A.2: Lake Assessments*); ten-year (2002-2011) growing season means (June through September) were calculated for total phosphorus, chlorophyll-a, and Secchi transparency.

Tributary Data: Flow Rate and Phosphorus Concentration
All of the watershed sources were combined into a single tributary input for each lake. Watershed phosphorus sources include watershed runoff (including runoff from feedlots), shallow groundwater (including subsurface sewage treatment systems), and loading from upstream waters.

Selection of Equations
Bathtub allows a choice among several different mass balance phosphorus models. For deep lakes in Minnesota, the option of the Canfield-Bachmann lake formulation (Canfield and Bachmann 1981) has proven to be appropriate in most cases. In order to perform a uniform analysis it was selected as the standard equation for the study.

Model Validation
The T statistics for all lake models were less than two; therefore it was assumed that the Canfield-Bachmann lake model was valid for all lakes. Tributary TP concentrations were modified so that the predicted values of total phosphorus matched the observed values. Because it is unknown whether the added load needed to calibrate the models is from internal loading or an unaccounted watershed source, we chose to modify tributary TP concentrations to calibrate the lake models instead of modifying internal loading. The difference in total load between these two methods is small and within the level of uncertainty of the BATHTUB model. Matches were made to the nearest tenth of a microgram per liter.

4.1.1.3 Streams: Load Duration Curve

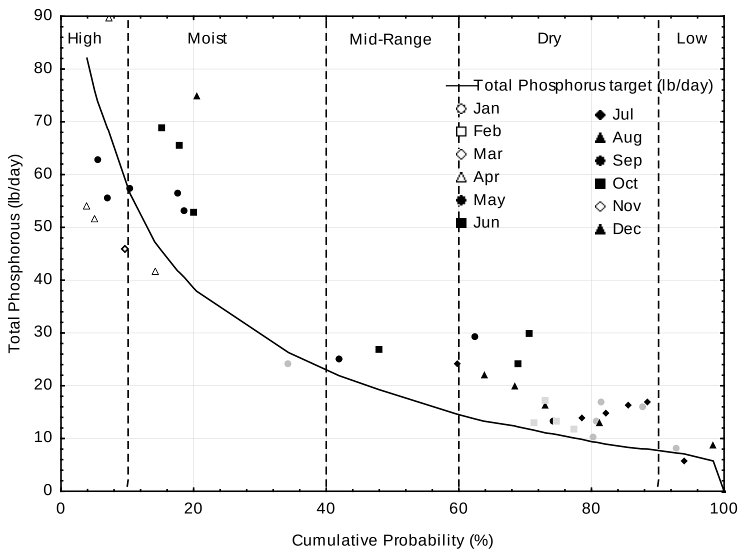
Flow and load duration curves (LDCs) were used to see under which flow regimes the standard exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis.

LDCs take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. The curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The curve represents the pollutant load that can be in the stream (loading capacity) at a particular flow without exceeding the standard for that pollutant. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

The loading capacity for the impaired reaches receiving a total phosphorus TMDL as a part of this study was determined using load duration curves. The LDC was developed using SWAT model results and the flow data at the MN DNR stream gage Sunrise River at Sunrise, CR-88 (37030001). The monitoring record collected at the Sunrise River at Sunrise stream gage contains daily mean flow data for a period of record (2006-2012) that appears to contain the full range of flow conditions. In order to assign flows to the impaired reaches in the upper portions of the watershed, the Sunrise River SWAT model (Almendinger and Ulrich 2010a, Almendinger and Ulrich 2010b; refer to Section 3.6.1, Subsection *Watershed Runoff*) was used to develop an average coefficient of modeled flows. The average coefficient of modeled flows was determined by taking daily modeled flow at the downstream end of the impaired reach divided by the daily modeled flow at the location of the stream gage, which corresponds to the downstream end of the watershed. The average coefficient was generated for a 10-year model simulation period: 2000 to 2009. To generate the weighted flows to be used in the development of the load duration curves, the average coefficient (for each impaired reach) was multiplied by the daily flows collected at the Sunrise River at Sunrise, CR 88 for the 2006 to 2011 period of record.

The loading capacity for the Sunrise River, West Branch (07030005-529) was determined by subtracting the existing load, percent reduction and loading capacity for each flow zone from the Martin-Typo drainage area from the entire drainage area to the downstream end of the impaired reach. The existing load, percent reduction and loading capacity for the Martin-Typo drainage area was determined using the same approach for the Sunrise River WRAPS: monitoring data and the shallow lake standard of 60 µg/L were applied to the area weighted flows generated using output from the Sunrise River SWAT model. The phosphorus load duration curve and monitored data for the Sunrise River, West Branch (07030005-529) is illustrated in Figure 12.

Figure 12. Phosphorus load duration curve and monitored data, West Branch Sunrise River 07030005-529 (2002-2011)



4.1.2 Load Allocations

Load allocations (LAs) represent the portion of the loading capacity that is designated for non-regulated sources or phosphorus, described in Section 3.6.1.2, that are located downstream of any other impaired waters with TMDLs located in the watershed. The LA for each TMDL impairment was determined on an area basis as the TMDL minus the MOS and WWTF WLAs, which is then multiplied by the areal proportion of the TMDL watershed that is *not* considered to be regulated through the MS4 permit (see MS4 Regulated Stormwater below for a discussion on how the regulated watershed areas are those areas designated as *Developed* according to NLCD land cover data).

4.1.3 Wasteload Allocations

Wasteload allocations (WLA) were established for regulated stormwater and NPDES-permitted wastewater treatment facilities (WWTFs) and feedlots that are located downstream of any other impaired waters with TMDLs located in the watershed. Stormwater that is permitted under the NPDES/ SDS program includes regulated Municipal Separate Storm Sewer Systems (MS4), construction stormwater, and industrial stormwater. While there is some regulated watershed runoff in the watersheds, the majority of watershed runoff in the project area is not regulated through NPDES permits. There are no WWTFs receiving phosphorus WLA for the impaired stream and lakes.

Phosphorus loads from watershed runoff were estimated using the existing Sunrise River SWAT model; this approach is described in Section 3.6.1.2. The following is a description of the types of regulated watershed runoff in the project area.

4.1.3.1 MS4 Regulated Stormwater

MS4s are defined by the Minnesota Pollution Control Agency (MPCA) as conveyance systems owned or operated by an entity such as a state, city, town, county, district, or other public body having jurisdiction over disposal of stormwater. A conveyance system includes ditches, roads, storm sewers, stormwater ponds, etc. Certain MS4 discharges are regulated by NPDES/SDS permits administered by the MPCA.

Community storm sewer systems within the TMDL Subwatersheds that serve a population of at least 10,000 and systems with a population of 5,000 or greater and discharging to special or impaired water are required to obtain coverage under the Municipal Separate Storm Sewer System (MS4) General Permit. This permit requires a range of actions to reduce the impact of stormwater from these communities on downstream waterbodies. Since there are likely to be multiple sources of phosphorus contributing to the respective impairments, reductions may be needed from all contributing sources (both regulated and non-regulated entities). The MPCA administers the MS4 Program and is responsible for designating entities when they meet the Rule criteria requiring a permit.

An individual WLA for the City of East Bethel MS4 was determined on an area basis. It is the TMDL minus the Margin of Safety (MOS) and WWTF WLAs, which is then multiplied by the areal proportion of the TMDL watershed that is considered to be regulated through the MS4 permit. The area that falls under municipal MS4 regulation was approximated by the 2006 USGS National Land Cover Dataset (NLCD), a 30-meter grid that characterizes land cover. The following “developed” categories were used to approximate the regulated area in each municipal MS4:

- Developed, open space
- Developed, low intensity
- Developed, medium intensity
- Developed, high intensity

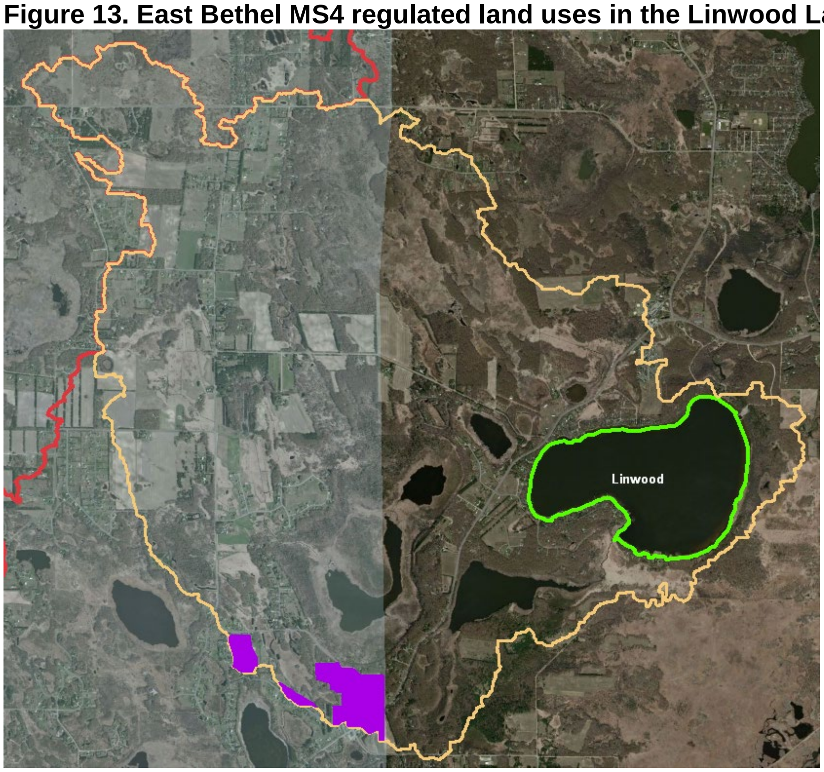
The developed land covers used to approximate the permitted area are appropriate because the MS4 permit covers only land area draining to the regulated MS4 conveyance system, which is assumed to be located in developed areas within the MS4. The remaining land cover categories are natural land covers and were used to approximate the areas *not* regulated by the MS4 permit (associated with the load allocation).

The following municipal MS4s were identified in the TMDL Watersheds (Table 24). The western half of the Linwood Lake watershed is located within the East Bethel MS4. Based on developed land cover data (Figure 13), it is estimated that approximately 111 acres (or 1.6% of the total Linwood watershed) are regulated by the MS4 permit.

Table 24. Municipal MS4s in the Phosphorus TMDL Subwatersheds

MS4	Permit ID	TMDL Watershed	Urban MS4 Area (% Total)
City of East Bethel	MS400087	Linwood Lake	111 acres (1.6%)

Figure 13. East Bethel MS4 regulated land uses in the Linwood Lake watershed



4.1.3.2 Regulated Construction Stormwater

Construction sites can contribute substantial amounts of sediment and phosphorus to watershed runoff. The NPDES/SDS Construction Stormwater Permit administered by the MPCA requires that all construction activity disturbing areas equal to or greater than one acre of land must obtain a permit and create a Stormwater Pollution Prevention Plan (SWPPP) that outlines how runoff pollution from the construction site will be minimized during and after construction. Construction stormwater permits cover construction sites throughout the duration of the construction activities, and the level of on-going construction activity varies.

The categorical WLA for regulated construction stormwater was determined on an area basis. It is the TMDL minus the Margin of Safety (MOS) and WWTF WLAs, which is then multiplied by the estimate of land area (in percent) that was under permit coverage in the watershed in the previous five years (2007-2012).

Table 25. Average annual percent area regulated under the NPDES/SDS Construction Stormwater Permit (2007-2012).

County	Average Annual Percent Area Under Construction (%)
Anoka	0.28%
Chisago	0.06%
Isanti	0.03%

4.1.3.3 Regulated Industrial Stormwater

The NPDES/SDS Industrial Stormwater Multi-Sector General Permit (permit #MN R050000) re-issued in April 2010 applies to facilities with Standard Industrial Classification Codes in 29 categories of industrial activity with the potential for significant materials and activities to be exposed to stormwater. Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite.

Industrial stormwater must receive a WLA only if the pollutant is part of benchmark monitoring for an industrial site in the watershed of an impaired water body (as detailed in the MPCA's June 8, 2011 memo, "Guidance for Setting TMDL Wasteload Allocations for Stormwater and Information on a MPCA-Mn/DOT Memo of Understanding (MOU) Regarding Total Maximum Daily Loads").

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

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

4.1.3.4 Feedlots Requiring NPDES/SDS Permit Coverage

An animal feeding operation (AFO) is a general term for an area intended for the confined holding of animals, where manure may accumulate, and where vegetative cover cannot be maintained within the enclosure due to the density of animals. Animal feeding operations that either (a) have a capacity of 1,000 animal units or more, or (b) meet or exceed the EPA's Concentrated Animal Feeding Operation (CAFO) threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. If item (a) is triggered, the permit can be an SDS or NPDES/SDS permit; if item (b) is triggered, the permit must be an NPDES permit. These permits require that the feedlots have zero discharge to surface water. Based on a desktop review of MPCA database there are no permitted feedlots within this watershed.

4.1.4 Margin of Safety

The margin of safety (MOS) accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload, monitored flows, and in-stream water quality. Ultimately, the MOS accounts for uncertainty that the allocations will result in attainment of water quality standards.

4.1.4.1 Lakes

A 10% explicit MOS was accounted for in the lake TMDLs. This MOS is sufficient to account for uncertainties in predicting loads to the lake and predicting how the lake responds to changes in phosphorus loading. This explicit MOS is considered to be appropriate based on the generally good agreement between the water quality models' predicted and observed values. Since the models reasonably reflect the conditions in the lake and its watershed, the 10% MOS is considered to be adequate to address the uncertainty in the TMDL, based upon the data available.

4.1.4.2 Streams

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Since the TMDL is developed for each of five flow regimes, most of the uncertainty in flow is a result of extrapolating (area-weighting) flows from the hydrologically-nearest stream gage. The explicit MOS, in part, accounts for this.
- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.

4.1.5 Seasonal Variation and Critical Conditions

In-lake and in-stream water quality varies seasonally. In Minnesota lakes and streams, the majority of the watershed phosphorus load often enters during the spring. During the growing season months (June through September), phosphorus concentrations may not change drastically if major runoff events do not occur. However, chlorophyll-a concentration may still increase throughout the growing season due to warmer temperatures fostering higher algal growth rates. In shallow lakes and streams, the phosphorus concentration more frequently increases throughout the growing season due to the additional phosphorus load from internal sources. This can lead to even greater increases in chlorophyll-a since not only is there more phosphorus but temperatures are also higher. This seasonal variation is taken into account in the TMDL by using the eutrophication standards (which are based on growing season averages) as the TMDL goals. The eutrophication standards were set with seasonal variability in mind. The load reductions are designed so that the lakes and streams will meet the water quality standards over the course of the growing season (June through September).

Critical conditions in the impaired lakes and stream occur during the growing season, which is when they are used for aquatic recreation. Similar to the manner in which the standards take into account seasonal variation, since the TMDL is based on growing season averages, the critical condition is covered by the TMDL.

4.1.6 Reserve Capacity and Future Growth

There are no new traditional permitted point sources planned in the watershed, and changes in loading due to land use changes will need to fit within the allocations presented here. No portion of the allowable loading was explicitly set aside as reserve capacity.

A process for incorporating future MS4 regulated areas into the WLAs was established. Future transfer of loads in this TMDL may be necessary if any of the following scenarios occur within a TMDL Subwatershed:

- New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be given additional WLA to accommodate the growth.
- One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
- 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.
- Expansion of an urban area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL was completed, but are now inside a newly expanded urban area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
- A new MS4 or other stormwater-related regulated source is identified and is covered under an 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. Load transfers may occur from LA to WLA or from WLA to WLA according to Table 26. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer.

Table 26. Phosphorus TMDL allocation transfer rates (lb/ac/day)

Impaired Water	Transfer rate (lb/ac/day)				
	High	Moist	Mid	Dry	Low
Sunrise River, West Branch (07030005-529)	0.003	0.001	0.0007	0.0004	0.0003
Linwood Lake (02-0026-00)	0.00045				
Second Lake (13-0025-00)	0.00043				
Vibo Lake (13-0030-00)	0.00025				
White Stone Lake (13-0048-00)	0.00010				

The MPCA, in agreement with the US EPA Region 5, have developed a streamlined process for wasteload allocations (WLAs) for new and expanding wastewater discharges to waterbodies with EPA approved TMDLs. This procedure will be used to update WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are sufficiently restrictive to ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying any and all WLAs after TMDL approval will be handled by the MPCA, with input and involvement of the US 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 US EPA to comment on the changes and recommendations based on the proposed WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that new or expanded WWTF is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made.

4.1.7 TMDL Summary

4.1.7.1 Linwood Lake Phosphorus TMDL

- The lake water quality violates the phosphorus standard.
- Curly leaf pondweed and common carp are present in the lake which can contribute to internal phosphorus load.
- Phosphorus concentration in the deep sediments is high and the lake strongly stratifies, indicating high potential for internal loading from sediment anoxic phosphorus release.
- Potential important sources of phosphorus from the watershed are developed shoreline (60% of the total shoreline), cropland and developed land covers (19% of the total watershed area), and upstream lakes (Boot Lake).
- There are approximately 114 shoreline private on-site septic systems, which are estimated to have an 11.4% failure rate for Anoka County (MPCA 2004). No known imminent threat to public health septic systems (ITPHSS) were recently upgraded.
- The lake model indicated that there is a large phosphorus load (417 lb/yr) that is unaccounted for in the SWAT modeled watershed load. This load is likely a mix of internal load and load from failing septic systems.

To meet the TMDL, the total load to Linwood Lake needs to be reduced by 341 lb/yr (21%). This can be achieved through:

- Internal load reductions of 9% to a rate of 0.15 mg/m^2/day
- SSTS reductions of 22% from upgrading all failing systems (i.e., 0% failure rate)
- Watershed runoff reductions of 27%

Table 27. Linwood Lake Phosphorus TMDL and Allocations

Linwood Lake Load Component		Existing (lb/yr)	TMDL Goal (lb/yr)	TMDL Goal (lb/day)	Reduction (lb/yr)	Reduction (%)
Wasteload Allocations	City of East Bethel (MS400087)	21.3	21.3	0.058	0.0	0%
	Construction stormwater (MNR100001)	3.7	3.7	0.010	0.0	0%
	Industrial stormwater (MNR50000)	3.7	3.7	0.010	0.0	0%
	Total WLA	**28.7**	**28.7**	**0.078**	**0.0**	
Load Allocations*	*Watershed*	*1050.3*	*762.0*	*2.088*	*288.3*	*27%*
	Internal/Unknown	*307.0*	*277.9*	*0.761*	*29.1*	*9%*
	SSTS	*110.3*	*86.4*	*0.237*	*23.9*	*22%*
	Total Watershed/In-lake	1,467.6	1,126.3	3.086	341.3	23%
	Atmospheric	152.3	152.3	0.417	0.0	0%
	Total LA	**1,619.9**	**1,278.6**	**3.503**	**341.3**	
MOS			**145.3**	**0.398**		
TOTAL		**1,648.6**	**1,452.6**	**3.979**		

* LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process.

4.1.7.2 Second Lake Phosphorus TMDL

- The lake water quality violates the phosphorus standard.
- Curly leaf pondweed is present in the lake which can contribute to internal phosphorus loading. However, in-lake phosphorus profiles and sediment phosphorus concentrations do not indicate a high potential for internal loading.
- A potential important source of phosphorus from the watershed is grassland (including pasture and hayland (51% of the total watershed area).
- Legacy loading from historic farming operations near the lake could be a large phosphorus source and there are still some animals within the watershed.
- There are 8 shoreline private on-site septic systems, which are estimated to have a 25% failure rate. One imminent threat to public health septic systems (ITPHSS) was recently upgraded.
- The lake model was calibrated without the addition of any internal/unknown loads, indicating that internal loading in Second Lake is similar in magnitude to natural background rates implicit in the lake model.

To meet the TMDL, the total load to Second Lake needs to be reduced by 72 lb/yr (40%). This can be achieved through:

- SSTS reductions of 42% from upgrading all failing systems (i.e., 0% failure rate)
- Watershed runoff reductions of 45%

Table 28. Second Lake Phosphorus TMDL and Allocations

Second Lake Load Component		Existing	TMDL Goal		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.07	0.07	0.0002	0.00	0%
	Industrial stormwater (MNR50000)	0.07	0.07	0.0002	0.00	0%
	Total WLA	**0.14**	**0.14**	**0.0004**	**0.00**	
Load Allocations*	*Watershed*	*148.5*	*80.9*	*0.222*	*67.6*	*46%*
	Internal/Unknown	*--*	*--*	*--*	*--*	*--*
	SSTS	*10.6*	*6.2*	*0.017*	*4.4*	*42%*
	Total Watershed/In-lake	159.1	87.1	0.239	72.0	45%
	Atmospheric	22.7	22.7	0.062	0.0	0%
	Total LA	**181.8**	**109.8**	**0.301**	**72.0**	
MOS			**12.2**	**0.033**		
TOTAL		**181.9**	**122.1**	**0.334**		

* LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process.

4.1.7.3 Vibo Lake Phosphorus TMDL

- The lake water quality violates the phosphorus standard.
- The lake is shallow and in a turbid, algae-dominated state with few macrophytes.
- Potential important sources of phosphorus from the watershed are cropland and developed land covers (43% of the total watershed area), agricultural ditches, and registered feedlots (13).
- There are 5 shoreline private on-site septic systems, which are estimated to have a 25% failure rate in Chisago County. Twelve imminent threat to public health septic systems (ITPHSS) were recently upgraded within the watershed.
- The lake model indicated that there is a large phosphorus load (1,209 lb/yr) that is unaccounted for in the SWAT modeled watershed load. This load is likely a mix of internal load and load from failing septic systems.

To meet the TMDL, the total load to Vibo Lake needs to be reduced by 9,718 lb/yr (93%). This can be achieved through:

- Internal load reductions of 98% to a rate of 0.15 mg/m^2/day
- SSTS reductions of 42% from upgrading all failing systems (i.e., 0% failure rate)
- Watershed runoff reductions of 92%

Table 29. Vibo Lake Phosphorus TMDL and Allocations

Vibo Lake Load Component		Existing	TMDL Goal		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.4	0.4	0.001	0.0	0%
	Industrial stormwater (MNR50000)	0.4	0.4	0.001	0.0	0%
	Total WLA	**0.8**	**0.8**	**0.002**	**0.0**	
Load Allocations*	*Watershed*	*9,238.2*	*698.0*	*1.912*	*8,540.2*	*92%*
	Internal/Unknown	*1,202.7*	*28.0*	*0.077*	*1,174.7*	*98%*
	SSTS	*6.6*	*3.8*	*0.010*	*2.8*	*42%*
	Total Watershed/In-lake	10,447.5	729.8	1.999	9,717.7	93%
	Atmospheric	15.4	15.4	0.042	0.0	0%
	Total LA	**10,462.9**	**745.2**	**2.041**	**9,717.7**	
MOS			**82.9**	**0.227**		
TOTAL		**10,463.7**	**828.9**	**2.270**		

* LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process.

4.1.7.4 White Stone Lake Phosphorus TMDL

- The lake water quality violates the phosphorus standard.
- Potential important sources of phosphorus from the watershed are cropland and developed land covers (23% of the total watershed area) and registered feedlots (1).
- There are 13 shoreline private on-site septic systems, which are estimated to have a 25% failure rate. No imminent threat to public health septic systems (ITPHSS) were recently upgraded in the watershed.
- The lake model indicated that there is a large phosphorus load (81 lb/yr) that is unaccounted for in the SWAT modeled watershed load. This load is likely a mix of internal load and load from failing septic systems.

To meet the TMDL, the total load to White Stone Lake needs to be reduced by 80 lb/yr (59%). This can be achieved through:

- Internal load reductions of 62% to a rate of 0.15 mg/m^2/day
- SSTS reductions of 42% from upgrading all failing systems (i.e., 0% failure rate)
- Watershed runoff reductions of 81%

Table 30. White Stone Lake Phosphorus TMDL and Allocations

White Stone Lake Load Component		Existing	TMDL Goal		Reduction	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.03	0.03	0.0001	0.00	0%
	Industrial stormwater (MNR50000)	0.03	0.03	0.0001	0.00	0%
	Total WLA	**0.06**	**0.06**	**0.0002**	**0.00**	
Load Allocations*	*Watershed*	*40.9*	*7.7*	*0.021*	*33.2*	*81%*
	Internal/Unknown	*63.5*	*23.9*	*0.065*	*39.6*	*62%*
	SSTS	*17.2*	*10.0*	*0.027*	*7.2*	*42%*
	Total Watershed/In-lake	121.6	41.6	0.114	80.0	66%
	Atmospheric	13.0	13.0	0.036	0.0	0%
	Total LA	**134.6**	**54.6**	**0.150**	**80.0**	
MOS			**6.1**	**0.017**		
TOTAL		**134.7**	**60.8**	**0.167**		

* LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process.

4.1.7.5 Sunrise River West Branch (07030005-529) Martin Lake to Sunrise River (Pool 1) TMDL

- There are no waste water treatment facilities in the watershed.
- No imminent threat to public health septic systems (ITPHSS) were recently upgraded in the watershed.
- Approximately 47% of the watershed is forested, and 15% is cropland or developed.
- The West Branch receives discharge from Martin Lake with TP concentrations exceeding state water quality standards. A TMDL is approved for Martin Lake to reduce in-lake TP.

To meet the TMDL, the total load to the Sunrise River West Branch from the direct drainage area (downstream of Martin Lake) needs to be reduced by 12-18% under mid-range to dry flow conditions. In addition, the total load from the upstream contributing drainage area (i.e., Martin Lake) also needs to be reduced by 2,973 lb/yr (41%) to meet water quality goals.

Table 31. Sunrise River West Branch (07030005-529) TMDL and Allocations

Sunrise River West Branch (07030005-529) Load Component		Flow Regime				
		High	Wet	Mid	Dry	Low
		(lb/day)				
	Existing Load	**60**	**55**	**25.3**	**17.1**	**5.7**
	Modified Existing Load*	**58.6**	**12.6**	**21**	**13.1**	**2.9**
Wasteload Allocations	*Construction stormwater (MNR100001)*	*4.1*	*1.79*	*0.99*	*0.58*	*0.37*
	Industrial stormwater (MNR50000)	*4.1*	*1.79*	*0.99*	*0.58*	*0.37*
	Total WLA**	**8.2**	**3.58**	**1.98**	**1.16**	**0.74**
Load Allocations	*Watershed runoff*	*26*	*11.3*	*6.33*	*3.64*	*2.33*
	*Upstream lake (Martin Lake)****	*34.2*	*15*	*8.27*	*4.83*	*3.07*
	Total LA	**60.2**	**26.3**	**14.6**	**8.47**	**5.4**
	MOS	**7.6**	**3.32**	**1.84**	**1.07**	**0.68**
	Total Loading Capacity	**76**	**33.2**	**18.4**	**10.7**	**6.82**
	Estimated Load Reduction	**0%**	**0%**	**12%**	**18%**	**0%**

* The modified existing load accounts for future load reductions as part of the Martin Lake TMDL.

** No WWTF, NPDES Permitted Feedlots or Communities Subject to MS4 NPDES requirements are located in the watershed.

*** A TMDL for excess phosphorous has been completed for Martin Lake and includes a WLA, LA and MOS for its drainage area. The load allocation presented here applies only to the -529 drainage area downstream of Martin Lake.

4.2 Escherichia Coli

4.2.1 Load Capacity

4.2.1.1 Streams: Load Duration Curve

Flow and load duration curves (LDCs) were used to see under which flow regimes the standard exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. LDCs take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. The curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The curve represents the pollutant load that can be in the stream (loading capacity) at a particular flow without exceeding the standard for that pollutant. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

The loading capacity for the impaired reaches receiving an *E. coli* TMDL as a part of this study was determined using load duration curves. The LDC was developed using SWAT model results and the flow data at the MN DNR stream gage Sunrise River at Sunrise, CR-88 (37030001). The monitoring record collected at the Sunrise River at Sunrise stream gage contains daily mean flow data for a period of record (2006-2012) that appears to contain the full range of flow conditions. In order to assign flows to the impaired reaches in the upper portions of the watershed, the Sunrise River SWAT model (Almendinger and Ulrich 2010a, Almendinger and Ulrich 2010b; refer to Section 3.6.1, Subsection *Watershed Runoff* on Page 28) was used to develop an average coefficient of modeled flows. The average coefficient of modeled flows was determined by taking daily modeled flow at the downstream end of the impaired reach divided by the daily modeled flow at the location of the stream gage, which corresponds to the downstream end of the watershed. The average coefficient was generated for a 10-year model simulation period: 2000 to 2009. To generate the weighted flows to be used in the development of the load duration curves, the average coefficient (for each impaired reach) was multiplied by the daily flows collected at the Sunrise River at Sunrise, CR 88 for the 2006 to 2011 period of record.

The loading capacity for the Sunrise River (07030005-543) was determined by subtracting contributions from the following upstream sources: Hay Creek (07030005-545), Sunrise River, North Branch (07030005-501), the drainage area contributing to the North Pool of the Carlos Avery Wildlife Management Area (area draining to subwatershed 57) and the drainage area contributing to the Chisago Chain-of-Lakes (area draining to subwatershed 84). The E. coli standard of 126 org/100 ml [billion org/day] was applied to monitored flows on the North Branch to determine the loading capacity of this portion of the system. However, in the case of the North Pool (aka Pool 3) of the Carlos Avery Wildlife Management Area and Chisago Lake, there is no E. coli monitoring data: as a result, it was assumed that discharge from these waterbodies met the standard of 126 org/100 ml [billion org/day]. The *E. coli* load duration curve and monitored data for the Sunrise River (07030005-543) is illustrated in Figure 14.

The loading capacity for Hay Creek (07030005-545) was determined directly from the contributing drainage area. The *E. coli* load duration curve and monitored data for Hay Creek (07030005-545) is illustrated in Figure 15.

Figure 14. *E. coli* load duration curve and monitored data for Sunrise River, 07030005-543 (2002-2011)

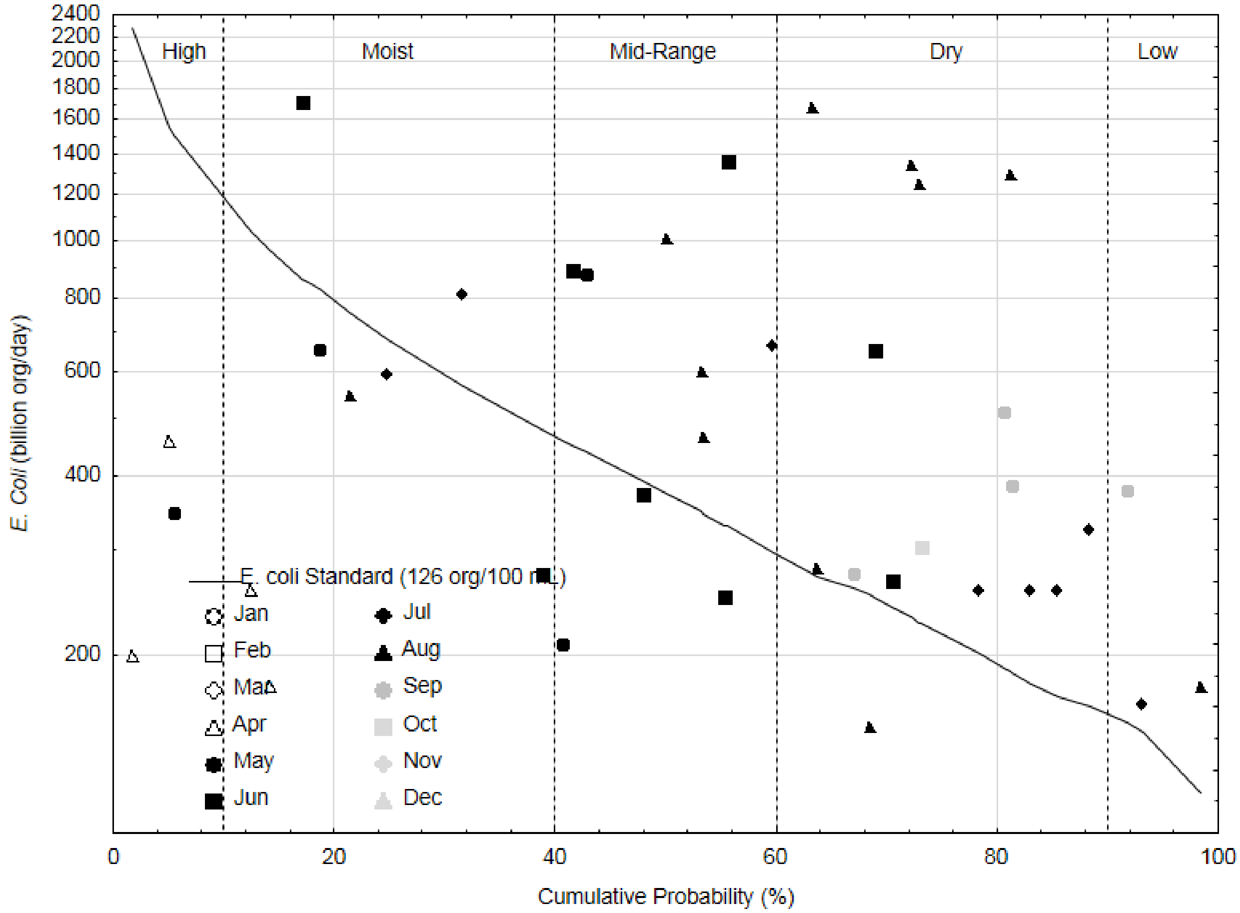
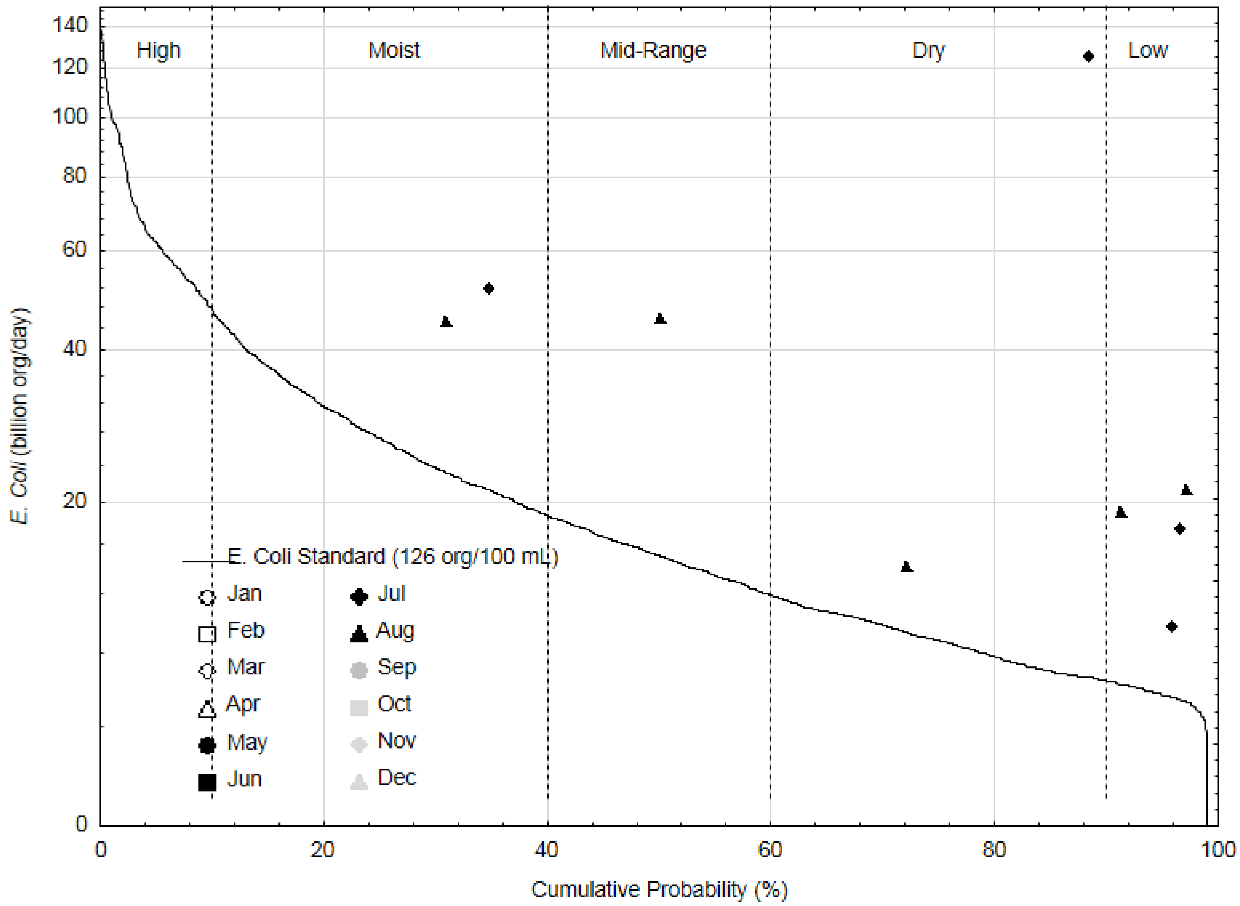


Figure 15. *E. coli* load duration curve and monitored data for Hay Creek, 07030005-545 (2002-2011)



4.2.2 Load Allocations

Load allocations (LAs) represent the portion of the loading capacity that is designated for non-regulated sources of *E. coli*, described in Section 3.6.1.2, that are located downstream of any other impaired waters with TMDLs located in the watershed. The LA for each TMDL impairment was determined on an area basis as the TMDL minus the MOS and WWTF WLAs, which is then multiplied by the areal proportion of the TMDL watershed that is *not* considered to be regulated through the MS4 permit (see MS4 Regulated Stormwater below for a discussion on how the regulated watershed areas are those areas designated as *Developed* according to NLCD land cover data).

4.2.3 Wasteload Allocations

Wasteload allocations (WLA) were established for regulated stormwater and NPDES-permitted wastewater treatment facilities (WWTFs) and feedlots that are located downstream of any other impaired waters with TMDLs located in the watershed. Stormwater that is permitted under the NPDES/ SDS program includes regulated Municipal Separate Storm Sewer Systems (MS4), construction stormwater, and industrial stormwater. While there is some regulated watershed runoff in the watersheds, the majority of watershed runoff in the project area is not regulated through NPDES permits.

4.2.3.1 Regulated MS4 Stormwater

MS4s are defined by the Minnesota Pollution Control Agency (MPCA) as conveyance systems owned or operated by an entity such as a state, city, town, county, district, or other public body having jurisdiction over disposal of stormwater. A conveyance system includes ditches, roads, storm sewers, stormwater ponds, etc. Certain MS4 discharges are regulated by NPDES/SDS permits administered by the MPCA.

Community storm sewer systems within the TMDL Subwatersheds that serve a population of at least 10,000 and systems with a population of 5,000 or greater and discharging to a special or impaired water are required to obtain coverage under the Municipal Separate Storm Sewer System (MS4) General Permit. This permit requires a range of actions to reduce the impact of stormwater from these communities on downstream waterbodies. Since there are likely to be multiple sources of bacteria contributing to the respective impairments, reductions may be needed from all contributing sources (both regulated and non-regulated entities). The MPCA administers the MS4 Program and is responsible for designating entities when they meet the Rule criteria requiring a permit. The following municipal MS4s were identified in the TMDL Watersheds (Table 32):

Table 32. Municipal MS4s in the *E. coli* TMDL Subwatersheds

MS4	Permit ID	TMDL Watershed
City of North Branch	MS400260	Hay Creek (Beaver Creek to Sunrise R), AUID 07030005-545

An individual WLA for the City of North Branch MS4 was determined on an area basis. It is the TMDL minus the Margin of Safety (MOS) and WWTF WLAs, which is then multiplied by the areal proportion of the TMDL watershed that is considered to be regulated through the MS4 permit. The area that falls under municipal MS4 regulation was approximated by the 2006 USGS National Land Cover Dataset (NLCD), a 30-meter grid that characterizes land cover. The following "developed" categories were used to approximate the regulated area in each municipal MS4:

- Developed, open space
- Developed, low intensity
- Developed, medium intensity
- Developed, high intensity

The developed land covers used to approximate the permitted area are appropriate because the MS4 permit covers only land area draining to the regulated MS4 conveyance system, which is assumed to be located in developed areas within the MS4. The remaining land cover categories are natural land covers and were used to approximate the areas *not* regulated by the MS4 permit (associated with the load allocation).

4.2.3.2 Regulated Construction Stormwater

E. coli WLAs for regulated construction stormwater (permit #MN R100001) were not developed since *E. coli* is not a typical pollutant from construction sites. Construction stormwater WLAs are developed where the pollutant or stressor is TSS, phosphorus, dissolved oxygen, or biota (as detailed in the MPCA's June 8, 2011 memo, "Guidance for Setting TMDL Wasteload Allocations for Stormwater and Information on a MPCA-Mn/DOT Memo of Understanding (MOU) Regarding Total Maximum Daily Loads").

4.2.3.3 Regulated Industrial Stormwater

There are no *E. coli* benchmarks associated with the industrial stormwater permit because no industrial sectors regulated under the permit are known to be *E. coli* sources. Therefore, *E. coli* TMDLs will not include an industrial stormwater WLA. Since sites with MNG permits are not known to be sources of *E. coli*, sites with MNG permits that are within the *E. coli* TMDL Subwatersheds will not receive an *E. coli* WLA.

4.2.3.4 Municipal and Industrial Wastewater Treatment Systems

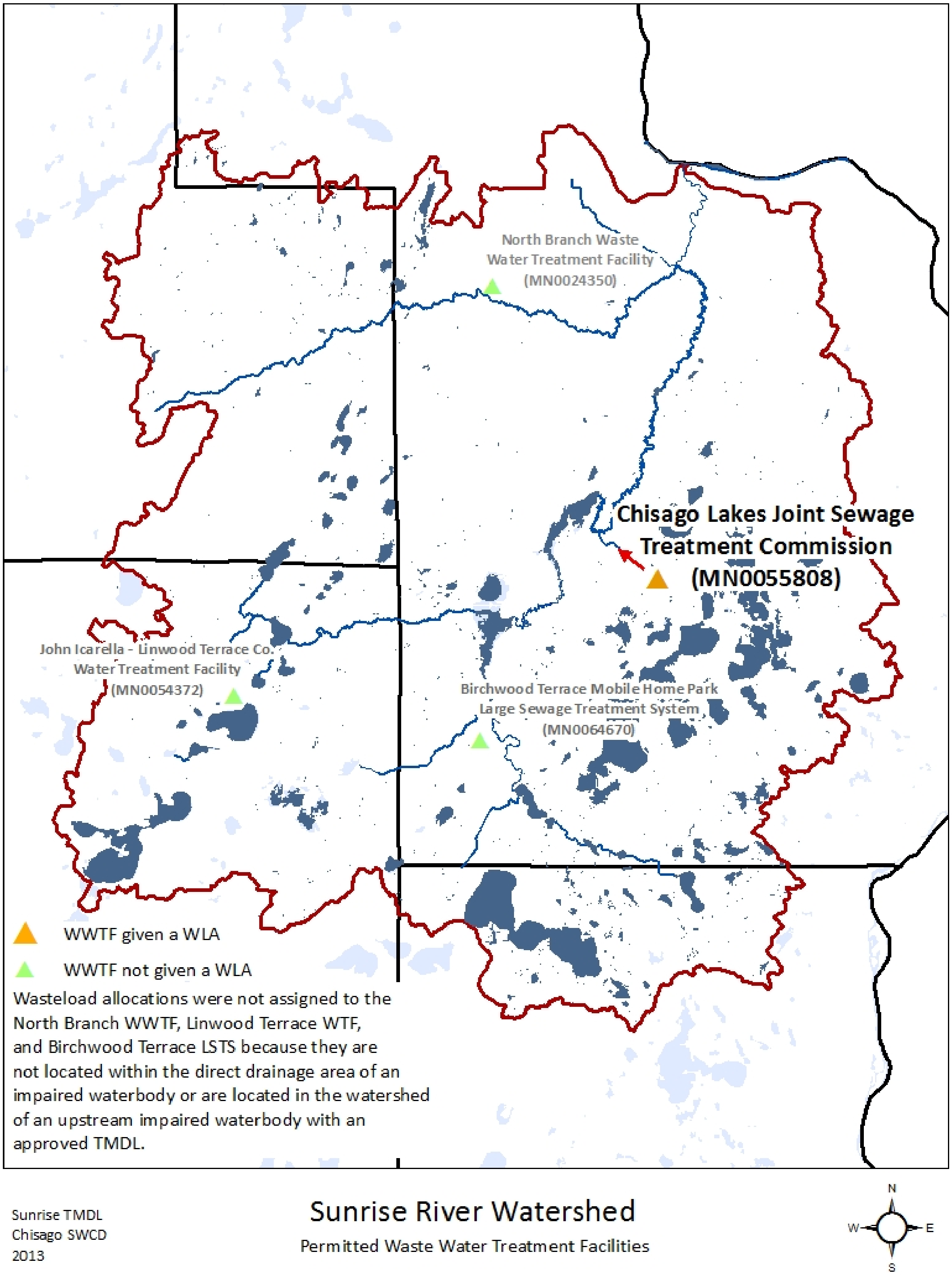
WLAs were provided for all NPDES-permitted WWTFs that have fecal coliform discharge limits (200 org/100mL, April 1 through October 31) and whose surface discharge stations fall within the TMDL Subwatersheds. Based on a desktop review of MPCA data there is one NPDES permitted wastewater facilities within the Sunrise River TMDL Subwatershed impaired for aquatic recreation due to *E. coli* (AUID 07030005-543) (Table 33). The WLA was calculated as the *E. coli* standard (126 org/100mL) multiplied by the average wet weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. Unlike the stream TMDL the WLAs for the WWTFs do not vary based on instream flow.

The WLAs are based on *E. coli* loads even though the facilities' discharge limits are based on fecal coliform. If a discharger is meeting the fecal coliform limits of their permit, it is assumed that they are also meeting the *E. coli* WLA in these TMDLs. Expanding and new dischargers permitted at the fecal coliform limit will be added to the *E. coli* WLA via the NPDES permit public notice process (see Section 4.2.6 for a discussion regarding new or expanded WWTFs).

Table 33. NPDES-permitted WWTFs in the TMDL Subwatersheds.

Permit Name (Number)	Permitted Discharge (million gal/day)	Relevant Permit Effluent Limits	Type	TMDL Subwatershed
Chisago Lakes Joint STC (MN0055808)	2.46	*E. coli*: 126 org /100 mL	Continuous domestic wastewater discharge	Sunrise River (N Br Sunrise R to St Croix R), AUID 07030005-543

Figure 16. Permitted Waste Water Treatment Facilities



4.2.3.5 Feedlots Requiring NPDES/SDS Permit Coverage

An animal feeding operation (AFO) is a general term for an area intended for the confined holding of animals, where manure may accumulate, and where vegetative cover cannot be maintained within the enclosure due to the density of animals. Animal feeding operations that either (a) have a capacity of 1,000 animal units or more, or (b) meet or exceed the EPA's Concentrated Animal Feeding Operation (CAFO) threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. If item (a) is triggered, the permit can be an SDS or NPDES/SDS permit; if item (b) is triggered, the permit must be an NPDES permit. These permits require that the feedlots have zero discharge to surface water. Based on a desktop review of MPCA data there are no permitted feedlots within this watershed. There are feedlots within this watershed, but none are large enough to trigger the MPCA permit requirements. The non-permitted feedlots are referenced in the non-point source inventory section (3.6.1.2 Non-permitted Sources of Phosphorus)

4.2.4 Margin of Safety

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Since the TMDL is developed for each of five flow regimes, most of the uncertainty in flow is a result of extrapolating (area-weighting) flows from the hydrologically-nearest stream gage. The explicit MOS, in part, accounts for this.
- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.
- With respect to the *E. coli* TMDLs, the load duration analysis does not address bacteria re-growth in sediments, die-off, and natural background levels. The MOS helps to account for the variability associated with these conditions.

4.2.5 Seasonal Variation and Critical Conditions

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

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

4.2.6 Reserve Capacity and Future Growth

Refer to the narrative developed for Phosphorus in 4.1.6 Reserve Capacity and Future Growth. Load transfers may occur from LA to WLA or from WLA to WLA according to Table 34. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer.

Table 34. *E. coli* TMDL allocation transfer rates

Impaired Water	Transfer rate (Billion org/day/ac)				
	High	Wet	Mid	Dry	Low
Sunrise River (07030005-543)	0.014	0.005	0.002	0.00014	0.00
Hay Creek (07030005-545)	0.006	0.003	0.002	0.00088	0.00056

4.2.7 TMDL Summary

4.2.7.1 Sunrise River (07030005-543) North Branch Sunrise River to St. Croix River

- Almost all of the 29 subwatersheds in the direct drainage area have high potential for bacterial contributions from wildlife (e.g. raccoons, deer, geese, and feral cats).
- The eastern portion of the direct drainage area (subwatersheds 38, 39 and 46) has medium-high potential for one or more of the following:
    - Illicit discharges from unsewered communities
    - Grazing of livestock
    - Animal feeding operations
    - Land application of manure
- One subwatershed in the lower eastern portion of the direct drainage area (subwatershed 13) has medium-high potential for the grazing of livestock.
- All subwatersheds in the direct drainage area have at least low potential for one or more of the following:
    - Illicit discharges from unsewered communities
    - Land application of septage
    - Companion animals
    - Wildlife

Table 35. Sunrise River (07030005-543) *E. coli* TMDL and allocations for the direct drainage area

Sunrise River (07030005-543) Load Component		Flow Regime				
		High	Wet	Mid	Dry	Low
		Billion organisms per day				
Existing Load		333.7	2,058.7	669.7	733.2	120
Modified Existing Load*		0	796.7	24.1	339.2	0
Wasteload Allocation	*Chisago Lakes Joint STC (MN0055808)*	*11.7*	*11.7*	*11.7*	*11.7*	*11.7*
	Total WLA**	11.7	11.7	11.7	11.7	11.7
Load Allocation	*Watershed runoff*	*624.5*	*209.4*	*75.7*	*6.4*	*0*
	*Upstream load (North Branch Fecal Coliform TMDL)****	*759.8*	*389.3*	*250.1*	*178.9*	*113.5*
	Total LA	1,384.3	598.7	325.8	185.3	113.5
MOS		155.1	67.8	37.5	21.9	13.9
Total Loading Capacity		1,551.1	678.2	375	218.9	139.1
Estimated Load Reduction		0%	19%	0%	38%	0%

* The modified existing load accounts for future load reductions as part of the North Branch Fecal Coliform TMDL as well as the assumption that the discharge from the Carlos Avery Wildlife Management Area and the Chisago Chain of Lakes meets the standard of 126 org/100 ml [billion org/day]. Refer to Section 3.3 Subwatersheds for the drainage area covered by this TMDL.

** No NPDES Permitted Feedlots or Communities Subject to MS4 NPDES requirements are located in the watershed.

*** A TMDL for excess fecal coliform has been completed for the Sunrise River (North Branch) and includes a WLA, LA and MOS for its drainage area. The WLA and LA presented here apply only to the -543 drainage area downstream of the Sunrise River (North Branch). Note that load allocations for fecal coliform have been converted to E. coli measurements at a ratio of 200 to 126 (equivalent to 0.63) per the MPCA Bacteria TMDL Protocols and Submittal Requirements, Revised March 2009.

4.2.7.2 Hay Creek (07030005-545) Beaver Creek to Sunrise River

- Over half of the subwatersheds appear to have a high potential for bacterial contributions from wildlife (e.g. raccoons, deer, geese, and feral cats).
- Middle portion of the drainage area (subwatershed 3) has high potential for illicit discharges from unsewered communities and bacterial contributions from wildlife (e.g. raccoons, deer, geese, and feral cats).
- Southwestern portion of the subwatershed (subwatershed 8) has high potential for land application of manure.
- All subwatersheds have at least low potential for one or more of the following:
  - Illicit discharges from unsewered communities
  - Land application of septage
  - Companion animals
  - Wildlife

Table 36. Hay Creek (07030005-545) *E. coli* TMDL and allocations

Hay Creek (07030005-545) Load Component		Flow Regime				
		High	Wet	Mid	Dry	Low
		lb/day				
Existing Load		**No data**	**48.4**	**45.9**	**69.8**	**16.8**
Wasteload Allocations	*City of North Branch (MS400260)*	*1.4*	*0.61*	*0.34*	*0.2*	*0.13*
	Total WLA	**1.4**	**0.61**	**0.34**	**0.2**	**0.13**
Load Allocations	*Watershed runoff*	*54.4*	*23.8*	*13.2*	*7.67*	*4.87*
	Total LA	**54.4**	**23.8**	**13.2**	**7.67**	**4.87**
MOS		**6.2**	**2.71**	**1.5**	**0.88**	**0.56**
Total Loading Capacity		**62**	**27.1**	**15**	**8.75**	**5.56**
Estimated Load Reduction		**N/A**	**44%**	**67%**	**87%**	**67%**

* Loading capacities and allocations for 545 based on a limited amount of data: July and August only.

5 REASONABLE ASSURANCES

5.1 Non-regulatory

At the local level, the Anoka Conservation District, Chisago Soil & Water Conservation District, Isanti Soil & Water Conservation District, Washington Conservation District, Sunrise River Water Management Organization, Comfort Lake Forest Lake Watershed District and other local entities currently implement programs that target improving water quality and have been actively involved in projects to improve water quality in the past. It is assumed that these activities will continue. Potential state funding of Restoration and Protection projects include Clean Water Fund grants. At the federal level, funding can be provided through Section 319 grants that provide cost-share dollars to implement activities in the watershed. Various other funding and cost-share sources exist, which will be listed in the Sunrise River WRAPS. The restoration strategies that will be identified in this document have demonstrated to be effective in reducing nutrient loading to lakes and streams. There are programs in place within the watershed to continue implementing the recommended activities. Each County and SWCD within the watershed have been working with producers, landowners, local government units, businesses, and other partners for over 50 years to install many types of BMPs including: bioretention, filter strips, water and sediment control basins, conservation tillage, manure storage facilities, tree plantings, native grass plantings, etc. The SWCDs and Counties have skilled staff available for assessments, design, and technical assistance. Monitoring will continue and adaptive management will be in place to evaluate the progress made towards achieving water quality goals.

5.2 Regulatory

5.2.1 Regulated Construction Stormwater

State implementation of the TMDL will be through action on NPDES permits for regulated construction stormwater. To meet the WLA for construction stormwater, construction stormwater activities are required to meet the conditions of the Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

5.2.2 Regulated Industrial Stormwater

To meet the WLA for industrial stormwater, industrial stormwater activities are required to meet the conditions of the industrial stormwater general permit or Nonmetallic Mining & Associated Activities general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

5.2.3 Municipal Separate Storm Sewer System (MS4) Permits

Stormwater discharges associated with MS4s are regulated through National Pollutant Discharge Elimination System/State Disposal System (NPDES/SDS) permits. The Stormwater Program for MS4s is designed to reduce the amount of sediment and pollution that enters surface and ground water from storm sewer systems to the maximum extent practicable. MS4 Permits require the implementation of BMPs to address WLAs. In addition, the owner or operator is required to develop a stormwater pollution prevention program (SWPPP) that incorporates best management practices (BMPs) applicable to their MS4. The SWPPP must cover six minimum control measures:

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

5.2.4 Wastewater & State Disposal System (SDS) Permits

The MPCA issues permits for wastewater treatment facilities that discharges into waters of the state. The permits have site specific limits on bacteria that are based on water quality standards. Permits regulate discharges with the goals of 1) protecting public health and aquatic life, and 2) assuring that every facility treats wastewater. In addition, SDS permits set limits and establish controls for land application of sewage.

5.2.5 Subsurface Sewage Treatment Systems Program (SSTS)

Subsurface Sewage Treatment Systems (SSTS), commonly known as septic systems, are regulated by Minnesota Statutes 115.55 and 115.56.
These regulations detail:

- Minimum technical standards for individual and mid-size SSTS;
- A framework for local administration of SSTS programs and;
- Statewide licensing and certification of SSTS professionals, SSTS product review and registration, and establishment of the SSTS Advisory Committee.

5.2.6 Feedlot Rules

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

There are two primary concerns about feedlots in protecting water:

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

6 MONITORING PLAN

6.1 Stream Monitoring

Each stream reach within the Sunrise River Watershed has a different monitoring schedule depending on who monitors the site.

Many Sunrise River Watershed sites in Anoka, Chisago, Isanti, and Washington Counties have been monitored through the years. There is currently not a watershed wide stream monitoring program. The pour point site (AUID 07030005-543) for the Sunrise that is in Sunrise, MN is monitored every year by MPCA's Load Monitoring Program that is funded through the Clean Water Fund for a variety of parameters including: continuous flow, total suspended solids, total phosphorus, total Kjeldahl nitrogen, and nitrates.

If funding is available, the SWCDs will set up a monitoring program to monitor for nutrients, E. coli, and flow. Ideally it would be a twice per month plus storm event program. If funding is not available for new monitoring programs, the monitoring that is completed will be done following MPCA's 10-year monitoring cycle.

Other streams within this watershed that are not included in this report are monitored on a regular basis.

Please refer to the following websites for monitoring plans and reports:

Table 37 - Monitoring Plans and Reports

Entity	Website
Anoka Conservation District	http://www.anokaswcd.org/index.php?option=com_content&view=article&id=119&Itemid=475
Chisago SWCD	www.chisagoswcd.org
Comfort Lake-Forest Lake Watershed District	http://www.clflwd.org/programs.php
Washington Conservation District	http://www.mnwcd.org/water_monitoring.php

6.2 Lake Monitoring

The Linwood Lake has been monitored by volunteers and staff over the years. This monitoring is planned to continue approximately every third year to keep a record of the changing water quality. The Lake is generally monitored for chlorophyll-a, total phosphorus, and Secchi disk transparency.

Second Lake is within the CLFLWD, the District has planned to do some investigative monitoring of surface total phosphorus, chlorophyll-a, Secchi disk transparency, dissolved oxygen profile, sediment sampling, and biological data collection in 2020 and 2021. Information on monitoring schedules for other lakes within the CLFLWD can be found in the Comfort Lake Forest Lake Watershed District 2012 Comprehensive Monitoring Plan.

No monitoring plans exist for White Stone Lake or Vibo Lake. Lakeshore owners and volunteers will be encouraged to monitor through the MPCA Citizen Assisted Monitoring Program in the future or have lakes added to a County wide monitoring program to be set up in the future.

The MN DNR will continue to conduct macrophyte and fish surveys as allowed by their regular schedule. Currently fish surveys are conducted every 5 years and macrophyte surveys are conducted as staffing and funding allow on a 10-year rotation, unless there are special situations – this mostly applies to Linwood Lake. The smaller lakes without public access are surveyed if the opportunity arises.

6.3 BMP Monitoring

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

7 IMPLEMENTATION STRATEGY

7.1 Adaptive Management

The response of the lakes and streams will be evaluated as management practices are implemented. This evaluation will occur every five years after the commencement of implementation actions; for the next 25 years. Data will be evaluated and decisions will be made as to how to proceed for the next five years. The management approach to achieving the goals should be adapted as new information is collected and evaluated.

7.2 Stormwater Ordinances

Each County within the Sunrise River Watershed has their own county-wide stormwater ordinance or individual municipality stormwater ordinances. In Anoka County, municipalities have these ordinances which must be consistent with the Sunrise River Watershed Management Organization (SRWMO). More information can be found on the websites listed below. Stormwater ordinances are necessary to regulate stormwater and erosion control for new developments.

Table 38. County Websites

Organization	Website
Anoka County	www.co.anoka.mn.us
Linwood Township	www.linwoodtownship.org
City of East Bethel	www.ci.east-bethel.mn.us
Chisago County	www.co.chisago.mn.us
City of Wyoming	www.wyomingmn.org/
City of North Branch	www.ci.north-branch.mn.us/
Isanti County	www.co.isanti.mn.us
Washington County	www.co.washington.mn.us
City of Forest Lake	www.ci.forest-lake.mn.us/
City of Scandia	www.ci.scandia.mn.us/
Sunrise River Watershed Management Organization	www.srwmo.org

7.3 Subwatershed Assessments

Urban subwatershed assessments have been developed for portions of the Sunrise Watershed. However, none of the assessments have been completed on sections of the watershed included in this report. These assessments help guide implementation activities by determining the potential runoff load as well as identifying the most logical locations to start with Best Management Practice (BMP) implementation. Local decision makers and the SWCDs use the subwatershed assessments to prioritize implementation activities and apply for funding.

Table 39. Subwatershed Assessments

Assessment Name	Year	Data Location
Anoka CD Assessments		
Martin Lake	2012	http://www.anokaswcd.org/index.php
Coon Lake	To be completed in 2013	
Chisago SWCD Assessments		
City of Lindstrom	2011	http://www.chisagoswcd.org/
Center City	2011	
Chisago City	2012	
Chisago Watershed Rural Assessment	To be completed in 2013	
Washington CD Assessments		
City of Forest Lake (South)	To be completed in 2013	http://www.clflwd.org/

7.4 Prioritization

Prioritization of implementation activities is going to be key in achieving the necessary reductions with the current level of funds and staff time available. Examples of prioritizing BMPs will include focusing on watershed loading reductions for lakes and stream reaches before implementing any major in-lake treatment efforts.

7.5 Education and Outreach

A crucial part in the success of the Restoration and Protection plan that will be designed to clean up the impaired lakes and streams and protect the non-impaired water bodies will be participation from local citizens. In order to gain support from these citizens, education and civic engagement opportunities will be necessary. A variety of educational avenues can and will be used throughout the watershed. These include (but are not limited to): press releases, meetings, workshops, focus groups, trainings, websites, etc. Local staff (conservation district, watershed, county, etc.) and board members work to educate the residents of the watersheds about ways to clean up their lakes and streams on a regular basis. Education will continue throughout the watershed.

The Comfort Lake Forest Lake Watershed District is a part of the East Metro Water Resource Education Program. The EMWREP is a city-county-watershed partnership formed to protect and improve local surface and groundwater resources through education and outreach.

7.6 Technical Assistance

The Anoka CD, Chisago SWCD, Isanti SWCD, and Washington CD provide assistance to landowners for a variety of projects that benefit water quality throughout the Sunrise River Watershed. Assistance provided to landowners varies from agricultural and rural best management practices to urban and lakeshore best management practices. This technical assistance includes education and one-on-one training. Many opportunities for technical assistance are as a result of educational workshops of trainings. It is important that these outreach opportunities for watershed residents continue. Marketing is necessary to motivate landowners to participate in voluntary cost-share assistance programs.

Technical assistance is provided by a variety of entities, including but not limited to the Anoka CD, Chisago SWCD, Isanti SWCD Washington CD, and NRCS. Programs such as State cost-share, Watershed District cost-share, Clean Water Legacy funding, Environmental Quality Incentives Program (EQIP), Conservation Reserve Program (CRP) are available to help implement the best conservation practices that each parcel of land is eligible for to target the best conservation practices per site. Conservation practices may include, but are not limited to: stormwater bioretention, septic system upgrades, feedlot improvements, invasive species control, wastewater treatment practices, agricultural and rural best management practices and internal loading reduction. More information about types of practices and implementation of BMPs will be discussed in the Sunrise River Watershed Restoration and Protection Plan.

7.7 Partnerships

Partnerships with counties, cities, townships, citizens, businesses, watersheds, and lake associations are one mechanism through which the Anoka CD, Chisago SWCD, Isanti SWCD, and Washington CD will protect and improve water quality. Strong partnerships with state and local government to protect and improve water resources and to bring waters within the Sunrise River Watershed into compliance with State standards will continue. A partnership with local government units and regulatory agencies such as cities, townships and counties may be formed to develop and update ordinances to protect the areas water resources.

7.8 Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation of the cost to implement a TMDL [MN Statutes 2007, section 114D.25]. The initial estimate for implementing the Sunrise River Watershed Restoration and Protection Plan is approximately $3,000,000 to $5,500,000. This estimate will be refined when the more detailed implementation plan is developed.

8 STAKEHOLDER PARTICIPATION

8.1 Steering Committee

On December 11, 2012 a Sunrise River Watershed Steering Committee meeting was held to discuss initial findings of the impaired lake models and preliminary information on the impaired stream segments. Groups and Agencies in attendance included: MN DOT, MN DNR (Fisheries and Eco/Waters), City of Wyoming, City of North Branch, Chisago County, Chisago SWCD, Anoka Conservation District, MPCA, USDA NRCS, Friends of the Sunrise River, Linwood Lake Improvement Association, Isanti County, and Emmons & Olivier Resources.

On January 9, 2013 a meeting was held to discuss the potential stressors within the Sunrise River Watershed. The group discussed if a TMDL calculation would be done on each of the impaired stretches of the Sunrise. Discussion also took place on the management activities within Carlos Avery Wildlife Management Area. A meeting will be scheduled to discuss this with DNR Wildlife Staff.

On January 28, 2013 SWCD staff met with DNR Eco/Waters and DNR Wildlife to talk about management strategies and activities that take place in Carlos Avery Wildlife Management Area on or near impaired stream reaches. DNR would like to be involved in the implementation plan phase of the WRAPS to discuss possibilities to improve water quality of the Sunrise River.

Other studies of the Sunrise River Watershed also exist. The U.S. Army Corps of Engineers is currently working on a Sunrise River Watershed Study. This study also included stakeholder participation in 2007 and 2008.

8.2 Public Meetings

On December 11, 2012 a Sunrise River Watershed Public meeting was held to discuss initial findings of the impaired lake models and preliminary information on the impaired stream segments. Five citizens attended the meeting.

Updates are provided to the Linwood Lake Association as information is gathered. The most recent update was provided by the Anoka Conservation District on July 14, 2012.

8.3 Farmer Focus Group Meetings

Farmer Focus Group meetings were held on March 28, 2011 and April 3, 2012 with a group of influential agricultural producers within Chisago County, local Agronomists, along with Chisago Soil & Water Conservation District and USDA Natural Resources Conservation Service staff. The focus of the meeting was the local TMDL studies currently happening in Chisago County. Statistics were shared with the group that included pollutant runoff potentials from different land uses; this showed that due to the large amount of land in agricultural production, there is the potential to reduce pollutant runoff in large quantities. The producers are interested in maximizing their production while preventing soil and nutrient loss.

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APPENDIX A. IMPAIRED WATERS CONDITION

A.1 Determination of Stream Conditions

A.1.1 Water Quality

Escherichia coli

Ten year growing season means were calculated for *E. coli* from the most recent ten-year (2002-2011) time period. Data were obtained from the MPCA Environmental Data Access database in April of 2012. *E. coli* concentrations were compared to the in-stream standard of 126 organisms per 100 mL. *E. coli* concentrations that exceed the numeric standard of 126 org/100mL are individual observations and are not, independently, used to determine whether the waterbody is impaired. In addition, the state standard applies only from April to October, but this analysis evaluates exceedances throughout the calendar year. Data are summarized using a geometric mean; therefore, a minimum of five samples per month was preferred.

Total Phosphorus

Ten year growing season means were calculated for total phosphorus (TP) from the most recent ten-year (2002-2011) time period. For Class 2B/3C waters, the standard for TP is 0.1 mg/L. Data were obtained from the MPCA Environmental Data Access database in April of 2012. Chlorophyll-a and DO flux data were not available for reach -529; therefore, no such data is shown. Figure 21 and Figure 22 illustrate data from all stations along the reach because the station furthest downstream only had one sample from two non-consecutive months of 2011.

A.2 Determination of Lake Conditions

A.2.1 Water quality

Ten-year growing season (June through September) means were calculated from the most recent ten-year (2002-2011) time period for total phosphorus, chlorophyll-a, and Secchi transparency. Data were obtained from the MPCA Environmental Data Access database in June of 2012. The 10-year means were used to evaluate compliance with water quality standards and to calibrate the Bathtub model. Water quality data collected prior to 2002 were included in graphs for illustration but were not used to calculate the 10-year growing season means. Seasonal trends of total phosphorus, chlorophyll-a, and Secchi transparency were shown for a representative year

A.2.2 Aquatic macrophytes

Information about aquatic plants was obtained from MN DNR fish surveys and the Chisago SWCD. Surveys for Second Lake, Vibo Lake and White Stone Lake were not available.

A.2.3 Fish

Information on the fish species within these lakes was compiled from the MN DNR LakeFinder website and MN DNR Fisheries Staff. Formal fish surveys have not been completed for Second, Vibo, and White Stone Lakes.

A.3 Sunrise River (07030005-543)

E. coli concentrations were compared to the in-stream standard of 126 organisms per 100mL. The standard was developed using a geometric mean; therefore, a minimum of five samples per month is preferred. *E. coli* concentration was monitored at one station on Sunrise River reach 543 between April and October in 2006-2010. Of the available data for the Sunrise River reach 543, April, May, and October had fewer than five samples. In June, July and August, the geometric mean *E. coli* concentration exceeded the standard (Figure 17). Annual average *E. coli* concentrations exceeded the standard in all years (Figure 18).

Figure 17. *E. coli* geometric mean and standard deviation in 07030005-543 by month (2006-2010)

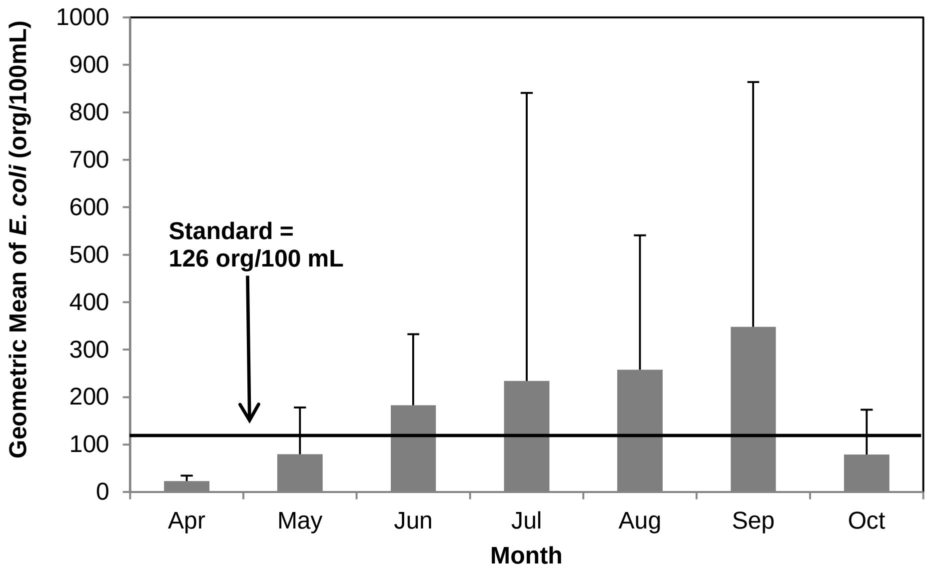
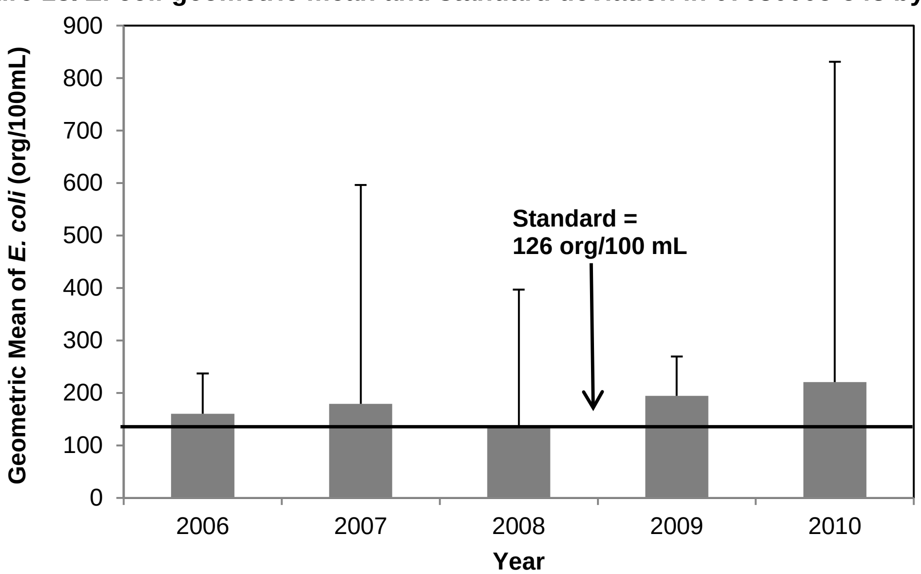


Figure 18. *E. coli* geometric mean and standard deviation in 07030005-543 by year (2006-2010)



A.4 Hay Creek (07030005-545)

E. coli concentrations were compared to the in-stream standard of 126 organisms per 100mL. The standard was developed using a geometric mean; therefore, a minimum of five samples per month is preferred. *E. coli* concentration was monitored at one station on Hay Creek. Data were collected in July and August of 2009 and 2010. Of the available data for the Sunrise River reach 545, no months had more than five *E. coli* samples with the most samples collected in July (4) and August (5). For each month across both years, the concentration of *E. coli* exceeded the standard (Figure 19 and Figure 20).

Figure 19. *E. coli* geometric mean and standard deviation in 07030005-545 by month and year

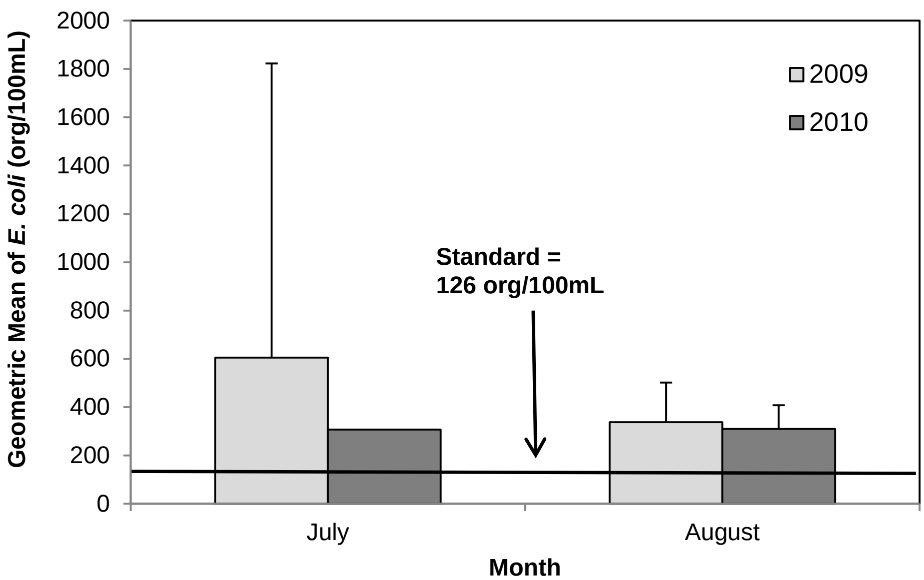
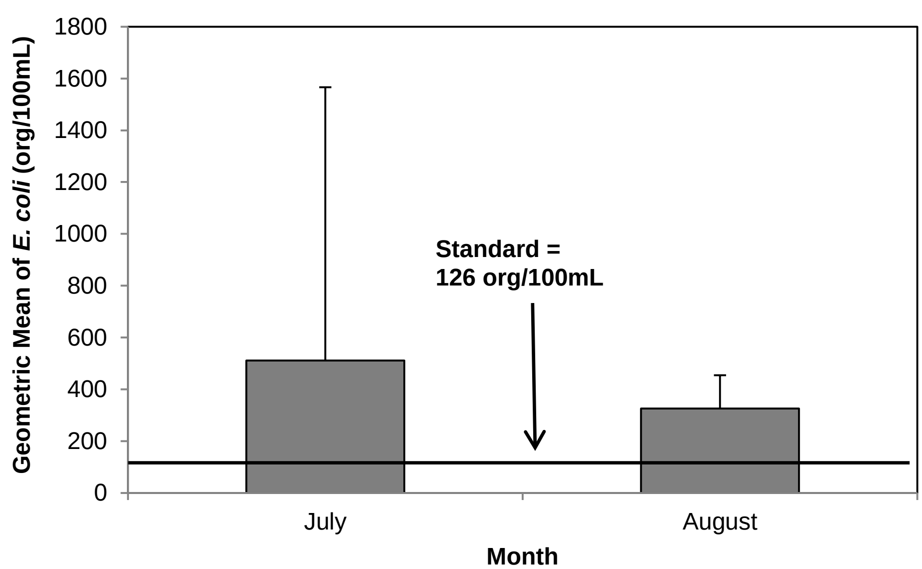


Figure 20. *E. coli* geometric mean and standard deviation in 07030005-545 by month (2009-2010)



A.5 Sunrise River West Branch (07030005-529)

Total phosphorus (TP) was monitored at five stations on the Sunrise River West Branch (07030005-529) between 2003 and 2011 (Table 40). TP exceeded the draft standard of 0.1 mg/L during the growing season every year (Figure 21) and every month (Figure 22) data was collected. In 2011, TP concentrations were the highest near the outlet of Martin Lake, the most upstream station (Figure 23). Generally, TP concentrations were higher in June than in September along the reach, with the exception of station S003-222. In June, the TP concentration at the most downstream station (S001-600) differed little from the TP concentration at the most upstream station (S003-222).

Table 40. Total Phosphorus monitoring data for reach 07030005-529

Station	Year(s)	Month	N
S001-424	2003, 2006, 2008, 2009	March-October	50
S001-600	2011	June, September	2
S003-222	2011	June, September	2
S003-482	2011	June, September	2
S006-777	2011	June, September	2

Figure 21. Total Phosphorus Growing Season Means ± SE by year for reach 07030005-529

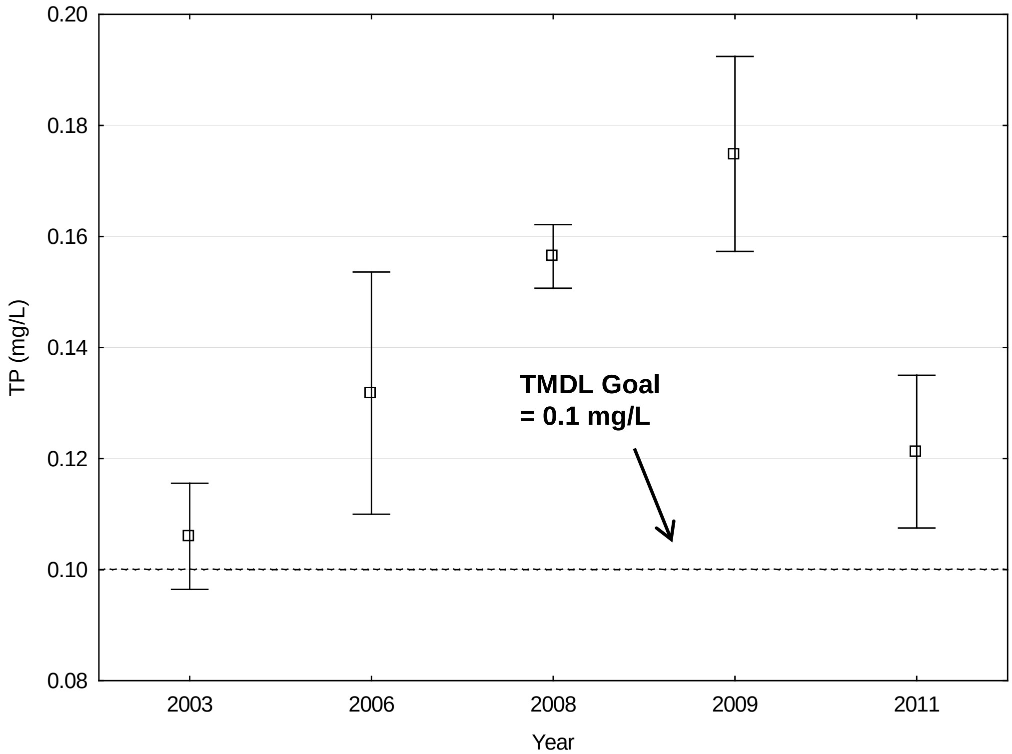


Figure 22. Total Phosphorus Growing Season Means ± SE by month for reach 07030005-529

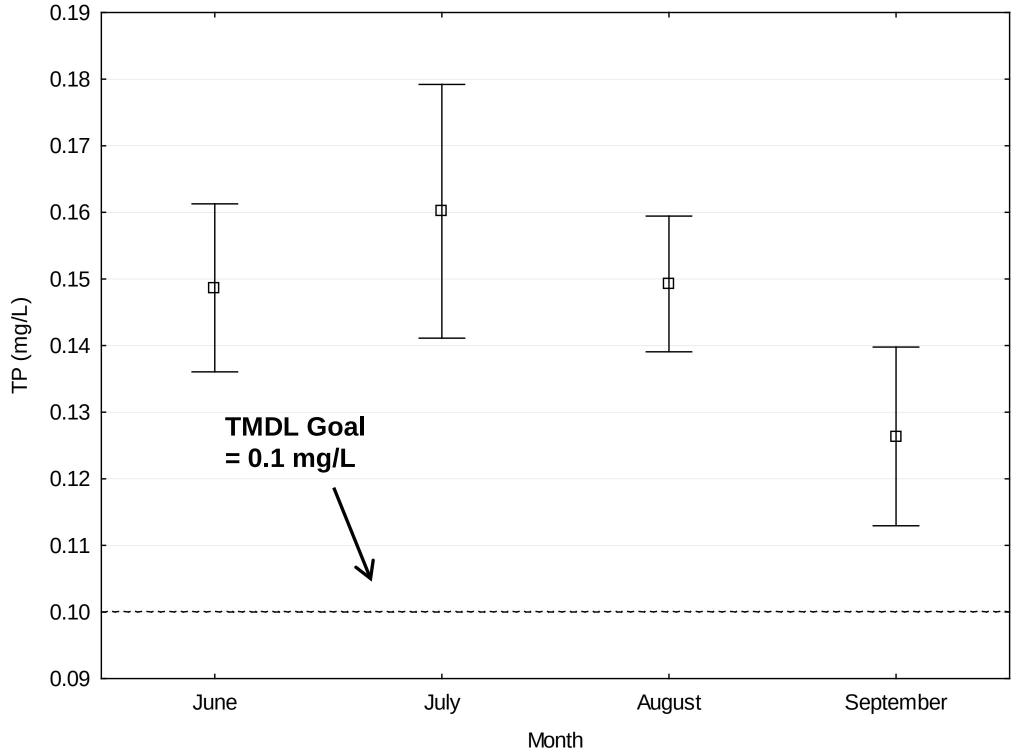
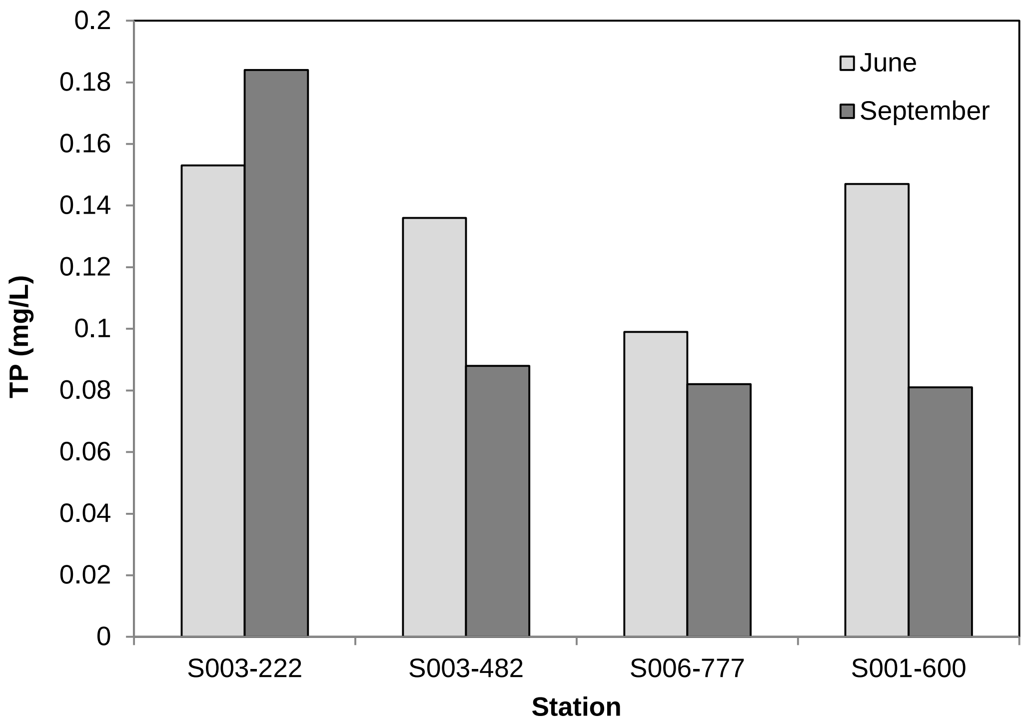


Figure 23. TP concentrations along reach -529 in 2011
In order from upstream to downstream: left to right.



A.6 Linwood Lake

A.6.1 Physical Characteristics

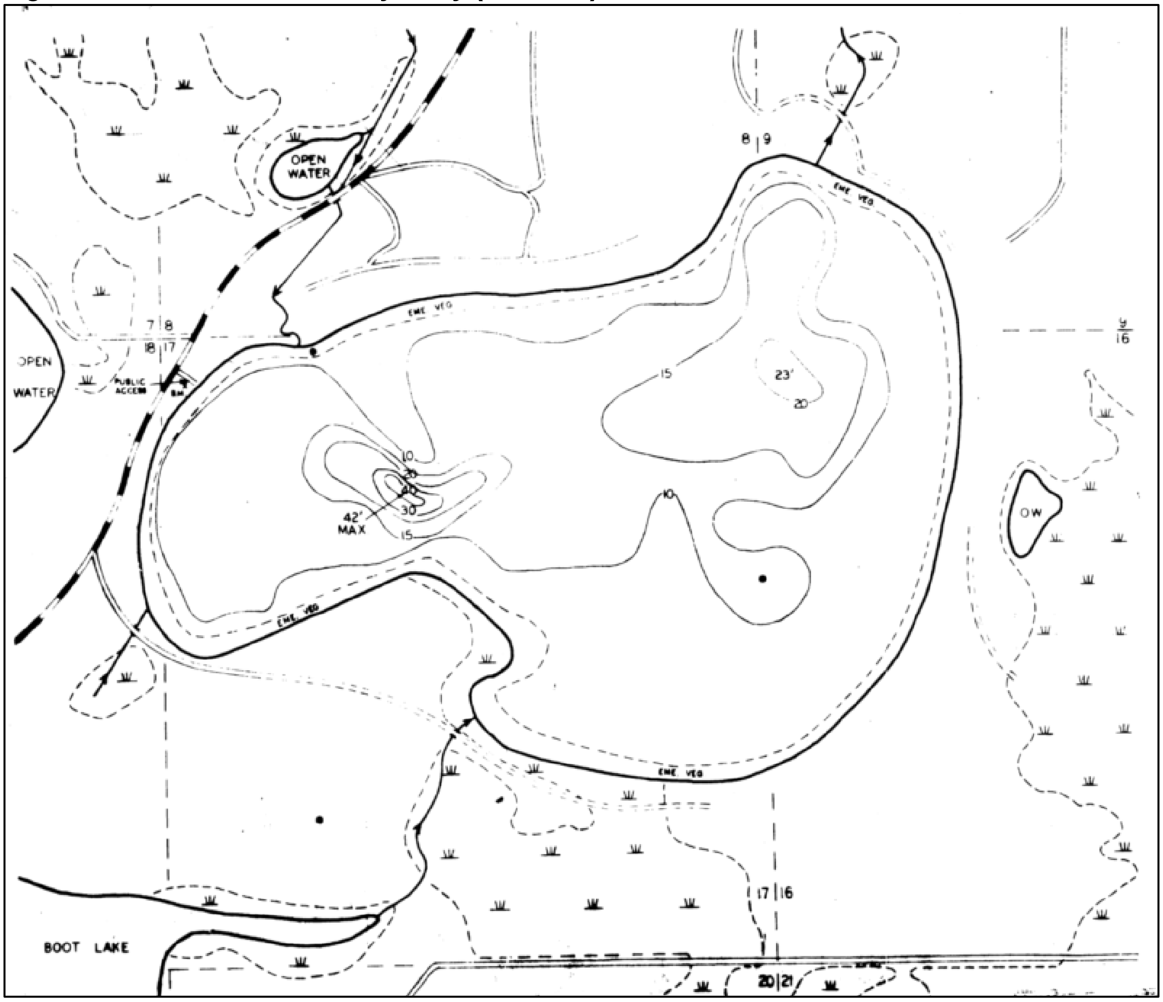
Linwood Lake (MN DNR Lake ID 02-0026-00) is located in Anoka County. Table 41 summarizes the lake's physical characteristics, Figure 24 shows the 2012 aerial photography, and Figure 25 illustrates the available bathymetry.

Table 41. Linwood Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acres)	569	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	85	Calculated from MN DNR bathymetric data using 2010 surface contour (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	5,252	
Mean depth (feet)	9.2	Lake volume ÷ surface area
Maximum depth (feet)	42	MN DNR Lake Finder
Watershed area (acre)	6,797	SWAT model (Almendinger and Ulrich 2010b)
Watershed area: Lake area	12	Calculated

Figure 24. Aerial photograph of Linwood Lake (Google Earth, August 2011)

Figure 25. Linwood Lake Bathymetry (MN DNR)



A.6.2 Land Cover

Table 42. Linwood Lake Watershed Land Cover

Land Cover	Total Acres	% of Watershed
Developed	323	4%
Forest	2,390	32%
Cropland	1,115	15%
Grassland	812	11%
Wetland	1,969	27%
Open Water	757	10%
Total	**7,366**	**100%**

A.6.3 Existing Studies, Monitoring, and Management

There are no current lake management plans for Linwood Lake. The lake is monitored for water quality yearly. This monitoring is completed by the Anoka Conservation District, or volunteers. All monitoring data can be obtained from the MPCA through STORET or EQuIS.

A.6.4 Lake Uses

Aquatic Recreation is the designated use for Linwood Lake which incorporates swimming, wading, aesthetics, and other related uses. The shoreline around the lake is about 60% developed and 40% natural. There is a large public access on the north east side of the lake which is large enough to support many boats with large motors at the same time. This lake has greater than average fishing pressure. The residents use it for canoeing, boating, and fishing.

A.6.5 Current Conditions

Water Quality

Water quality monitoring data were available for Linwood Lake from 1975-2011. Only data from the most recent 10 years (2002-2011) were used to determine whether Linwood Lake meets lake water quality standards. The lake does not meet the State lake water quality standards for TP, Chl-*a*, or Secchi (Table 43).

Growing season mean TP exceeded lake water quality standards in most years, except during the early 1980's, 2003, and 2005 (

Figure 26). This corresponded to growing season mean Chl-*a* and transparency that also exceeded lake water quality standards for the entire period of record, except transparency in 2002 (Figure 27 and Figure 28). Limited data for Chl-*a* since 2000, suggests that Chl-*a* levels are declining. However, there are no long-term trends in TP or transparency.

Growing season water quality trends from 2008 indicated that a peak in TP and Chl-*a* and minimum Secchi transparency occurred in early June and again in late August (Figure 29). Peak TP, peak Chl-*a* and minimum transparency typically occurs in the middle of the growing season due to rapid algal growth from warm water temperatures and high sunlight. Peaks in TP and Chl-*a* can also occur in the spring and fall during mixing events. Dissolved oxygen data from 1997 indicated that Linwood Lake was strongly stratified from June until mid-September in the western half of the lake (Figure 30). Bottom waters were devoid of oxygen during these months, with up to 6 meters of anoxic bottom waters prior to fall overturn at the end of September. The eastern half of the lake is shallower and likely mixes throughout the growing season.

Table 43. 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Linwood Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	Lake Standard
Total phosphorus (µg/L)	44	5%	< 40
Chlorophyll-*a* (µg/L)	27	5%	< 14
Secchi transparency (m)	0.90	3%	> 1.4

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

Figure 26. Growing Season Means ± SE of Total Phosphorus for Linwood Lake by Year. The dashed line represents the lake water quality standard for TP (40 µg/L).

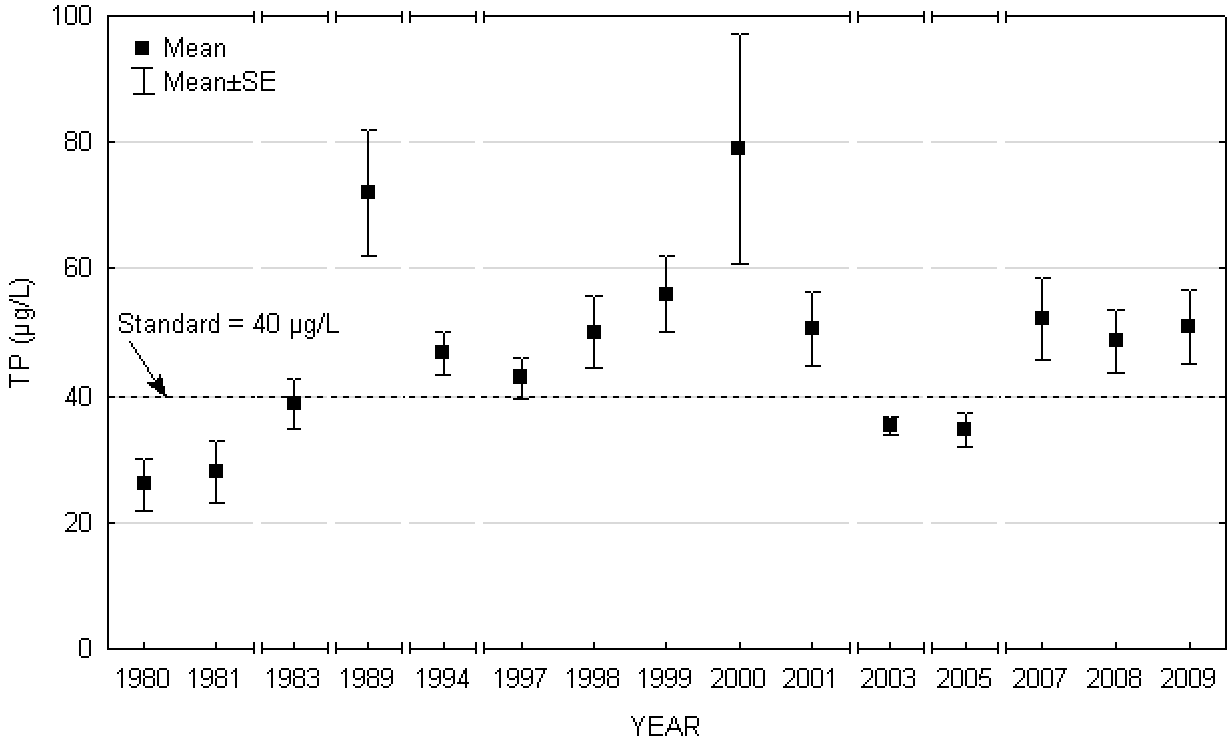


Figure 27. Growing Season Means ± SE of Chlorophyll-*a* for Linwood Lake by Year. The dashed line represents the lake water quality standard for Chl-*a* (14 µg/L).

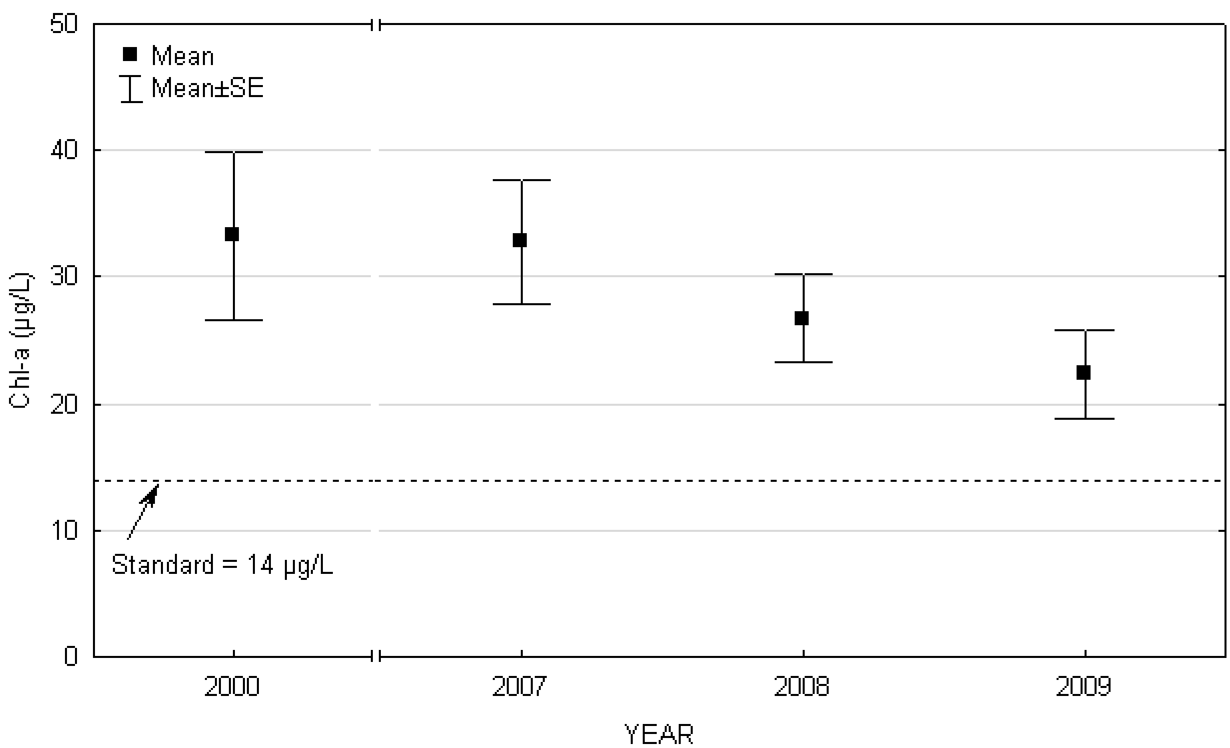


Figure 28. Growing Season Means ± SE of Secchi Transparency for Linwood Lake by Year. The dashed line represents the lake water quality standard for transparency (1.4 m).

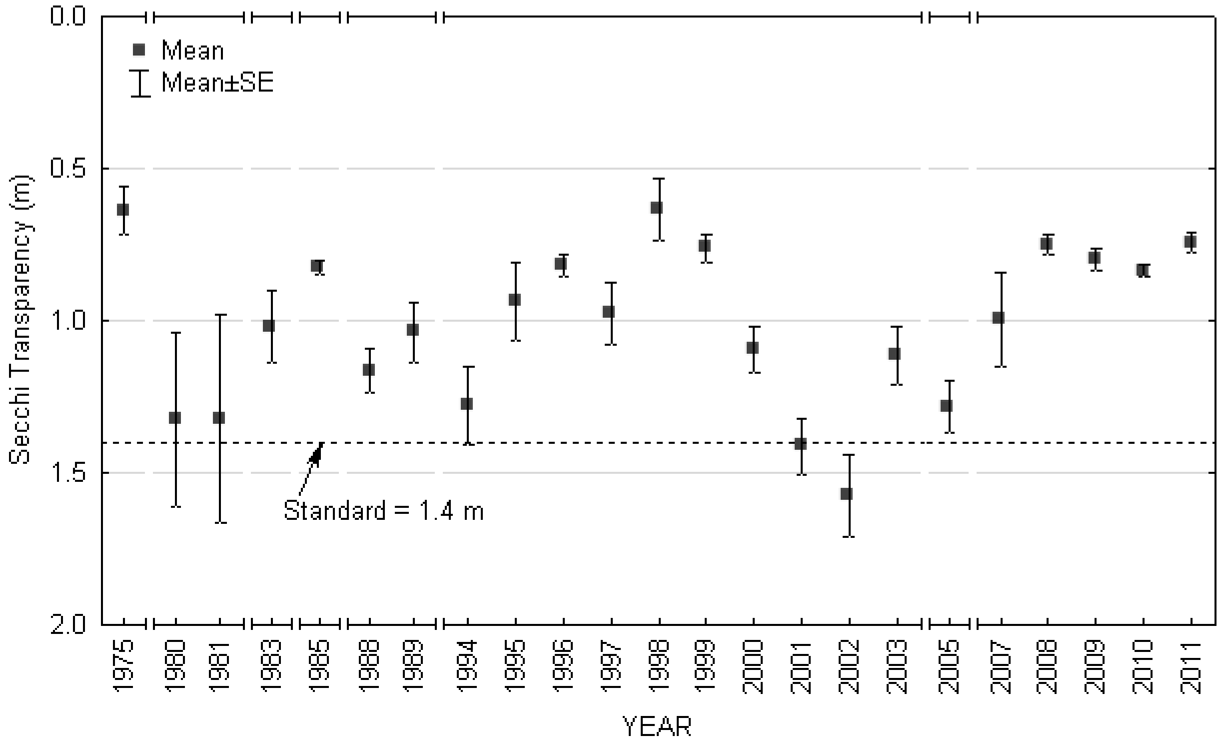


Figure 29. Growing Season Trends of Chl-*a*, TP, and Secchi Transparency, Linwood Lake, 2009

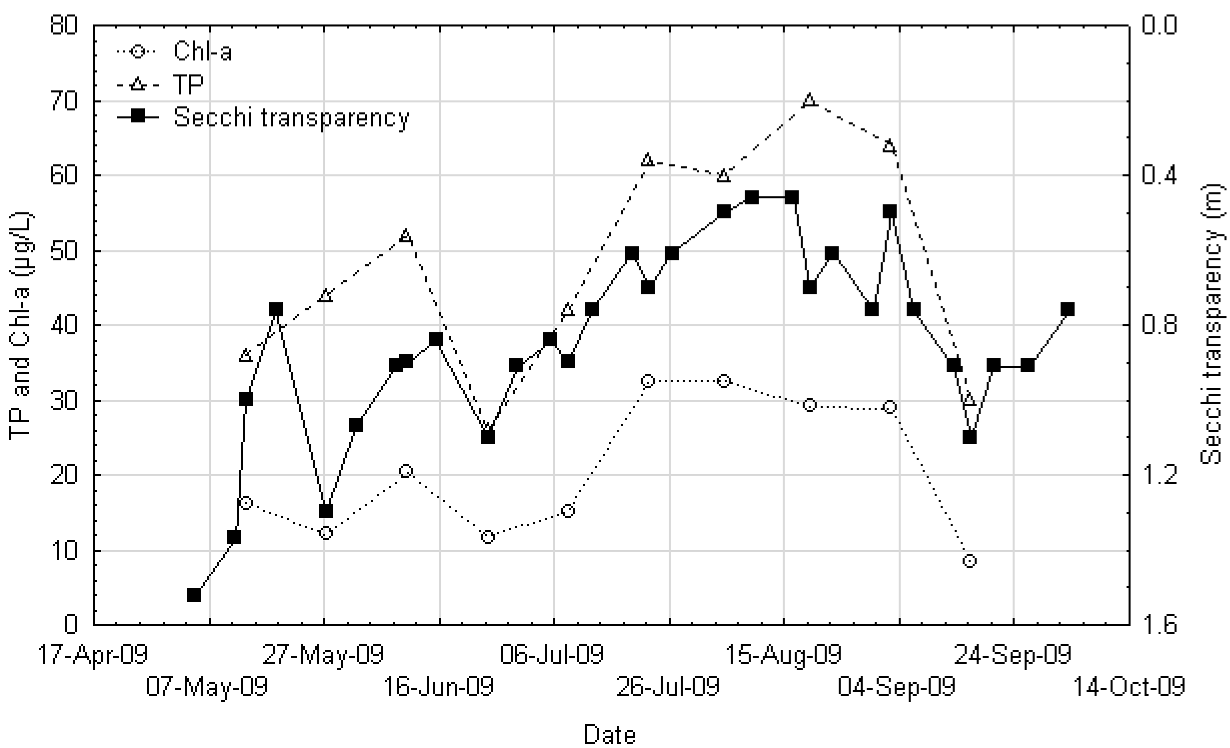
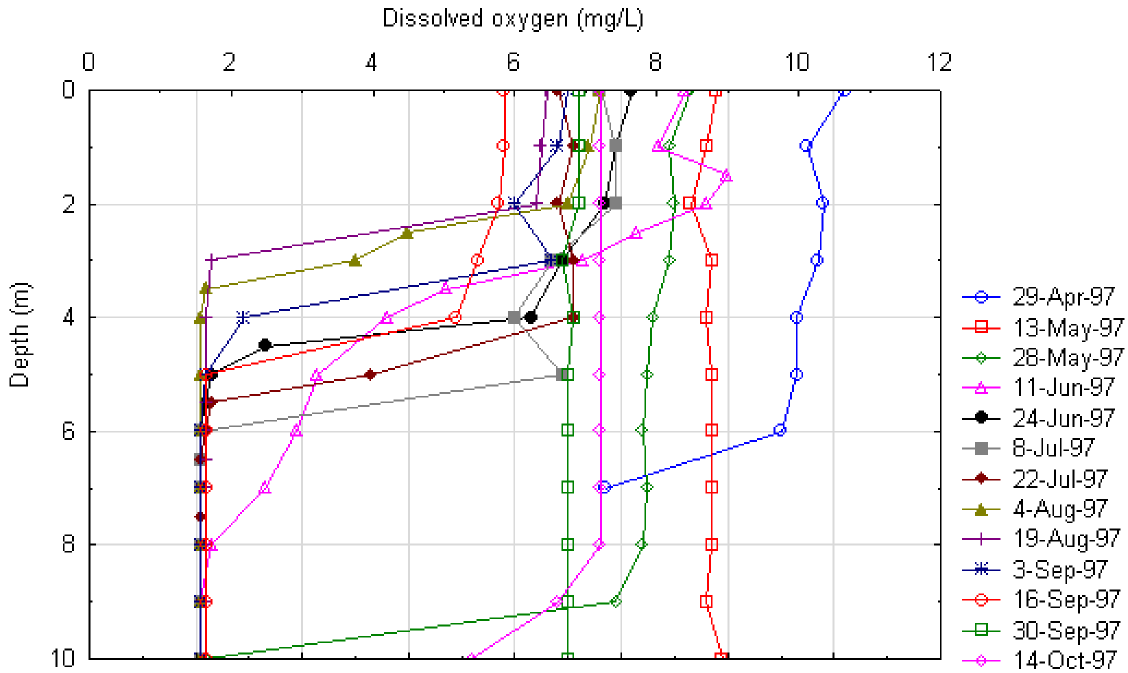


Figure 30. Dissolved oxygen depth profiles for Linwood Lake, 1997



Macrophytes

Good aquatic plant information is available from the MN DNR fish surveys. The lake has a good number of native submergent and emergent aquatic plant species (including white waterlily, coontail, flatstem pondweed, bushy pondweed). The most recent DNR aquatic plant survey (August 2009) was conducted following curly-leaf pondweed (CLP) senescence and therefore does not provide an accurate estimate of abundance. However, anecdotal information from lake residents suggests that CLP abundance has been present in moderate abundance since at least 1979, no Eurasian watermilfoil is present.

Fish

Linwood Lake is primarily managed for walleye. They continue to be found in normal abundance. Their average size was 20.76 inches and 3.91 pounds as of the most recent MN DNR Fisheries Survey. Walleye fingerlings are stocked every other year. Northern pike were found in good numbers and size. Nearly 30% of the catch exceeded 25 inches in length. Bluegills were sampled in average numbers and size. The average size bluegill was 5.82 inches. Black crappies were very abundant but were small sized. Largemouth bass aren't sampled well in the type of gear used during this survey, but their catch rate in the gill nets was within normal ranges (MN DNR). The MN DNR reports that there is moderately heavy fishing pressure year round on Linwood Lake. The first time carp showed up in the fisheries survey was 1975. It is suspected that the upstream Boot Lake is a spawning and nursery area for the carp present in Linwood Lake. In the most recent survey, the number of carp caught per net was lower than the normal range for other lakes with similar physical and chemical characteristics, but the average weight of the carp was greater than the normal range. Fish species recently reported include: Black bullhead, black crappie, bluegill, northern pike, largemouth bass, hybrid sunfish, pumpkinseed sunfish, walleye, yellow bullhead, and yellow perch.

A.7 Second Lake

A.7.1 Physical Characteristics

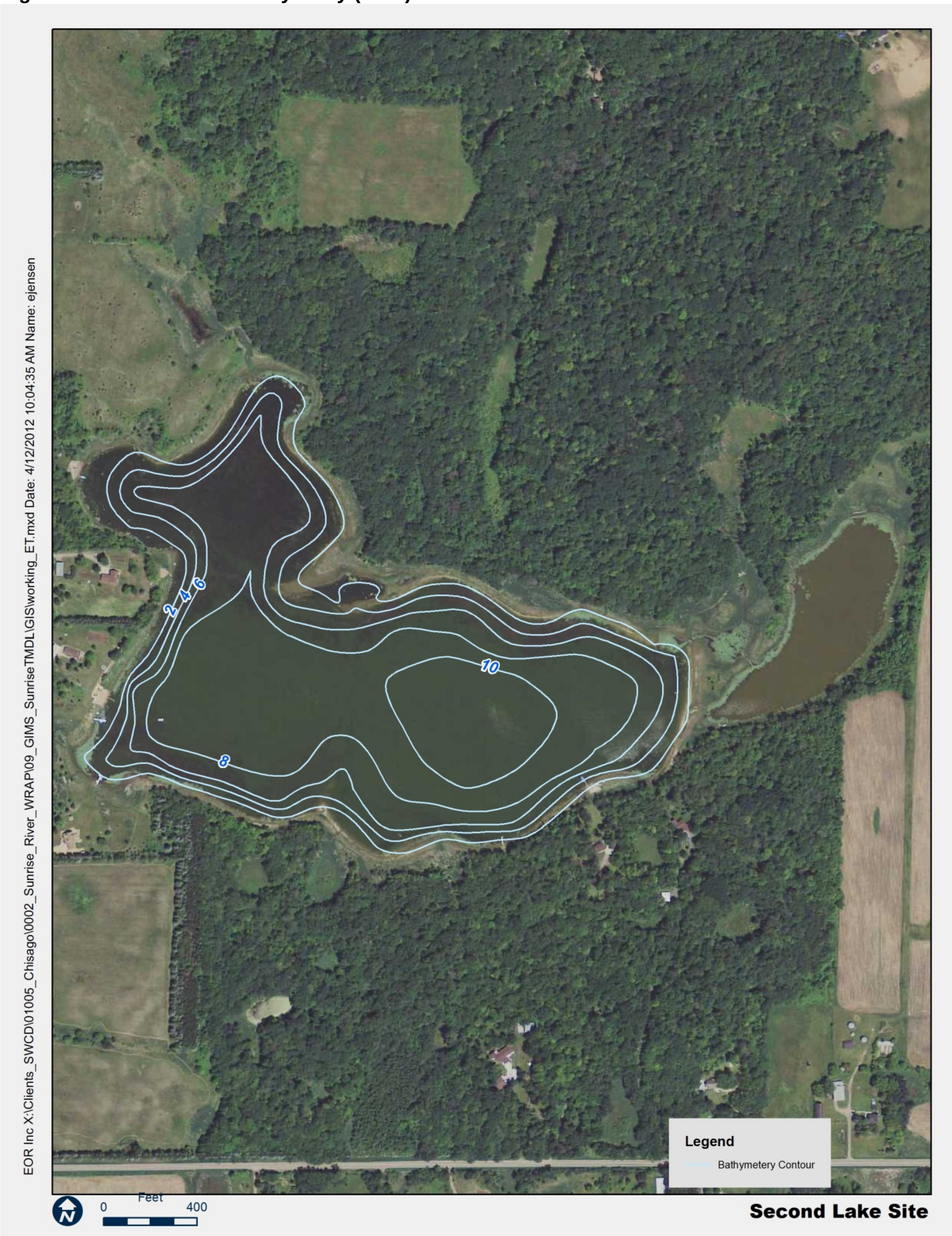
Second Lake (MN DNR Lake ID 13-0025-00) is a shallow lake located in Chisago County. Table 44 summarizes the lake's physical characteristics, Figure 31 shows the 2012 aerial photography, and Figure 32 illustrates the available bathymetry.

Table 44. Second Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	85	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	100%	Calculated from EOR 2012 bathymetric data using 2010 surface contour (aerial photo)
Lake volume (acre-feet)	446	
Mean depth (feet)	5.3	Lake volume ÷ surface area
Maximum depth (feet)	10.8	EOR 2012 field survey
Watershed area (acre)	520	SWAT model (Almendinger and Ulrich 2010b)
Watershed area: Lake area	6:1	Calculated

Figure 31. Aerial photograph of Second Lake (Google Earth, May 2010)

Figure 32. Second Lake Bathymetry (EOR)



A.7.2 Land Cover

Table 45. Second Lake Watershed Land Cover

Land Cover	Total Acres	% of Watershed
Developed	8	1%
Forest	282	47%
Cropland	22	4%
Grassland	169	28%
Wetland	41	7%
Open Water	84	14%
	605	**100%**

A.7.3 Existing Studies, Monitoring, and Management

Second Lake was monitored through a Surface Water Assessment Grant by volunteers in 2008 and 2009. The volunteers collected 10 samples during each of those two years. No other data or studies are known to exist for this lake.

A.7.4 Lake Uses

Aquatic Recreation is the designated use for Second Lake which incorporates swimming, wading, aesthetics, and other related uses. There is no public access to the lake. There are 15 lakeshore parcels around Second Lake. The residents use it for canoeing, boating, and some fishing.

A.7.5 Current Conditions

Water Quality

Water quality monitoring data were available for Second Lake from 2008-2009 and were used to determine whether Second Lake meets shallow lake water quality standards. The lake does not meet the State lake water quality standards for TP, Chl-*a*, or Secchi (Table 46). Growing season mean TP and Secchi transparency exceeded shallow lake water quality standards in both years (Figure 33 and Figure 35), while Chl-*a* exceeded shallow lake water quality standards only in 2009 (Figure 34). Due to limited available data, no long-term trends in water quality are known. Growing season water quality trends from 2008 indicated that a peak in TP and Chl-*a* and minimum Secchi transparency occurred near the end of July and again at the end of September (Figure 36). Peak TP, peak Chl-*a* and minimum transparency typically occurs in the middle of the growing season due to rapid algal growth from warm water temperatures and high sunlight. Peaks in TP and Chl-*a* can also occur in the spring and fall during mixing events.

Table 46. 10-year Growing Season Mean TP, Chl-a, and Secchi depth for Second Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	77	7%	< 60
Chlorophyll-*a* (µg/L)	30	13%	< 20
Secchi transparency (m)	0.64	12%	> 1.0

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

Figure 33. Growing Season Means ± SE of Total Phosphorus for Second Lake by Year. The dashed line represents the shallow lake water quality standard for TP (60 µg/L).

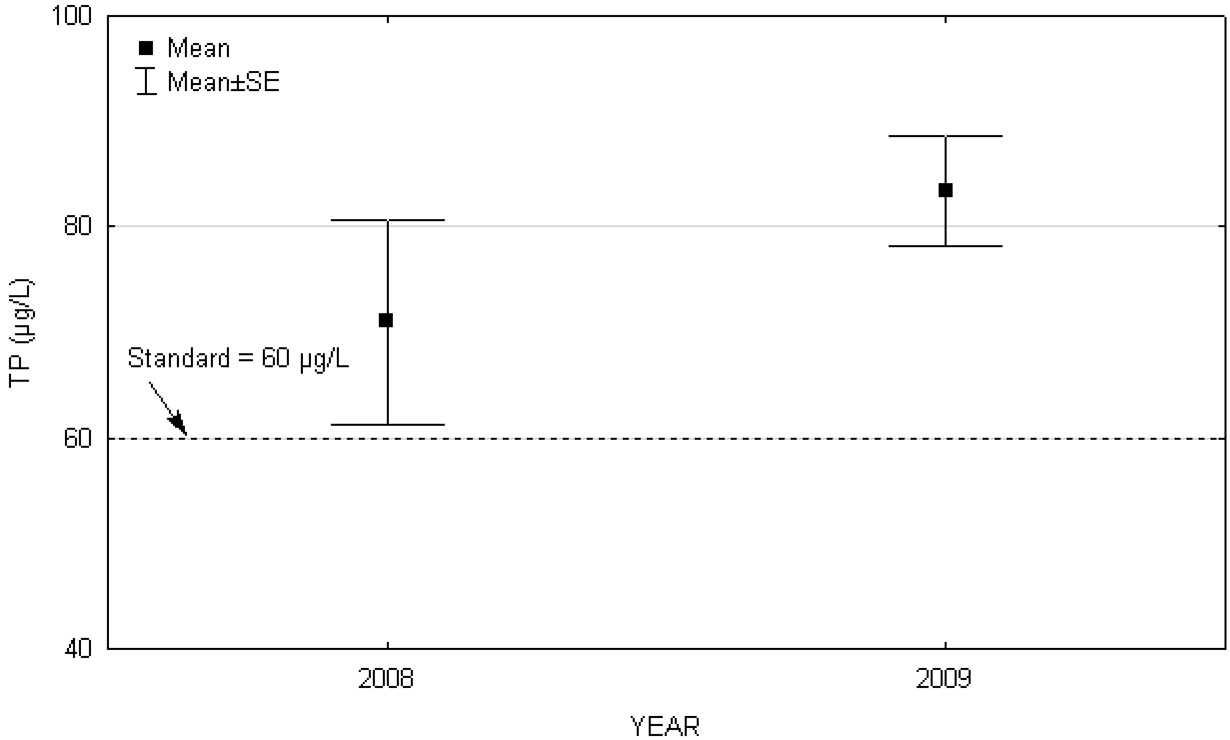


Figure 34. Growing Season Means ± SE of Chlorophyll-*a* for Second Lake by Year. The dashed line represents the shallow lake water quality standard for Chl-*a* (20 µg/L).

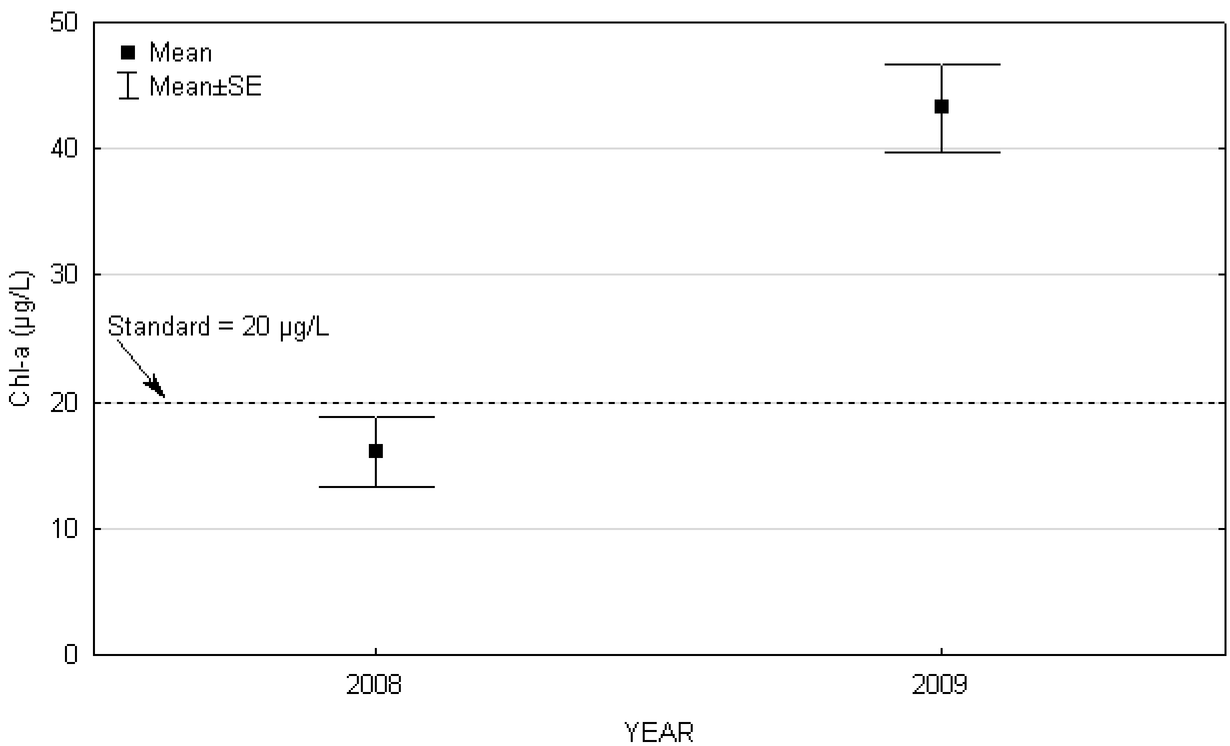


Figure 35. Growing Season Means ± SE of Secchi Transparency for Second Lake by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

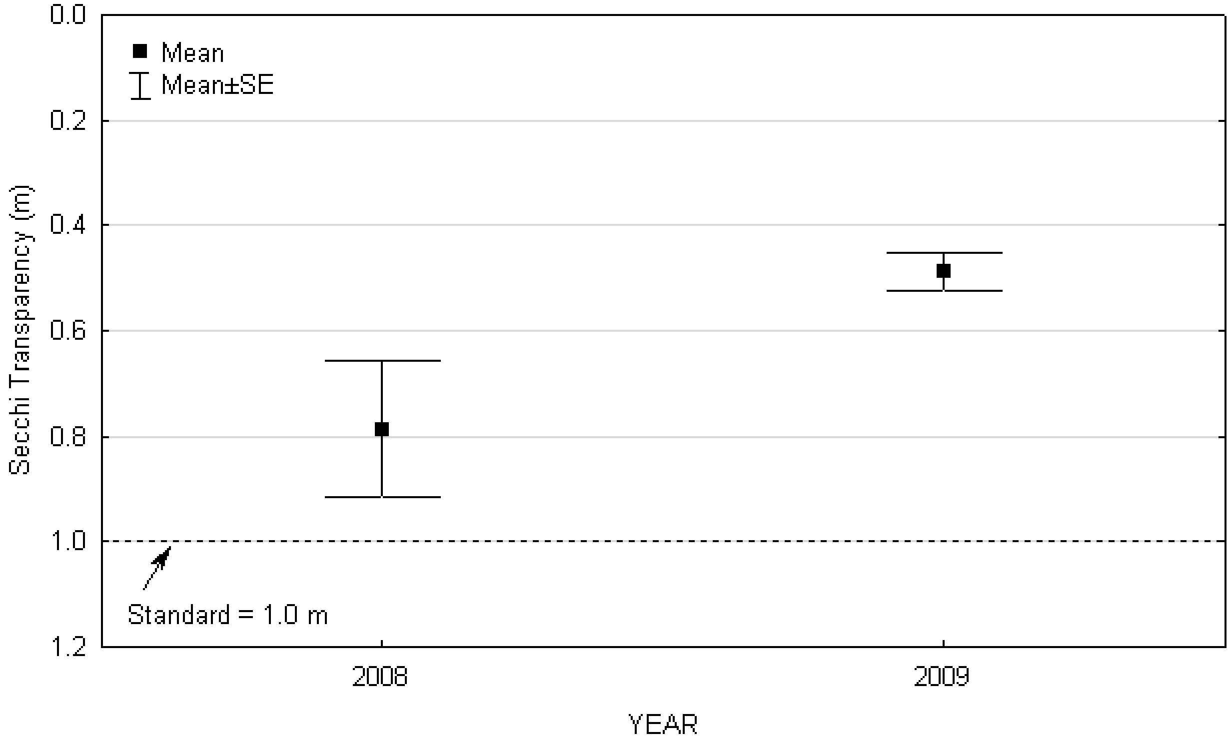
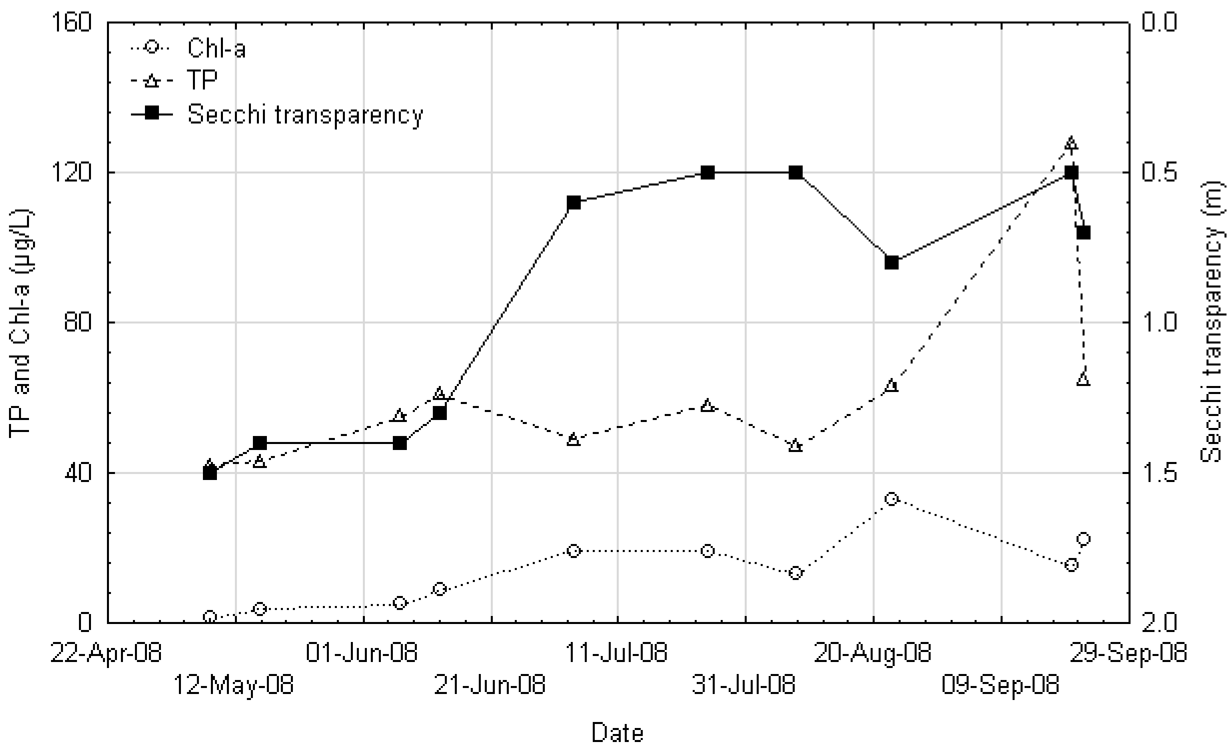


Figure 36. Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for Second Lake, 2008



Macrophytes

Little is known about the macrophyte population in Second Lake as no formal aquatic plant surveys have been completed. Curlyleaf pondweed has been identified and is quite extensive.

Fish

Formal fish surveys have not been completed for Second Lake by the MN DNR. In 1998 Second Lake was used for a walleye rearing pond. Fish species that were present at the time were: black crappie, bluegill, black bullhead, and yellow bullhead. Second Lake has had winter fish kills in the past, but when and how often is not known.

A.8 Vibo Lake

A.8.1 Physical Characteristics

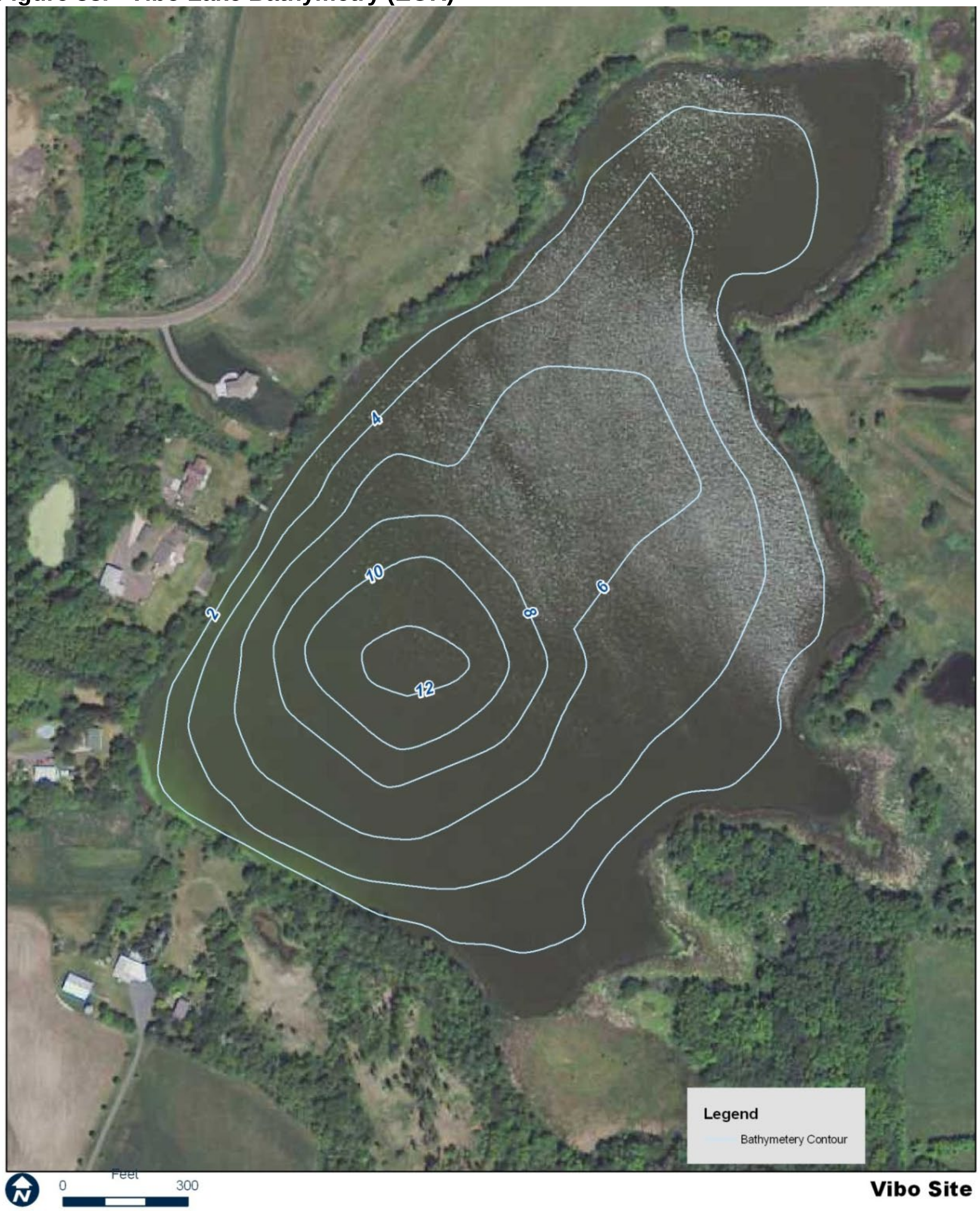
Vibo Lake (MN DNR Lake ID 13-0030-00) is a shallow lake located in Chisago County. Table 47 summarizes the lake's physical characteristics, Figure 37 shows the 2012 aerial photography, and Figure 38 illustrates the available bathymetry.

Table 47. Vibo Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	57	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	100%	Calculated from EOR 2012 bathymetric data using 2010 surface contour (aerial photo)
Lake volume (acre-feet)	265	
Mean depth (feet)	4.6	Lake volume ÷ surface area
Maximum depth (feet)	12.1	EOR 2012 field survey
Drainage area (acre)	7,676	SWAT model (Almendinger and Ulrich 2010b)
Watershed area: Lake area	135: 1	Calculated

Figure 37. Aerial photograph of Vibo Lake (Google Earth, August 2011)

Figure 38. Vibo Lake Bathymetry (EOR)



A.8.2 Land Cover

Table 48. Vibo Lake Watershed Land Cover

Land Cover	Total Acres	% of Watershed
Developed	383	5%
Forest	867	11%
Cropland	2,847	37%
Grassland	3,422	44%
Wetland	181	2%
Open Water	37	0%
	7,737	**100%**

A.8.3 Existing Studies, Monitoring, and Management

Vibo Lake was monitored through a Surface Water Assessment Grant by volunteers in 2008 and 2009. The volunteers collected 10 samples during each of those two years. No other data or studies are known to exist for this lake.

A.8.4 Lake Uses

Aquatic Recreation is the designated use for Vibo Lake which incorporates swimming, wading, aesthetics, and other related uses. There is no public access to the lake. There are 19 lakeshore parcels around Vibo Lake. The residents use it for canoeing, boating, and some fishing.

A.8.5 Current Conditions

Water Quality

Water quality monitoring data were available for Vibo Lake from 2008-2009 and were used to determine whether Vibo Lake meets shallow lake water quality standards. The lake does not meet the State lake water quality standards for TP, Chl-*a*, or Secchi (Table 49). Growing season mean TP, Chl-*a*, and Secchi transparency greatly exceeded shallow lake water quality standards in both years (Figure 39, Figure 40, Figure 41). Due to limited available data, no long-term trends in water quality are known. Growing season water quality trends from 2008 indicated that a peak in TP and Chl-*a* and minimum Secchi transparency occurred near the end of July and again at the end of September (Figure 42). Peak TP, peak Chl-*a* and minimum transparency typically occurs in the middle of the growing season due to rapid algal growth from warm water temperatures and high sunlight. Peaks in TP and Chl-*a* can also occur in the spring and fall during mixing events.

Table 49. 10-year Growing Season Mean TP, Chl-a, and Secchi depth for Vibo Lake, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	516	8%	< 60
Chlorophyll-*a* (µg/L)	91	19%	< 20
Secchi transparency (m)	0.36	9%	> 1.0

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

Figure 39. Growing Season Means ± SE of Total Phosphorus for Vibo Lake by Year.
The dashed line represents the shallow lake water quality standard for TP (60 µg/L).

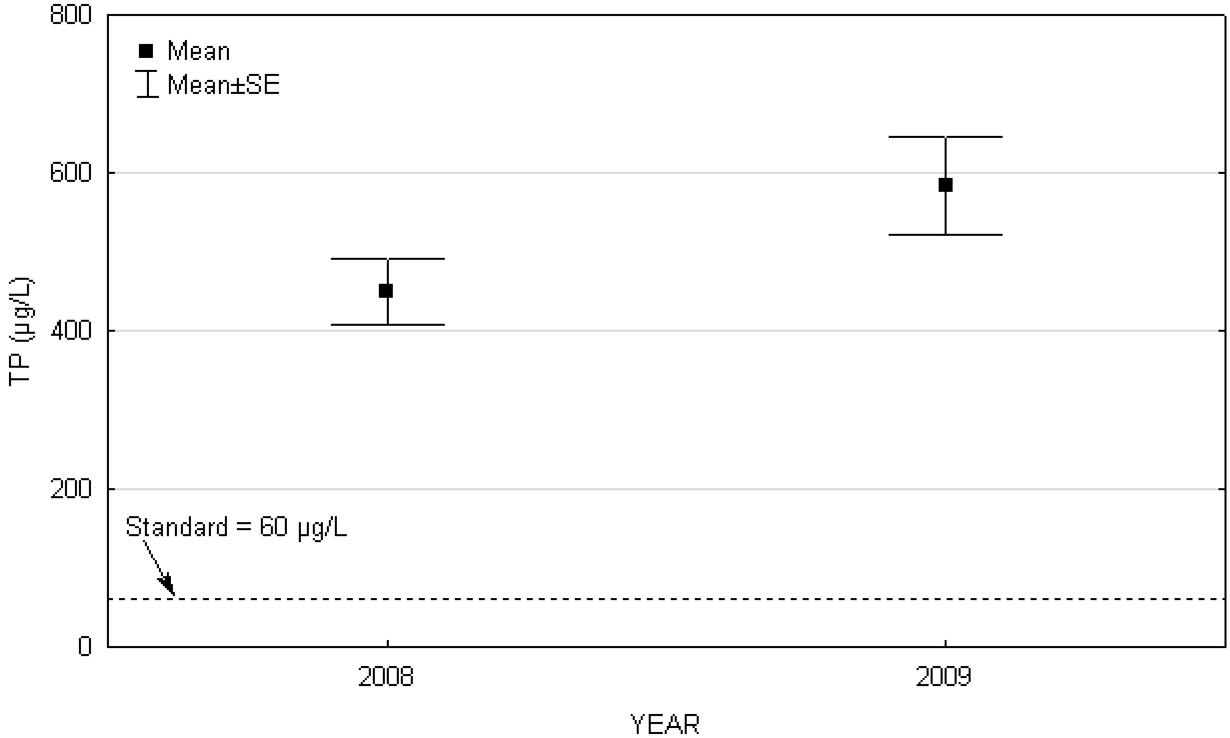


Figure 40. Growing Season Means ± SE of Chlorophyll-*a* for Vibo Lake by Year.
The dashed line represents the shallow lake water quality standard for Chl-*a* (20 µg/L).

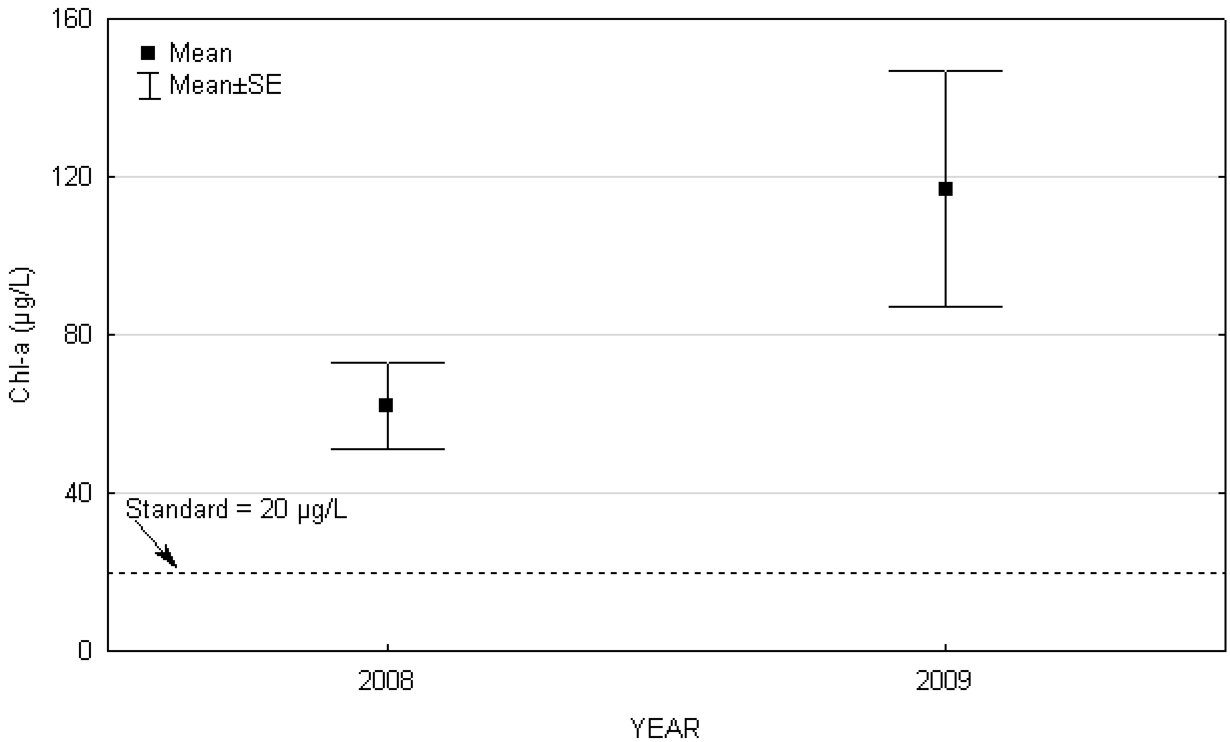


Figure 41. Growing Season Means ± SE of Secchi Transparency for Vibo Lake by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

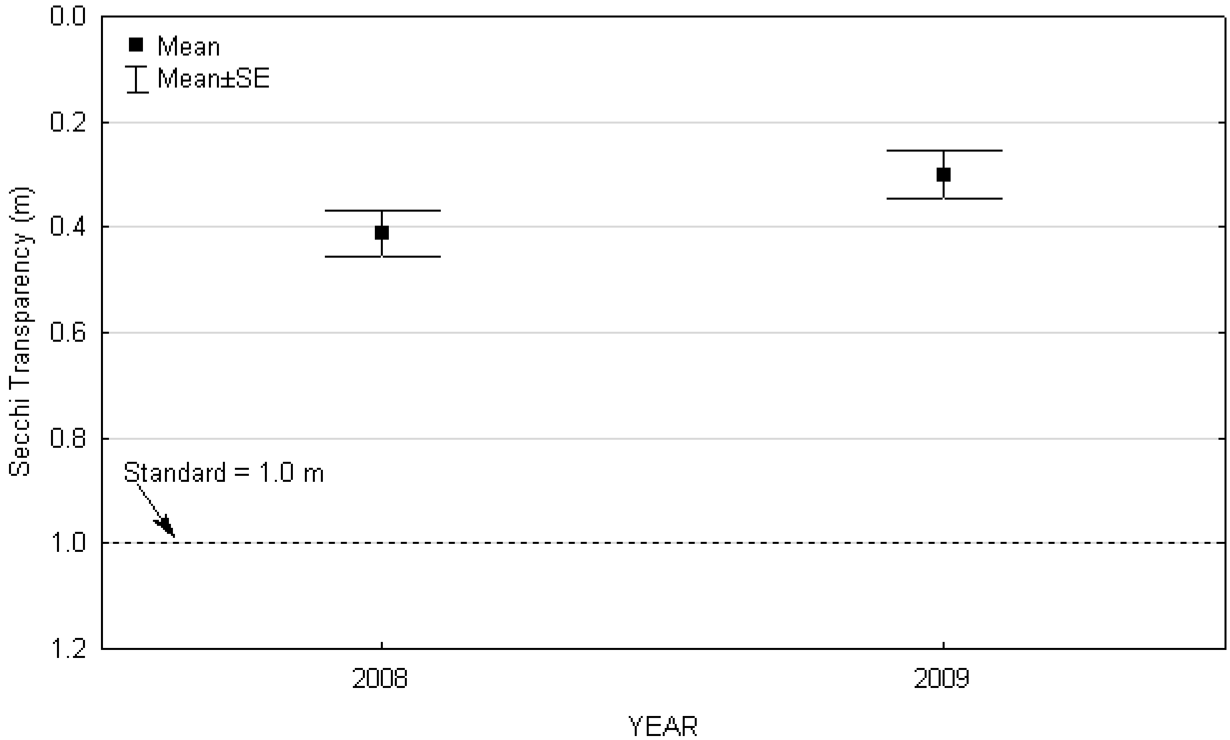
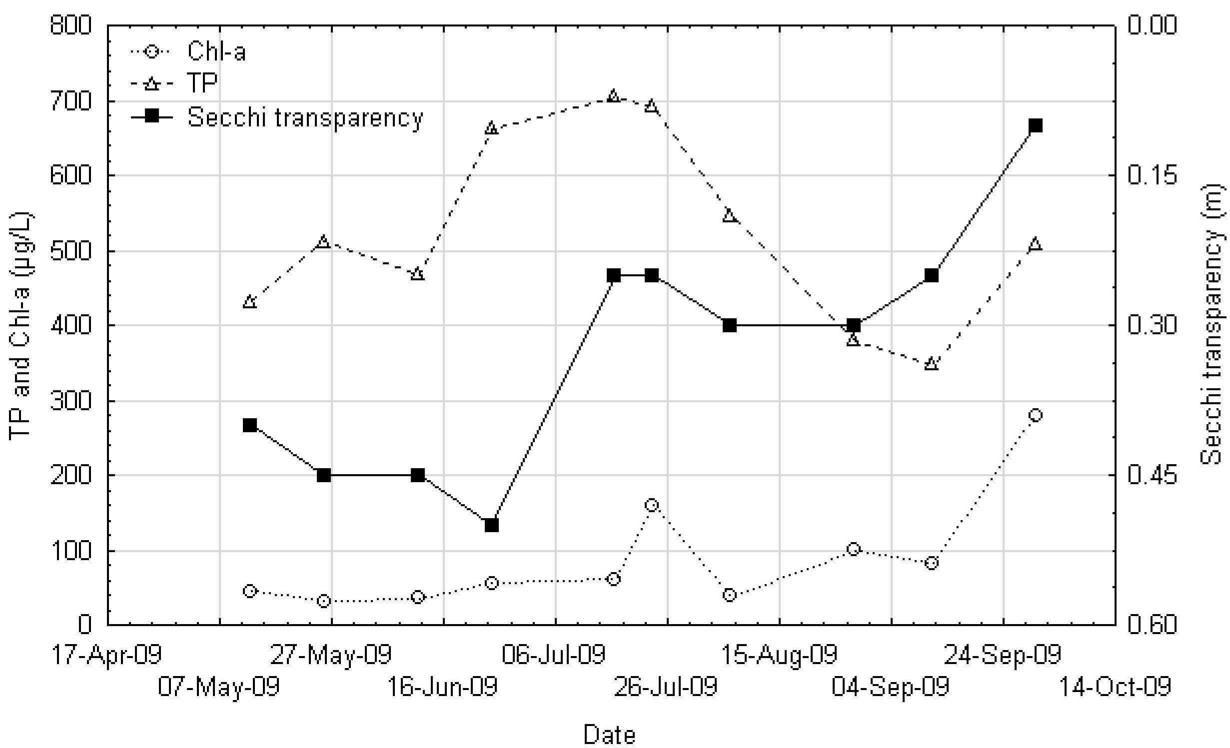


Figure 42. Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for Vibo Lake, 2009



Macrophytes

Little is known about the macrophyte population in Vibo Lake as no formal aquatic plant surveys have been completed. Due to the poor water quality of this lake, there are very few aquatic macrophytes growing. Emergent vegetation is present around the perimeter of the lake.

Fish

Nothing is known about the fish populations in Vibo Lake. It is likely that some stunted panfish and bullheads do exist.

A.9 White Stone Lake

A.9.1 Physical Characteristics

White Stone Lake (MN DNR Lake ID 13-0048-00) is a shallow lake located in Chisago County. Table 50 summarizes the lake's physical characteristics, Figure 43 shows the 2012 aerial photography, and Figure 44 illustrates the available bathymetry.

Table 50. White Stone Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	49	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	100%	Calculated from EOR 2012 bathymetric data using 2010 surface contour (aerial photo)
Lake volume (acre-feet)	244	
Mean depth (feet)	5.0	Lake volume ÷ surface area
Maximum depth (feet)	8.2	EOR 2012 field survey
Drainage area (acre)	219	SWAT model (Almendinger and Ulrich 2010b)
Watershed area: Lake area	4.5: 1	Calculated

Figure 43. Aerial photograph of White Stone Lake (Google Earth, May 2010)

Figure 44. White Stone Lake Bathymetry (EOR)

A.9.2 Land Cover

Table 51. White Stone Lake Watershed Land Cover

Land Cover	Total Acres	% of Watershed
Developed	24	9%
Forest	72	27%
Cropland	38	14%
Grassland	68	25%
Wetland	21	8%
Open Water	45	17%
	268	**100%**

A.9.3 Existing Studies, Monitoring, and Management

White Stone Lake was monitored through a Surface Water Assessment Grant by volunteers in 2008 and 2009. The volunteers collected 10 samples during each of those two years. No other data or studies are known to exist for this lake.

A.9.4 Lake Uses

Aquatic Recreation is the designated use for White Stone Lake which incorporates swimming, wading, aesthetics, and other related uses. There is no public access to the lake. There are 11 lakeshore parcels around White Stone Lake. The residents use it for canoeing, swimming, boating, and some fishing.

A.9.5 Current Conditions

Water Quality

Water quality monitoring data are available for White Stone Lake from 2008-2009 and were used to determine whether White Stone Lake meets shallow lake water quality standards. The lake does not meet the State lake water quality standards for TP, Chl-*a*, or Secchi (Table 52). Growing season mean TP, Chl-*a*, and Secchi transparency exceeded shallow lake water quality standards in both years (Figure 45, Figure 46, Figure 47). Due to limited available data, no long-term trends in water quality are known. Growing season water quality trends from 2009 indicated that the peak in TP and Chl-*a* and minimum Secchi transparency occurred at the end of July (Figure 48). Peak TP, peak Chl-*a* and minimum transparency typically occurs in the middle of the growing season due to rapid algal growth from warm water temperatures and high sunlight.

Table 52. 10-year Growing Season Mean TP, Chl-a, and Secchi depth for White Stone, 2002-2011.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	97	8%	< 60
Chlorophyll-*a* (µg/L)	75	20%	< 20
Secchi transparency (m)	0.62	12%	> 1.0

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

Figure 45. Growing Season Means ± SE of Total Phosphorus for White Stone Lake by Year. The dashed line represents the shallow lake water quality standard for TP (60 µg/L).

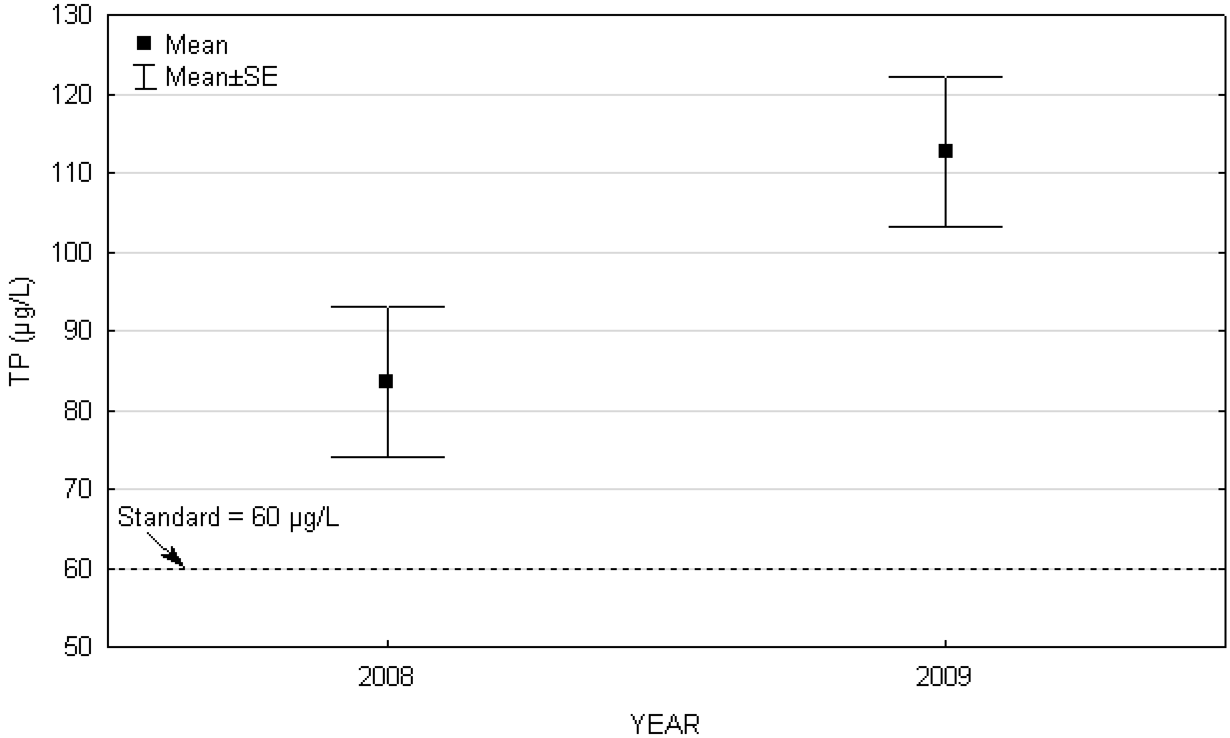


Figure 46. Growing Season Means ± SE of Chlorophyll-*a* for White Stone Lake by Year. The dashed line represents the shallow lake water quality standard for Chl-*a* (20 µg/L).

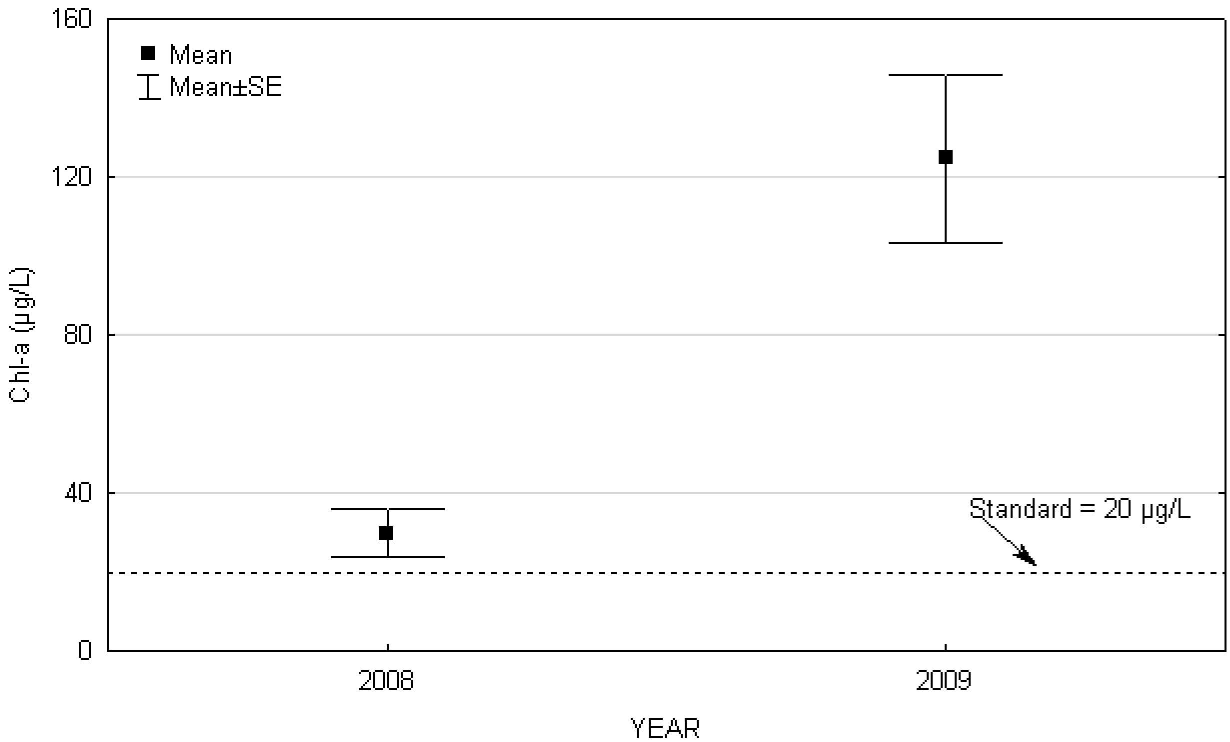


Figure 47. Growing Season Means ± SE of Secchi Transparency for White Stone Lake by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

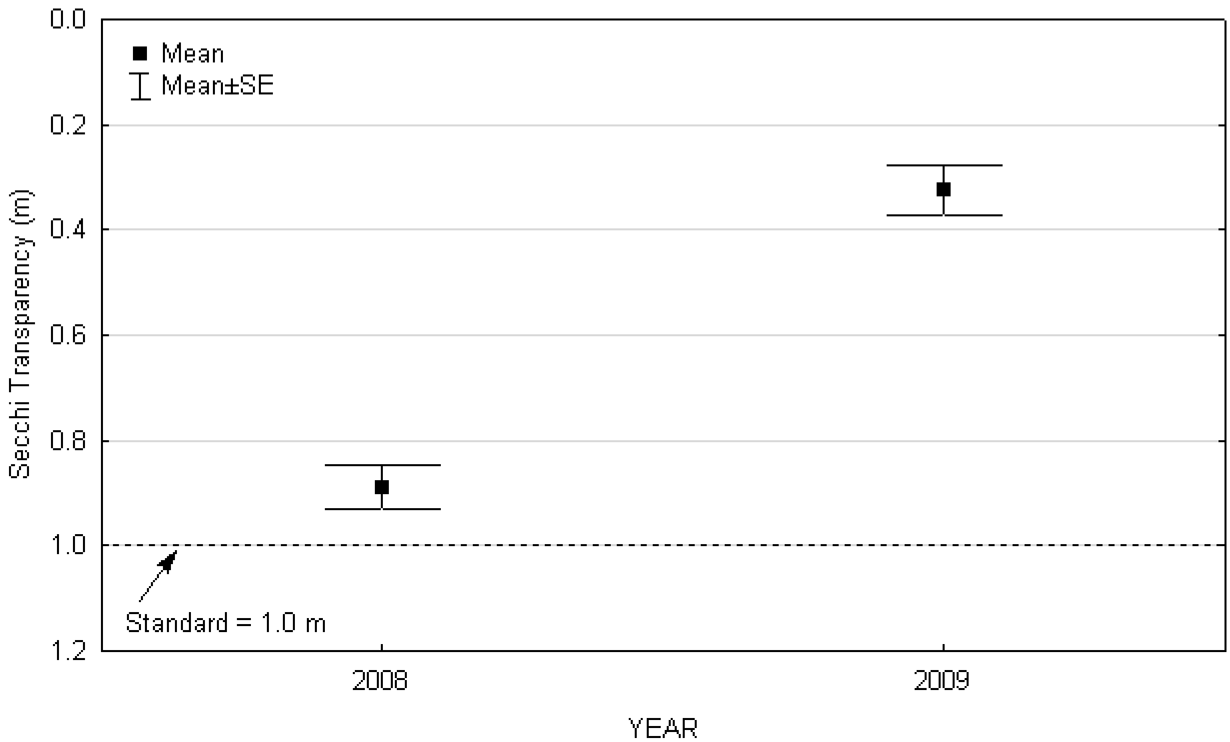
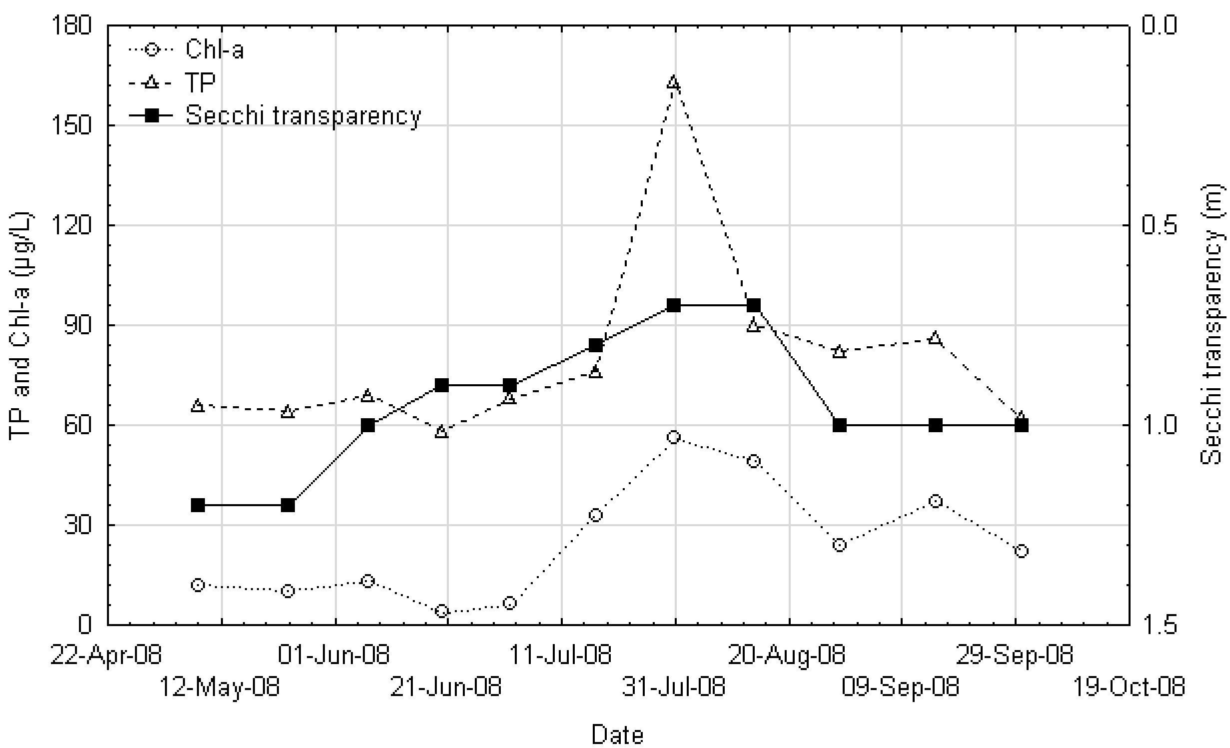


Figure 48. Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for White Stone, 2009



Macrophytes

No formal aquatic plant surveys have been completed on White Stone Lake. From MN DNR and SWCD site visits, emergent vegetation including water lily and pickerelweed is present around the perimeter of the lake and many species of submergent vegetation are also present. No invasive species are known to exist in this lake.

Fish

Formal fish surveys have not been completed for White Stone Lake by the MN DNR. In 2007 White Stone Lake was used for a walleye rearing pond. The lake underwent a partial fish kill in late winter 2007, but there were still high numbers of fish. Fish species that were present at the time were: black crappie, bluegill, pumpkinseed sunfish, and golden shiners. Flathead minnows were also present in low numbers. Black bullheads were present in 2000.

APPENDIX B. SIX LARGE SUBWATERSHED BACTERIA SOURCES

B.1 Approach

The purpose of this analysis was to identify *E. coli* production in six large subwatersheds constituting the Sunrise River watershed in areas downstream of Comfort Lake and the North Branch of the Sunrise River. For the bacteria source assessment of the 29 Target Subwatersheds discharging more directly to the reaches impaired due to bacteria (Sunrise River, N Br Sunrise R to St Croix R, AUID 07030005-543, and Hay Creek, Louden Ave to Sunrise River, AUID 07030006-545), refer to Section 3.6.2. The source assessment on the six large subwatersheds was conducted in a manner that is both meaningful for implementation of restoration and protection measures, and is feasible given the scale of the subwatersheds. Figure 49 includes a map of the six large subwatersheds. This section describes the approach applied to each subwatershed and provides the data sources used. This project area potential bacteria sources do not account for delivery of *E. coli* to surface waters (delivery was considered in the bacteria source assessment for the 29 Target Subwatersheds). Table 53 summarizes the data sources and assumptions for the estimated quantities of producer population for the potential bacteria sources in the six large subwatersheds.

Bacteria production was calculated for each subwatershed for each source based on production rates. However, for this study results are reported in relative terms [low, medium-low, medium-high, high]. The relative rankings relate multiple sources in a single subwatershed.

Bacteria production estimates are based on the bacteria content in feces and an average excretion rate [with units of cfu/day-head; where 'head' implies an individual animal]. Bacteria content and excretion rates vary by animal type (a.k.a. *producer*). The EPA's *Protocol for developing pathogen TMDLs* provides estimates for bacteria production by producer for most producers shown in Table 15 on Page 42 (EPA 2001); values for deer and raccoons were obtained from other sources (Zeckoski et al. 2005; Yagow 1999). *E. coli* production rates are based on fecal coliform production rates and a conversion factor. All production rates obtained from the literature are for fecal coliform rather than *E. coli* due to the availability of fecal coliform data. The production rate was multiplied by 0.5 to estimate the *E. coli* production rate, which is based on the rule of thumb that 50% of fecal coliform are *E. coli* (Doyle and Erikson 2006). Bacteria production estimates are ultimately reported using relative rankings only.

Figure 49. Six large subwatersheds on which a bacteria source assessment was conducted.

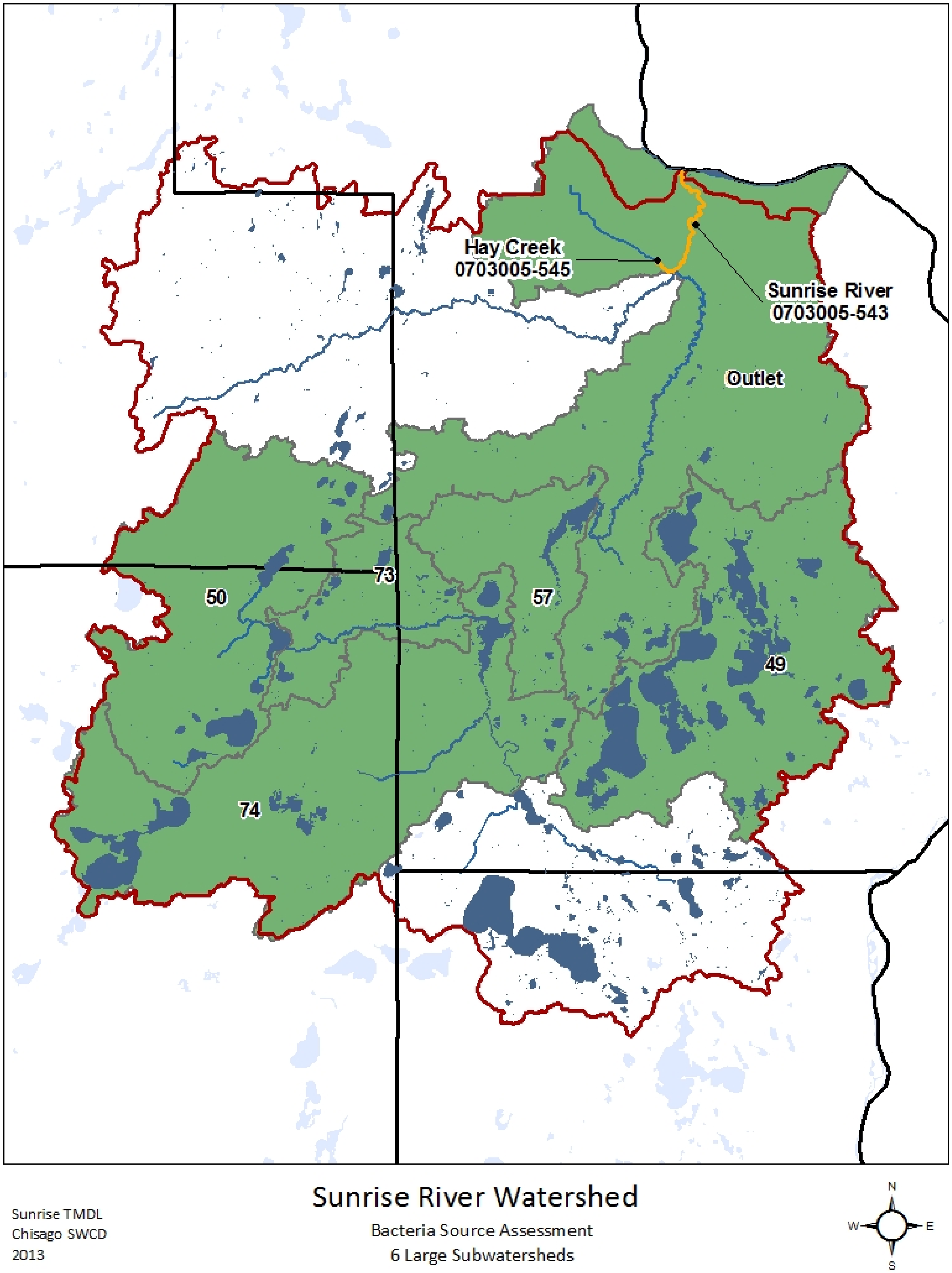


Table 53. Data Source and Assumptions for Estimates of Animal Populations

Producer	Basis for Estimates of Producer Population
Humans	Block groups from the 2010 Census data (U.S. Census Bureau 2011)
Dogs	American Veterinary Medical Association's (AVMA) 2006 data for % of households that own dogs and mean number of dogs in each household (AVMA 2007); 2010 Census block group data for number of households (U.S. Census Bureau 2011)
Cats	AVMA's 2006 data for % of households that own cats and mean number of cats in each household (AVMA 2007); 2010 Census block group data for number of households (U.S. Census Bureau 2011). Feral cat populations are unknown, but are suspected to be comparable to that of pet cats (AVMA 2010).
Horses	AVMA's 2006 data for % of households that own horses and mean number of horses in each household in the West North Central Region (AVMA 2007); 2010 Census block group data for number of households (U.S. Census Bureau 2011)
Cattle, hogs, sheep, goats, and poultry	USDA 2007 Census of Agriculture for livestock numbers by county (USDA NASS 2009)
Deer	DNR report *Status of Wildlife Populations, Fall 2009*, which entails pre-fawn densities by DNR deer permit area based on field surveys and modeling as reported in *Population Trends of White-Tailed Deer in Minnesota's Farmland/Transition Zone, 2009* by Marrett Grund and *Population Trends Of White-Tailed Deer In The Forest Zone, 2009* by Mark Lenarz (see Dexter 2009); missing data for the metro area (Permit Area 601) and three additional small permit areas were estimated based on the average density of surrounding permit areas
Geese	DNR report *Status of Wildlife Populations, Fall 2009*, estimates by Minnesota ecoregion based on a spring helicopter survey and modeling and reported in the *Minnesota Spring Canada Goose Survey, 2009* by David Rave (see Dexter 2009)
Breeding Ducks	State-wide estimate between the years 2005-2009 in a presentation by the Minnesota DNR Wetland Wildlife Population and Research Group at the 2010 Minnesota DNR Roundtable (http://files.dnr.state.mn.us/fish_wildlife/roundtable/2010/wildlife/wf_pop-harvest.pdf), distributed equally among areas of open water; annual *E. coli* production estimates include only the seven-month residence period (April through October)
Raccoons	A state-wide DNR estimate (DNR 2011) distributed on an area-weighted basis among raccoon habitat of prairie, woodland, and developed area based on the 2001 National Land Cover Dataset

B.1.1 Humans

Human population data were obtained using block groups[1] from the 2010 Census data (U.S. Census Bureau 2011). The census block groups that overlap sub watershed boundaries were distributed between each applicable subwatershed on an area-weighted basis.

B.1.2 Companion Animals

Numbers of households were used to estimate companion animal populations and were obtained using block groups from the 2010 Census data (U.S. Census Bureau 2011). The census block groups that overlap subwatershed boundaries were distributed between each applicable sub watershed on an area-weighted basis.

Dogs

According to the American Veterinary Medical Association's (AVMA) 2006 data, 34.2% of Minnesota households own dogs with a mean number of 1.4 dogs in each of those households (AVMA 2007).

Cats

According to the American Veterinary Medical Association's (AVMA) 2006 data, 31.9% of Minnesota. households own cats with a mean number of 2.3 cats in each of those households (AVMA 2007).

B.1.3 Livestock

The Census of Agriculture is a complete count of U.S. farms and ranches. The Census definition of a farm is "any place from which $1,000 or more of agricultural products were produced and sold, or normally would have been sold, during the census year" (USDA 2009). The Census looks at data in many areas, including animal ownership and sales. The authority for the Census comes from federal law under the *Census of Agriculture Act of 1997* (Public Law 105-113, Title 7, United States Code, Section 2204g). The Census is taken every fifth year, covering the prior year. The most recent Census was completed for the year 2007. The USDA National Agricultural Statistics Service (NASS) conducts the survey. Livestock numbers, by county, are available for cattle, hogs, sheep, goats, and poultry. Data for counties that overlap HUC 10 watershed boundaries were distributed between each applicable HUC 10 watershed on an area-weighted basis. For example, County A with 100 square miles and 100 heads of cattle would be treated as having 1 head of cattle per square mile; the HUC 10 watershed that includes 50 square miles of County A would be estimated to have 50 head of cattle. MPCA's geographic feedlot database developed for registration and NPDES permitting provides location data and related accounting. However, the numbers of animal units recorded in the database are the *allowable* numbers under the permit/registration and not the *actual* numbers on site; actual animal units are often lower and could be significantly lower. Therefore, USDA NASS data was used.

[1] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g. a municipality or a portion of a large city). There could be hundreds of census tracts in large cities like Chicago.

The fate and transport of manure is not considered in the project area estimates of potential bacteria sources. In addition, hobby farms, which do not produce $1,000 or more of agricultural products, are not included in the estimates.

Horses

The AVMA's 2006 data (AVMA 2007) includes horses for the West North Central Region (Minnesota, North Dakota, South Dakota, Nebraska, Kansas, Missouri, and Iowa). The horse ownership rate among West North Central Region households is 2.6% with a mean number of 3.4 horses owned in each of those households.

B.1.4 Other Wildlife

Permit areas or zones do not align with subwatershed boundaries. In order to distribute population data from permit areas or zones into multiple intersecting subwatershed boundaries, population data for any single permit area or zone was distributed between each intersecting sub watershed on an area-weighted basis.

Deer

The DNR report *Status of Wildlife Populations, Fall 2009* includes a collection of studies that estimate wildlife populations of various species (Dexter 2009). These data enabled the estimation of deer populations throughout the project area. Deer population estimates are based on field surveys and modeling as reported in the following studies: *Population Trends of White-Tailed Deer in Minnesota's Farmland/Transition Zone, 2009* by Marrett Grund and *Population Trends Of White-Tailed Deer In The Forest Zone, 2009* by Mark Lenarz. Pre-fawn deer densities were reported by DNR deer permit area. Data for permit areas that overlap subwatershed boundaries were distributed between each applicable subwatershed on an area-weighted basis.

Geese

The DNR report *Status of Wildlife Populations, Fall 2009* also includes a collection of studies that estimate wildlife populations of various species (Dexter 2009). These data enabled the estimation of goose populations throughout the project area. Goose population estimates are based on a spring helicopter survey and modeling and are reported in the *Minnesota Spring Canada Goose Survey, 2009* by David Rave. Counts were reported by Minnesota ecoregion: Prairie Parkland, Eastern Broadleaf Forest/Tallgrass Aspen Parklands, Laurentian Mixed Forest (less Lake and Cook Counties, the Boundary Waters Canoe Area, and the Northwest Angle).

Ducks

A presentation by Steve Cordts of the Minnesota DNR Wetland Wildlife Population and Research Group at the 2010 Minnesota DNR Roundtable reported on duck population status (http://files.dnr.state.mn.us/fish_wildlife/roundtable/2010/wildlife/wf_pop-harvest.pdf). According to DNR estimates, Minnesota's annual breeding duck population between the years 2005-2009 averaged 550,000. While the breeding range of the canvasback and lesser scaup is typically outside of the project area, the majority of the breeding duck population (including blue-winged teal, mallards, ring-necked ducks, and wood ducks) has a state-wide breeding range. The statewide population estimate was distributed on an area-weighted basis among subwatersheds including only areas of open water. This population is assumed to be present in

Minnesota from April through October; annual *E. coli* production estimates, therefore, include only a seven-month period.

Raccoon

Raccoon population data were provided by a state-wide DNR estimate of 800,000 to one million individuals (DNR 2011). An average value of 900,000 was used. Raccoon habitat is known to consist of prairie, woodland, and developed area (DNR 2011). Barding and Nelson (2008) document raccoon foraging in wetland, cropland, and forest. Therefore, the raccoon population was distributed among sub watersheds on an area-weighted basis including all land covers except open water (as classified by the 2001 National Land Cover Dataset).

Feral Cats

Feral cat populations are unknown, but are suspected to be comparable to that of pet cats (AVMA 2010). Therefore, the household cat population was used (2.3 cats for each household that owns cats) in order to account for feral cats in the overall cat population estimate. Feral cat populations are assumed to be distributed throughout the project area in the same relative proportions as domestic cats.

B.1.5 Strengths and Limitations

The bacteria production estimates are provided at the subwatershed scale. The results inform stakeholders as to the types and relative magnitude of bacteria produced in their watershed. This information is a valuable tool for the planning and management of water bodies with respect to bacteria contamination.

The project area potential bacteria source estimates use a GIS-based approach. However, available data sources are at different scales and have different boundaries than that of the study subwatersheds. A limitation to the estimation process is that populations must be distributed geographically (e.g. county to subwatersheds) using assumptions related to population density. There is a probable minimum scale at which bacteria production estimates are useful.

A significant portion of bacteria producers were accounted for in the potential bacteria sources. However, several animals were not included: birds other than geese and ducks (e.g. song birds and wading birds) and many wild animals (e.g. bear and wild turkey). Data, resource limitations, and consideration for the major bacteria producers in the project area led to the selected set of bacteria producers accounted for in these estimates.

The project area estimates of potential bacteria sources is also limited by the fact that bacteria delivery is not addressed (e.g. treatment of human waste at wastewater treatment facilities prior to discharge to receiving waters, pet waste management, zero discharge feedlot facilities, incorporation of manure into soil, geese gathering directly on stormwater ponds). The bacteria source assessment for the 29 Target Subwatersheds addresses bacteria delivery.

The potential bacteria source estimates also do not account for the relative risk among different types of bacteria. Instead, *E. coli* production is estimated as an indicator of the likelihood of pathogen contamination of our waterbodies.

B.2 Results

Bacteria production is reported by source for each of six large subwatersheds constituting the project area downstream of Comfort Lake and the North Branch of the Sunrise River. Table 54 illustrates relative production across source categories for each subwatershed. Refer to Figure 49 for a map of the subwatersheds.

For results of the bacteria source assessment of the 29 Target Subwatersheds discharging more directly to the reaches impaired due to bacteria (Sunrise River, N Br Sunrise R to St Croix R, AUID 07030005-543, and Hay Creek, Louden Ave to Sunrise River, AUID 07030006-545), refer to Section 3.6.2.

Table 54. Bacteria Production Across Source Categories for Six Large Subwatersheds
Comparison across source categories of relative amounts of each sub watershed. For example, the “0” row presents a comparison of the *E. coli* production in Subwatershed 0 by one source category vs. another source category. (Symbols are viewed relative to other symbols within the same row.)
• - low (0-25th percentile), ž - medium-low (26th-50th percentile), œ - medium-high (51st-75th percentile), ˜ - high (76th-100th percentile)

Subwatershed	Area [sq. mi]	Relative Annual *E. coli* Production Rank (based on the number of *E. coli* organisms produced per year)													
		Human	Dog	House Cat	Horse	Cattle	Goat	Hog	Sheep	Poultry	Deer	Geese	Breeding Duck	Raccoon	Feral Cat
Outlet	86	•	•	•	•	ž	•	˜	•	˜	•	•	•	•	•
49	50	•	•	•	•	•	•	œ	•	˜	•	•	•	•	•
50	48	•	•	•	•	•	•	œ	•	˜	•	•	•	•	•
57	15	•	•	•	•	•	•	œ	•	˜	•	•	•	•	•
73	14	•	•	•	•	ž	•	˜	•	˜	•	•	•	•	•
74	49	•	•	•	•	•	•	œ	•	˜	•	•	•	•	•

APPENDIX C. SUPPORTING DATA FOR BATHTUB MODELS

Bathtub modeling diagnostics (results) and segment balances (water and phosphorus budgets) are presented for both the calibrated (benchmark/existing) model and the TMDL scenario. In-lake water quality concentrations for the calibrated and TMDL scenarios were evaluated to the nearest tenth for TP. The tributary goal reported in the Bathtub model output does not take into account the MOS, and is therefore larger than the loading goals listed in the individual lake TMDL and allocation tables in Section 4.1.7.

C.1 Linwood Lake Calibrated Model

Table 55. Calibrated (benchmark) Bathtub model diagnostics (model results) for Linwood Lake

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Segname 1**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	44.0	0.25	46.3%	44.0	0.05	46.2%

Table 56. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Linwood Lake

Overall Water Balance					**Averaging Period =**	**1.00**	**years**
	Area	**Flow**	**Variance**	**CV**	**Runoff**		
Trb Type Seg Name	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**		
1 1 1 Trib 1	27.51	8.08	6.53E-01	0.10	0.29		
PRECIPITATION	2.30	1.73	0.00E+00	0.00	0.75		
TRIBUTARY INFLOW	27.51	8.08	6.53E-01	0.10	0.29		
***TOTAL INFLOW	29.81	9.81	6.53E-01	0.08	0.33		
ADVECTIVE OUTFLOW	29.81	7.76	6.53E-01	0.10	0.26		
***TOTAL OUTFLOW	29.81	7.76	6.53E-01	0.10	0.26		
***EVAPORATION		2.05	0.00E+00	0.00			

Overall Mass Balance Based Upon	**Predicted**		**Outflow & Reservoir Concentrations**				
Component:	**TOTAL P**						
	Load		**Load Variance**			**Conc**	**Export**
Trb Type Seg Name	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1 1 1 Trib 1	678.7	90.8%	9.21E+03	88.5%	0.14	84.0	24.7
PRECIPITATION	69.1	9.2%	1.19E+03	11.5%	0.50	40.0	30.0
TRIBUTARY INFLOW	678.7	90.8%	9.21E+03	88.5%	0.14	84.0	24.7
***TOTAL INFLOW	747.8	100.0%	1.04E+04	100.0%	0.14	76.3	25.1
ADVECTIVE OUTFLOW	341.5	45.7%	9.25E+03		0.28	44.0	11.5
***TOTAL OUTFLOW	341.5	45.7%	9.25E+03		0.28	44.0	11.5
***RETENTION	406.3	54.3%	9.89E+03		0.24		
Overflow Rate (m/yr)	3.4		Nutrient Resid. Time (yrs)			0.3808	
Hydraulic Resid. Time (yrs)	0.8338		Turnover Ratio			2.6	
Reservoir Conc (mg/m3)	44		Retention Coef.			0.543	

C.2 Linwood Lake TMDL Model

Table 57. TMDL scenario Bathtub model diagnostics (model results) for Linwood Lake

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Segname 1**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	40.0	0.25	42.1%	44.0	0.05	46.2%

Table 58. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Linwood Lake

Overall Water Balance						**Averaging Period =**		**1.00**	**years**
				Area	**Flow**	**Variance**		**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**		**-**	**m/yr**
1	1	1	Trib 1	27.51	8.08	6.53E-01		0.10	0.29
PRECIPITATION				2.30	1.73	0.00E+00		0.00	0.75
TRIBUTARY INFLOW				27.51	8.08	6.53E-01		0.10	0.29
***TOTAL INFLOW				29.81	9.81	6.53E-01		0.08	0.33
ADVECTIVE OUTFLOW				29.81	7.76	6.53E-01		0.10	0.26
***TOTAL OUTFLOW				29.81	7.76	6.53E-01		0.10	0.26
***EVAPORATION					2.05	0.00E+00		0.00	

Overall Mass Balance Based Upon				**Predicted**		**Outflow & Reservoir Concentrations**				
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Trib 1	589.8	89.5%	6.96E+03	85.4%	0.14	73.0	21.4
PRECIPITATION				69.1	10.5%	1.19E+03	14.6%	0.50	40.0	30.0
TRIBUTARY INFLOW				589.8	89.5%	6.96E+03	85.4%	0.14	73.0	21.4
***TOTAL INFLOW				658.9	100.0%	8.15E+03	100.0%	0.14	67.2	22.1
ADVECTIVE OUTFLOW				310.4	47.1%	7.34E+03		0.28	40.0	10.4
***TOTAL OUTFLOW				310.4	47.1%	7.34E+03		0.28	40.0	10.4
***RETENTION				348.5	52.9%	7.66E+03		0.25		
Overflow Rate (m/yr)				3.4		Nutrient Resid. Time (yrs)			0.3928	
Hydraulic Resid. Time (yrs)				0.8338		Turnover Ratio			2.5	
Reservoir Conc (mg/m3)				40		Retention Coef.			0.529	

C.3 Second Lake Calibrated Model

Table 59. Calibrated (benchmark) Bathtub model diagnostics (model results) for Second Lake

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment: 1 Segname 1						
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	77.0	0.37	70.1%	77.0	0.07	70.1%

Table 60. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Second Lake

Overall Water Balance						Averaging Period = 1.00 years			
				Area	**Flow**	**Variance**	**CV**	**Runoff**	
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**	
1	1	1	Trib 1	2.11	0.23	5.29E-04	0.10	0.11	
PRECIPITATION				0.34	0.26	0.00E+00	0.00	0.75	
TRIBUTARY INFLOW				2.11	0.23	5.29E-04	0.10	0.11	
***TOTAL INFLOW				2.45	0.49	5.29E-04	0.05	0.20	
ADVECTIVE OUTFLOW				2.45	0.19	5.29E-04	0.12	0.08	
***TOTAL OUTFLOW				2.45	0.19	5.29E-04	0.12	0.08	
***EVAPORATION					0.30	0.00E+00	0.00		

Overall Mass Balance Based Upon Component:				**Predicted TOTAL P**		**Outflow & Reservoir Concentrations**				
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Trib 1	72.2	87.5%	1.04E+02	79.8%	0.14	314.0	34.2
PRECIPITATION				10.3	12.5%	2.65E+01	20.2%	0.50	40.0	30.0
TRIBUTARY INFLOW				72.2	87.5%	1.04E+02	79.8%	0.14	314.0	34.2
***TOTAL INFLOW				82.5	100.0%	1.31E+02	100.0%	0.14	169.3	33.6
ADVECTIVE OUTFLOW				14.3	17.3%	3.29E+01		0.40	77.0	5.8
***TOTAL OUTFLOW				14.3	17.3%	3.29E+01		0.40	77.0	5.8
***RETENTION				68.2	82.7%	1.14E+02		0.16		

Overflow Rate (m/yr)	0.5	Nutrient Resid. Time (yrs)	0.5154
Hydraulic Resid. Time (yrs)	2.9784	Turnover Ratio	1.9
Reservoir Conc (mg/m3)	77	Retention Coef.	0.827

C.4 Second Lake TMDL Model

Table 61. TMDL scenario Bathtub model diagnostics (model results) for Second Lake

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Segname 1**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60.0	0.36	59.8%	77.0	0.07	70.1%

Table 62. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Second Lake

Overall Water Balance					**Averaging Period =**	**1.00**	**years**
				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Trib 1	2.11	0.23	5.29E-04	0.10	0.11
PRECIPITATION				0.34	0.26	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				2.11	0.23	5.29E-04	0.10	0.11
***TOTAL INFLOW				2.45	0.49	5.29E-04	0.05	0.20
ADVECTIVE OUTFLOW				2.45	0.19	5.29E-04	0.12	0.08
***TOTAL OUTFLOW				2.45	0.19	5.29E-04	0.12	0.08
***EVAPORATION					0.30	0.00E+00	0.00	

Overall Mass Balance Based Upon				**Predicted**		**Outflow & Reservoir Concentrations**				
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Trib 1	45.1	81.4%	4.06E+01	60.6%	0.14	196.0	21.4
PRECIPITATION				10.3	18.6%	2.65E+01	39.4%	0.50	40.0	30.0
TRIBUTARY INFLOW				45.1	81.4%	4.06E+01	60.6%	0.14	196.0	21.4
***TOTAL INFLOW				55.4	100.0%	6.71E+01	100.0%	0.15	113.6	22.6
ADVECTIVE OUTFLOW				11.1	20.1%	1.88E+01		0.39	60.0	4.5
***TOTAL OUTFLOW				11.1	20.1%	1.88E+01		0.39	60.0	4.5
***RETENTION				44.3	79.9%	5.89E+01		0.17		
Overflow Rate (m/yr)				0.5		Nutrient Resid. Time (yrs)			0.5979	
Hydraulic Resid. Time (yrs)				2.9784		Turnover Ratio			1.7	
Reservoir Conc (mg/m3)				60		Retention Coef.			0.799	

C.5 Vibo Lake Calibrated Model

Table 63. Calibrated (benchmark) Bathtub model diagnostics (model results) for Vibo Lake

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Segname 1**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	516.0	0.22	99.6%	516.0	0.08	99.6%

Table 64. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Vibo Lake

Overall Water Balance					**Averaging Period =**	**1.00**	**years**
				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Trib 1	31.06	4.96	2.46E-01	0.10	0.16
PRECIPITATION				0.23	0.17	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				31.06	4.96	2.46E-01	0.10	0.16
***TOTAL INFLOW				31.29	5.13	2.46E-01	0.10	0.16
ADVECTIVE OUTFLOW				31.29	4.93	2.46E-01	0.10	0.16
***TOTAL OUTFLOW				31.29	4.93	2.46E-01	0.10	0.16
***EVAPORATION					0.20	0.00E+00	0.00	

Overall Mass Balance Based Upon				**Predicted**	**Outflow & Reservoir Concentrations**					
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Trib 1	4739.3	99.9%	4.49E+05	100.0%	0.14	955.5	152.6
PRECIPITATION				7.0	0.1%	1.21E+01	0.0%	0.50	40.0	30.0
TRIBUTARY INFLOW				4739.3	99.9%	4.49E+05	100.0%	0.14	955.5	152.6
***TOTAL INFLOW				4746.2	100.0%	4.49E+05	100.0%	0.14	924.5	151.7
ADVECTIVE OUTFLOW				2543.8	53.6%	4.16E+05		0.25	516.0	81.3
***TOTAL OUTFLOW				2543.8	53.6%	4.16E+05		0.25	516.0	81.3
***RETENTION				2202.4	46.4%	3.74E+05		0.28		
Overflow Rate (m/yr)				21.2		Nutrient Resid. Time (yrs)			0.0356	
Hydraulic Resid. Time (yrs)				0.0664		Turnover Ratio			28.1	
Reservoir Conc (mg/m3)				516		Retention Coef.			0.464	

C.6 Vibo Lake TMDL Model

Table 65. TMDL scenario Bathtub model diagnostics (model results) for Vibo Lake

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Segname 1**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	60.0	0.13	59.9%	516.0	0.08	99.6%

Table 66. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Vibo Lake

Overall Water Balance					**Averaging Period =**	**1.00 years**	
				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Trib 1	31.06	4.96	2.46E-01	0.10	0.16
PRECIPITATION				0.23	0.17	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				31.06	4.96	2.46E-01	0.10	0.16
***TOTAL INFLOW				31.29	5.13	2.46E-01	0.10	0.16
ADVECTIVE OUTFLOW				31.29	4.93	2.46E-01	0.10	0.16
***TOTAL OUTFLOW				31.29	4.93	2.46E-01	0.10	0.16
***EVAPORATION					0.20	0.00E+00	0.00	

Overall Mass Balance Based Upon Component:				**Predicted TOTAL P**		**Outflow & Reservoir Concentrations**				
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Trib 1	369.0	98.1%	2.72E+03	99.6%	0.14	74.4	11.9
PRECIPITATION				7.0	1.9%	1.21E+01	0.4%	0.50	40.0	30.0
TRIBUTARY INFLOW				369.0	98.1%	2.72E+03	99.6%	0.14	74.4	11.9
***TOTAL INFLOW				376.0	100.0%	2.74E+03	100.0%	0.14	73.2	12.0
ADVECTIVE OUTFLOW				295.8	78.7%	2.55E+03		0.17	60.0	9.5
***TOTAL OUTFLOW				295.8	78.7%	2.55E+03		0.17	60.0	9.5
***RETENTION				80.2	21.3%	9.31E+02		0.38		
Overflow Rate (m/yr)				21.2		Nutrient Resid. Time (yrs)			0.0522	
Hydraulic Resid. Time (yrs)				0.0664		Turnover Ratio			19.2	
Reservoir Conc (mg/m3)				60		Retention Coef.			0.213	

C.7 White Stone Lake Calibrated Model

Table 67. Calibrated (benchmark) Bathtub model diagnostics (model results) for White Stone Lake

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:	**1**	**Segname 1**					
	Predicted Values--->			**Observed Values--->**			
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3		97.0	0.39	78.4%	97.0	0.08	78.3%

Table 68. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for White Stone Lake

Overall Water Balance					**Averaging Period =**	**1.00**	**years**
				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Trib 1	0.89	0.10	1.00E-04	0.10	0.11
PRECIPITATION				0.20	0.15	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				0.89	0.10	1.00E-04	0.10	0.11
***TOTAL INFLOW				1.09	0.25	1.00E-04	0.04	0.23
ADVECTIVE OUTFLOW				1.09	0.07	1.00E-04	0.13	0.07
***TOTAL OUTFLOW				1.09	0.07	1.00E-04	0.13	0.07
***EVAPORATION					0.17	0.00E+00	0.00	

Overall Mass Balance Based Upon				**Predicted**		**Outflow & Reservoir Concentrations**				
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Trib 1	55.2	90.3%	6.09E+01	87.4%	0.14	552.0	62.0
PRECIPITATION				5.9	9.7%	8.82E+00	12.6%	0.50	40.0	30.0
TRIBUTARY INFLOW				55.2	90.3%	6.09E+01	87.4%	0.14	552.0	62.0
***TOTAL INFLOW				61.1	100.0%	6.98E+01	100.0%	0.14	246.0	56.2
ADVECTIVE OUTFLOW				7.2	11.8%	9.52E+00		0.43	97.0	6.6
***TOTAL OUTFLOW				7.2	11.8%	9.52E+00		0.43	97.0	6.6
***RETENTION				53.9	88.2%	6.00E+01		0.14		
Overflow Rate (m/yr)				0.4		Nutrient Resid. Time (yrs)			0.4776	
Hydraulic Resid. Time (yrs)				4.0528		Turnover Ratio			2.1	
Reservoir Conc (mg/m3)				97		Retention Coef.			0.882	

C.8 White Stone Lake TMDL Model

Table 69. TMDL scenario Bathtub model diagnostics (model results) for White Stone Lake

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:	**1**	**Segname 1**					
	Predicted Values--->			**Observed Values--->**			
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60.0	0.38	59.9%	97.0	0.08	78.3%

Table 70. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for White Stone Lake

Overall Water Balance					**Averaging Period =**	**1.00**	**years**
				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km²**	**hm³/yr**	**(hm3/yr)²**	**-**	**m/yr**
1	1	1	Trib 1	0.89	0.10	1.00E-04	0.10	0.11
PRECIPITATION				0.20	0.15	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				0.89	0.10	1.00E-04	0.10	0.11
***TOTAL INFLOW				1.09	0.25	1.00E-04	0.04	0.23
ADVECTIVE OUTFLOW				1.09	0.07	1.00E-04	0.13	0.07
***TOTAL OUTFLOW				1.09	0.07	1.00E-04	0.13	0.07
***EVAPORATION					0.17	0.00E+00	0.00	

Overall Mass Balance Based Upon Component:				**Predicted TOTAL P**		**Outflow & Reservoir Concentrations**				
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**(kg/yr)²**	**%Total**	**CV**	**mg/m³**	**kg/km²/yr**
1	1	1	Trib 1	21.7	78.5%	9.42E+00	51.6%	0.14	217.0	24.4
PRECIPITATION				5.9	21.5%	8.82E+00	48.4%	0.50	40.0	30.0
TRIBUTARY INFLOW				21.7	78.5%	9.42E+00	51.6%	0.14	217.0	24.4
***TOTAL INFLOW				27.6	100.0%	1.82E+01	100.0%	0.15	111.2	25.4
ADVECTIVE OUTFLOW				4.5	16.1%	3.35E+00		0.41	60.0	4.1
***TOTAL OUTFLOW				4.5	16.1%	3.35E+00		0.41	60.0	4.1
***RETENTION				23.2	83.9%	1.58E+01		0.17		
Overflow Rate (m/yr)				0.4		Nutrient Resid. Time (yrs)			0.6533	
Hydraulic Resid. Time (yrs)				4.0528		Turnover Ratio			1.5	
Reservoir Conc (mg/m3)				60		Retention Coef.			0.839	