Ramsey-Washington Metro Watershed District Total Maximum Daily Load Study

Quantification of the pollutant reductions necessary
to restore aquatic recreation in Bennett Lake, Wakefield Lake and Fish Creek;
and to restore aquatic life in Battle Creek

Minnesota Pollution Control Agency

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Cover Photo of Bennett Lake Courtesy of Ramsey-Washington Metro Watershed District
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TMDL Summary Table			
EPA/MPCA Required Elements	**Summary**		**TMDL Page #**
Applicable Water Quality Standards/ Numeric Targets (continued)	Bennett Lake and Wakefield Lake	Growing Season (June-September) means of total phosphorus concentration ≤ 60 µg/L, chlorophyll-*a* concentration ≤ 20 µg/L, and Secchi disc transparency ≥ 1.0 meter. Applies to shallow lake Class 2B waters located in the North Central Hardwood Forest Ecoregion.	Pp. 5
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Acronyms

ac-ft	acre feet
BMP	Best Management Practice
BOD	Biological Oxygen Demand
CADDIS	Casual Analysis/Diagnosis Decision Information System
cfu	colony-forming unit
CWLA	Clean Water Legacy Act
DNR	Minnesota Department of Natural Resources
DO	Dissolved Oxygen
E. coli	*Escherichia coli* bacteria
EPA	Environmental Protection Agency
GS	Growing season
GW	Groundwater
HUC	Hydrologic Unit Code
IBI	Index of Biological Integrity
LA	Load Allocation
lb	pound
m	meter
MDA	Minnesota Department of Agriculture
mg/L	milligrams per liter
mL	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
MSHA	MPCA Stream Habitat Assessment
NCHF	North Central Hardwood Forest Ecoregion
NLCD	National Land Use Database
NPDES	National Pollutant Discharge Elimination System
P8	Program for Predicting Polluting Particle Passage thru Pits, Puddles, and Ponds
RWMWD	Ramsey Washington Metro Watershed District
SID	Stressor Identification Report
SDS	State Disposal System
SSTS	Subsurface Sewage Treatment System or Systems
SWPPP	Stormwater Pollution Prevention Plan
TCMA	Twin Cities Metropolitan Area
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	Total Suspended Solids
µg/L	microgram per liter
WLA	Wasteload Allocation
WMP	Watershed Management Plan
WOMP	Watershed Outlet Monitoring Program
WRAPS	Watershed Restoration and Protection Strategy

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses aquatic life and aquatic recreation impairments in Battle Creek and Fish Creek, and nutrient impairments in Bennett Lake and Wakefield Lake. The goal of this TMDL report is to quantify the pollutant reductions needed to meet the Minnesota Pollution Control Agency's (MPCA's) water quality standards for all four Ramsey-Washington Metro Watershed District (RWMWD) water bodies. This TMDL report was established in accordance with Section 303(d) of the Clean Water Act and provides the wasteload allocations (WLAs) and load allocations (LAs) for the impaired water resources.

This report outlines the development of the TMDLs for Battle Creek, Bennett Lake, Fish Creek, and Wakefield Lake and describes best management practices (BMPs) that can be implemented to work towards achieving the required pollutant reductions to these resources.

A Biological Stressor Identification (SID) Report was completed in spring 2015 for Battle Creek using the United States Environmental Protection Agency's (EPA's) 2010 Casual Analysis/Diagnosis Decision Information System (CADDIS) (Barr 2015). The SID report found that chloride and total suspended solids (TSS) are the primary stressors to the fish and macroinvertebrate assemblages within Battle Creek. To evaluate sources of TSS to Battle Creek, sediment transport modeling was compared to annual TSS loading predicted from observed water quality data. This analysis indicates that elevated TSS concentrations in Battle Creek are caused by high sediment loading mobilized by watershed runoff and erosion within the immediate stream channel and stream corridor.

The TSS load reductions of 66% to 91% are required to meet water quality standards, depending on the flow conditions. Primary implementation strategies include increasing flow detention and treatment within the watershed and restoration of sections of the stream corridor.

Fish Creek was placed on the 303(d) list for *Escherichia coli* bacteria (*E. coli)* impairment in 2014. *E. coli* bacteria is used in water quality monitoring as an indicator organism to identify water that is contaminated with human or animal waste and the accompanying disease-causing organisms. Bacterial abundance in excess of the water quality standards can pose a human health risk. A population source inventory and assumed bacteria availability were used to estimate the sources of bacteria loading to Fish Creek. The analysis indicated that runoff from urban areas mobilizing bacteria from improperly managed pet waste is the main source of *E. coli* loading during wet-weather conditions, and failing subsurface septic treatment systems (SSTSs) and sanitary sewer exfiltration are the main sources of loading during dry-weather conditions.

Overall *E. coli* load reductions up to 62% are required in order to meet water quality standards, depending on the flow conditions. The primary implementation strategies include education and outreach related to pet waste management, and an inventory of and improvements to non-compliant SSTSs and sanitary sewer infrastructure within the watershed.

Bennett and Wakefield Lakes are impaired for aquatic recreation due to excess nutrients. The main phosphorus sources to Bennett Lake are both watershed runoff and internal sediment. The major source of phosphorus loading to Wakefield Lake is phosphorus mobilized by watershed runoff. Secondary sources of phosphorus loading include release from lake sediment, release from die back of aquatic plants, and direct atmospheric deposition.

To achieve the TMDL and state water quality standards, a 71% reduction of the growing season phosphorus load is required for Bennett Lake, and a 46% reduction for Wakefield Lake. The primary implementation strategies to address internal load for Bennet Lake include carp and curly-leaf pondweed management to reduce internal phosphorus loading. Whole-lake alum treatment and herbicide treatment to control curly-leaf pondweed are the primary recommendations to reduce internal phosphorus loading in Wakefield Lake. A variety of water quality BMPs can be implemented to achieve the required watershed runoff phosphorus loading reduction in both watersheds.

1. Project Overview

1.1 Purpose

Section 303(d) of the Clean Water Act requires that every two years all states publish a list of streams and lakes that do not meet water quality standards. Waters placed on the list are considered impaired. States are required to set TMDLs for impaired waters in order to define the maximum amount of pollutant a waterbody can receive while maintaining water quality standards, and to determine the load reductions necessary to achieve water quality standards. A TMDL is divided into a WLA for point sources (permitted sources), a LA for nonpoint sources (non-permitted sources) and natural background, a reserve capacity for future loadings (if necessary) and a margin of safety (MOS).

The Ramsey-Washington Metro Watershed District (RWMWD) is located in eastern Ramsey County and western Washington County in the state of Minnesota. The RWMWD historically covered an area of about 56.5 square miles. However, in 2012, the RWMWD boundary expanded with the acquisition of the area formerly encompassed by the Grass Lake Watershed Management Organization, an additional nine square miles. The RWMWD encompasses portions of a number of communities including White Bear Lake, Vadnais Heights, Gem Lake, Little Canada, Maplewood, Landfall, North St. Paul, St. Paul, Oakdale, Woodbury, Roseville, and Shoreview.

One of the primary goals of the RWMWD is to maintain or improve the quality of surface waters to meet or exceed the water quality standards set by the state of Minnesota.

1.2 Identification of Waterbodies

Table 1-1 summarizes the year the water resource was listed as impaired, and the targeted start dates and completion dates for the TMDLs.

Battle Creek was listed on the 303(d) list for chloride impairment and biological impairment in 2008 and 2014, respectively. Impairment of aquatic life has been identified due to elevated chloride loading and poor fish and macroinvertebrate assemblages. A Biological Stressor Identification (SID) Report was completed in spring 2015 to identify primary sources of stress to fish and macroinvertebrate within Battle Creek (Barr 2015). The report found that chloride and TSS are the primary stressors to the fish and macroinvertebrate assemblages within Battle Creek, therefor requiring TMDLs to address the biological impairments. Additionally, analysis of water quality data conducted for the report found that the stream is impaired by TSS, based on the Class 2B stream standard for the Central River Nutrient Region (Section 2.2). Chloride impairment will not be included in this TMDL study, as a chloride TMDL for Battle Creek has been developed as part of the TCMA Chloride TMDL (MPCA 2016).

Fish Creek was placed on the MPCA's 303(d) list of impaired waters in 2014. The affected designated use was identified as aquatic recreation due to bacteria (*E. coli*). *E. coli* bacteria is used in water quality monitoring as an indicator organism to identify water that is contaminated with human or animal waste and the accompanying disease-causing organisms. Bacterial abundance in excess of the water quality standards can pose a health risk to humans.

Bennett Lake and Wakefield Lake were listed on the MPCA 303(d) list of impaired waters in 2006 and 2002, respectively for not meeting the MPCA's shallow lake eutrophication standards for the North Central Hardwood Forests (NCHF) ecoregion. The affected designated use for both lakes was identified as aquatic recreation due to excess nutrients. In freshwater lakes, phosphorus is often the limiting nutrient and there is typically a direct relationship between the amount of phosphorus and the amount of algae in the lake. Excess phosphorus in lakes can result in nuisance algal blooms that impact water clarity, recreational uses of the lake, and overall aesthetics. In addition to excess nutrients, Bennett Lake was listed for mercury impairment in 2012. Bennett Lake is included in the approved MPCA Statewide Mercury TMDL (EPA ID# 52290) and, for this reason, mercury impairment will not be addressed in this TMDL study.

1.3 Priority Ranking

The MPCA's schedule for TMDL completions, as indicated on the 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned our TMDL priorities with the watershed approach and our WRAPS cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on the ten-year cycle. The MPCA developed a state plan Minnesota's TMDL Priority Framework Report to meet the needs of EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments, which will be addressed by TMDLs by 2022. The RWMWD Watershed waters addressed by this TMDL are part of that MPCA prioritization plan to meet EPA's national measure

Table 1-1 Impairments addressed in the TMDL Report

Water Body	Pollutant or Stressor	Impaired Use	Year Listed as Impaired	Target Start Date	Target Completion Date
Battle Creek (07010206-592)	Chloride	Aquatic Life	2008	2009[1]	2015[1]
	Fishes Bioassessments	Aquatic Life	2014	2011	2015
	Aquatic Macroinvertebrate Bioassessments	Aquatic Life	2014	2011	2015
Fish Creek (07010206-606)	*E. coli*	Aquatic Recreation	2014	2011	2015
Bennett Lake (62-0048-00)	Nutrient/Eutrophication Biological Indicators	Aquatic Recreation	2006	2012	2015
	Mercury in fish tissue	Aquatic Consumption	2012	N/A[2]	N/A[2]
Wakefield Lake (62-0011-00)	Nutrient/Eutrophication Biological Indicators	Aquatic Recreation	2002	2011	2015

1 Chloride impairment in Battle Creek addressed in the approved https://www.pca.state.mn.us/sites/default/files/wq-iw11-06e.pdf.

2 Mercury impairment in Bennett Lake addressed in the approved MPCA Statewide Mercury TMDL.

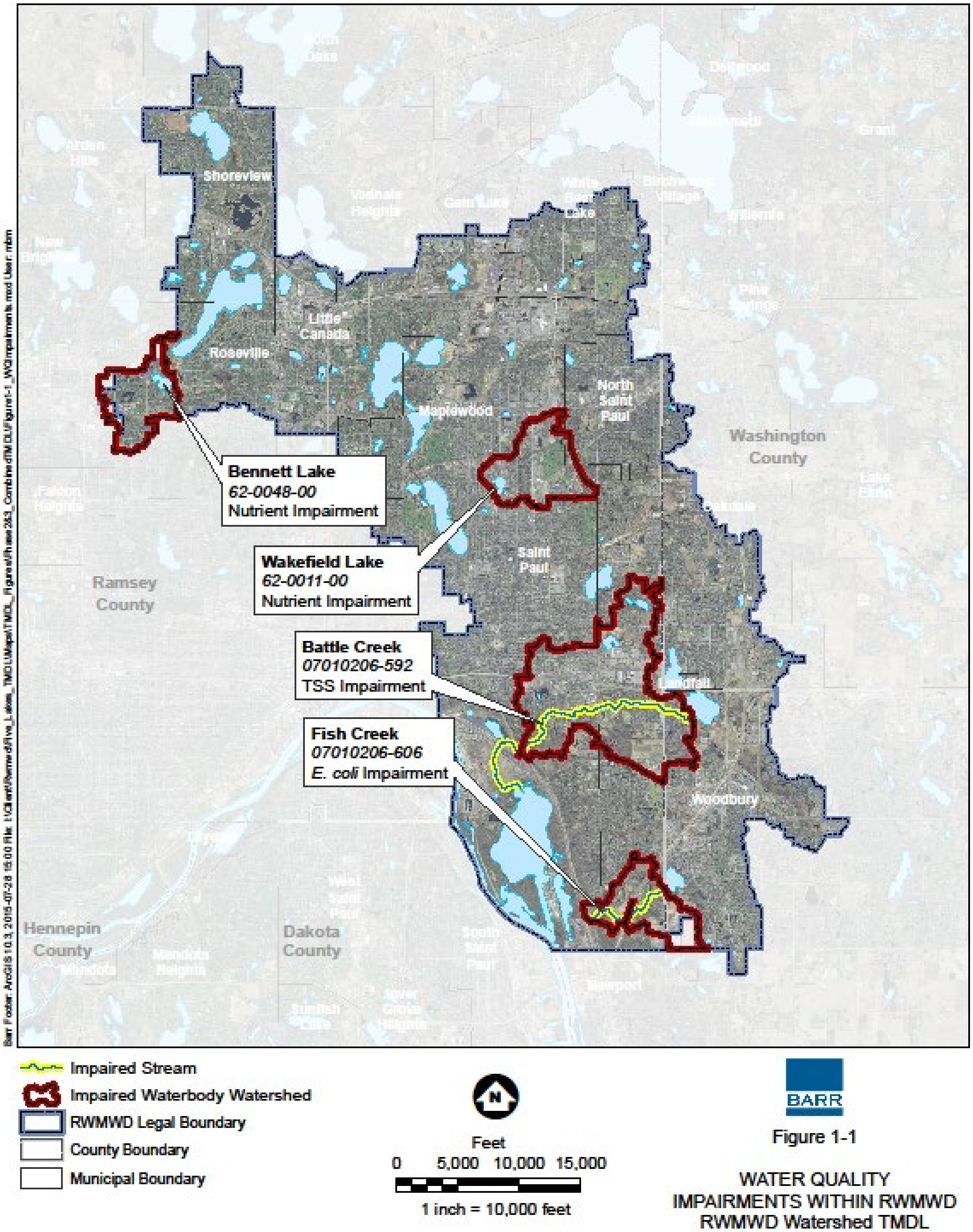

Figure 1-1 Water Quality Impairments within RWMWD

2. Applicable Water Quality Standards and Numeric Water Quality Targets

The following sections discuss the applicable water quality standards that apply to the TMDLs being completed as part of this study.

2.1 Biological Impairment

The narrative standard for biological impairment in Class 2 waters (aquatic life and recreation) is defined in Minn. R. 7050.0150:

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

Biological impairment is evaluated using an Index of Biological Integrity (IBI), which aggregates and scores diversity and abundance within an aquatic population based on grouped attributes of the community, often referred to as biological metrics. These biological metrics are groupings of similar species, based on structural (e.g., species composition) or functional (e.g., feeding habits) characteristics, which respond to human disturbance in predictable ways. Fish and macroinvertebrate scores vary from 0-100, with 100 representing the highest quality of species abundance and diversity.

The MPCA has evaluated aquatic populations at minimally impacted references sites across the state and has developed impairment thresholds for various stream classifications. Stream classifications are defined by stream drainage area, morphology, ecoregion, and major basin. A stream within a given classification is considered impaired if its fish and/or macroinvertebrate IBI score falls below the established threshold IBI value. The IBI threshold values and stream classifications applicable to Battle Creek are shown in Table 2-1.

Table 2-1 IBI threshold values applicable to Battle Creek

Community	Class	Classification	Threshold IBI Value
Fish	2	Southern Headwaters	54
Fish	3	Southern Streams	58
Macroinvertebrate	5	Southern Streams (Riffle/Run)	36
Macroinvertebrate	6	Southern Streams (Glide/Pool)	47

2.2 Total Suspended Solids (TSS)

The TSS standards for rivers and streams were adopted at a June 24, 2014, the MPCA Citizen Board meeting. Adopted TSS standards supersede and replace all standards related to turbidity (i.e., the measure of the cloudiness or haziness of water caused by suspended and dissolved substances in the water column) formerly listed in Minn. R. 7050.0222.

Battle Creek is classified as a Class 2B water (cool/warm water) and is located in the Central River Nutrient Region. The TSS standard applicable to Battle Creek as defined by Minn. R. 7050.0222 is outlined below:

- TSS Standard (Class 2B, Central River Nutrient Region) = 30 mg/L
- TSS standards for the Class 2B North, Central, and South River Nutrient Regions and the Red River mainstem may be exceeded for no more than 10% of the time. This standard applies April 1 through September 30.

2.3 Bacteria (*E. coli*)

Fish Creek is classified as Class 2C water (indigenous fish and associated aquatic life and habitat). Narrative and numeric standards for *E. coli* applicable to Class 2C streams are outlined below.

The narrative standard for Class 2B waters (also applicable to Class 2C waters) is defined in Minn. R. 7050.0222:

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

The numeric standard for Class 2C waters is in terms of *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 10% of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31.*

2.4 Excess Nutrients

According to Minn. R. ch. 7050.0150 and Minn. R. ch. 7050.0222, subp. 4, Bennett Lake and Wakefield Lake are located in the NCHF ecoregion and both are considered shallow lakes.

The MPCA's shallow lake eutrophication standards for the NCHF ecoregion are shown in Table 2-2. To be listed as impaired by the MPCA, the monitoring data must show that the standards for both total phosphorus (TP) (the causal factor) and either Chlorophyll *a* (Chl-*a*) or Secchi disc transparency depth (the response factors) are not met (MPCA 2014a).

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

Table 2-2 Numeric water quality standards for shallow lakes in the North Central Hardwood Forest Ecoregion

Parameters	Shallow[1] Lake Standard
Total Phosphorus µg/L	≤ 60
Chlorophyll *a* (µg/L)	≤ 14
Secchi Disc (meters)	≥ 1.0

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

2.4.1 Analysis of Impairment

The criteria used for determining impairments are outlined in the MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List (MPCA 2014a).

3. Watershed and Waterbody Characterization

The RWMWD is a special purpose unit of local government that manages water resources on a watershed basis. Watershed district boundaries generally follow natural watershed divides, rather than political boundaries. The general purposes of a watershed district are to conserve natural resources through land use planning, flood control, and other conservation projects to protect the public health and welfare and for the wise use of the natural resources. The boundaries of the RWMWD are shown on Figure 1-1.

The communities that lie or partially lie within the RWMWD include the city of Gem Lake, city of Landfall, city of Little Canada, city of Maplewood, city of North St. Paul, city of Oakdale, city of Roseville, city of Shoreview, city of St. Paul, city of Vadnais Heights, city of White Bear Lake, and the city of Woodbury. The RWMWD lies within the Upper Mississippi River Basin and all eventually drains to the Mississippi River.

The mission statement, as outlined on the RWMWD website (www.rwmwd.org), is as follows:

> *The mission of the RWMWD is to protect and improve the water resource and water related environment in the District. The RWMWD seeks to accomplish its mission through analysis of the causes of harmful impacts on the water resources, public information and education, regulation of land and water resource disturbing activities, and capital improvement projects.*

3.1 Streams

Battle Creek and Fish Creek (Figure 1-1, Figure 3-1, and Figure 3-2) are perennial streams located in the southern-portion of the RWMWD. Battle Creek drains from Battle Creek Lake for 5.2 miles through the cities of Woodbury, Maplewood, and St. Paul before discharging the Pigs Eye Lake and ultimately the Mississippi River. The direct drainage area to Battle Creek is about 4.5 square miles, and land use within the watershed is primarily low-density residential and developed parkland. Fish Creek is a 1.8-mile reach, draining from Carver Lake through the same three municipalities listed above before discharging to Eagle Lake and ultimately the Mississippi River. The direct drainage area to Fish Creek is 783 acres. Land use within the watershed includes park and open space owned by Ramsey County or the city of Maplewood as well as single-family residential land use, some highway, and commercial areas.

The RWMWD has completed large restoration projects on both streams. In response to urbanization, both stream reaches were becoming highly incised and unstable. The Battle Creek Restoration Project was completed from 1981 to 1982 and involved the installation of many gradient control structures (step weirs, sheet pile check dams, etc.) as well as a high-flow diversion system. A similar project was completed on Fish Creek in 1988 to 1989, also involving installation of gradient control structures and a high-flow diversion system. The restoration projects significantly reduced degradation of both stream channels.

3.2 Lakes

Bennett Lake is a shallow lake located in the city of Roseville's Central Park, roughly 0.4 miles southwest of Lake Owasso. Circled by softball fields, picnic areas, and an adjacent lakeshore pavilion, Bennett Lake is an important recreational and aesthetic amenity for the city of Roseville's park system. The drainage area to the shallow lake is over 750 acres, is considered fully developed, and is completely contained within the municipal boundary of the city of Roseville. The dominant land use within the watershed is low-density residential, followed by institutional and developed parkland. The lake has an open surface area of 28 acres and a maximum depth of 9 feet. Wakefield Lake is a shallow lake located in the city of Maplewood within the greater Lake Phalen drainage area. The Lake is surrounded by city of Maplewood developed parkland, and is used primarily for shoreline and pier fishing, picnicking, wildlife habitat, and aesthetic viewing. The majority of the 945-acre drainage area to Wakefield Lake is contained within the city of Maplewood, with small portions of the watershed crossing the municipal boundaries of the cities of North St. Paul and St. Paul. The dominant land use in the watershed is low-density residential, followed by developed parkland, institutional, and commercial. Lake morphometry of Bennett Lake and Wakefield Lake is described in Table 3-1.

Table 3-1 Lake morphometry of Bennett Lake and Wakefield Lake

Parameter	Bennett Lake	Wakefield Lake
Surface Area (acres)	28	22
Drainage Area (acres)	772	945
Average Depth (ft)	5.6	4.6
Maximum Depth (ft)	9	9
Lake Volume (acre-ft)	158	101
Littoral Area (%)	100	100
Depth Class	Shallow	Shallow

3.3 Subwatersheds

Drainage areas to the four waterbodies included in this TMDL study span 8.4-square miles (5400 acres) across the RWMWD, covering nearly 13% of the total area within the legal boundary of the RWMWD. Figures depicting subwatershed divides generated for impaired waterbodies included in this TMDL study are shown in Figure 3-1 through Figure 3-4, below.

3.4 Land Use

Land use throughout the TMDL study areas was analyzed using Metropolitan Council 2010 land use classifications (Metropolitan Council 2011). Typical land use varies widely across the four study areas. The Bennett Lake and Wakefield Lake drainage area are nearly fully developed, whereas the Battle Creek and Fish Creek drainage areas, located in the less-developed southern portion of the District, contain significant portions of agricultural and undeveloped land area. The single-family detached classification is the dominant land use type across all four study areas, composing 35% in Battle Creek, 24% in Fish Creek, 50% in Bennett Lake and 44% in Wakefield Lake, of the drainage areas. Metropolitan Council Land use classifications areas are summarized for each study area below in Table 3-2.

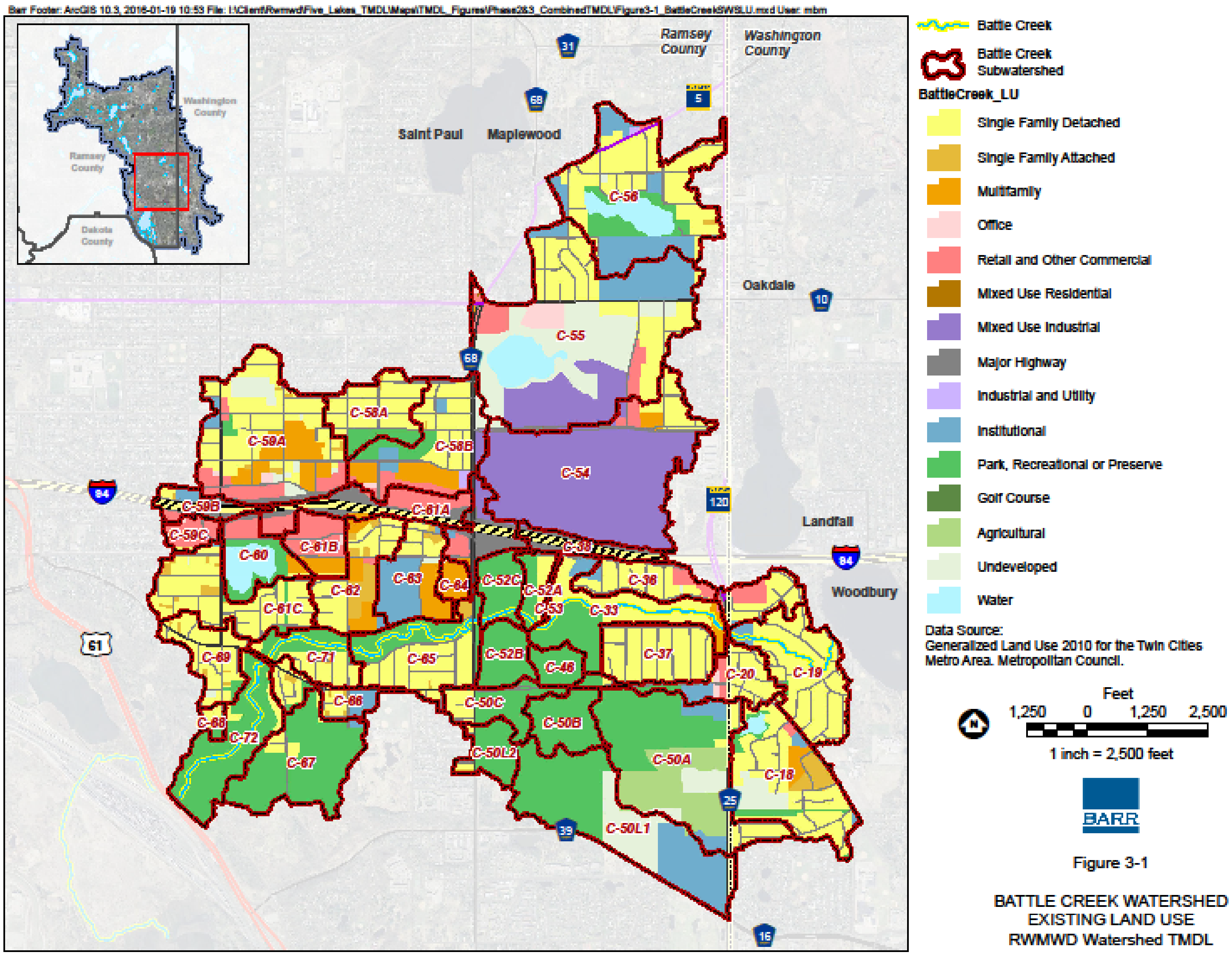

Figure 3-1 Battle Creek Watershed existing land use

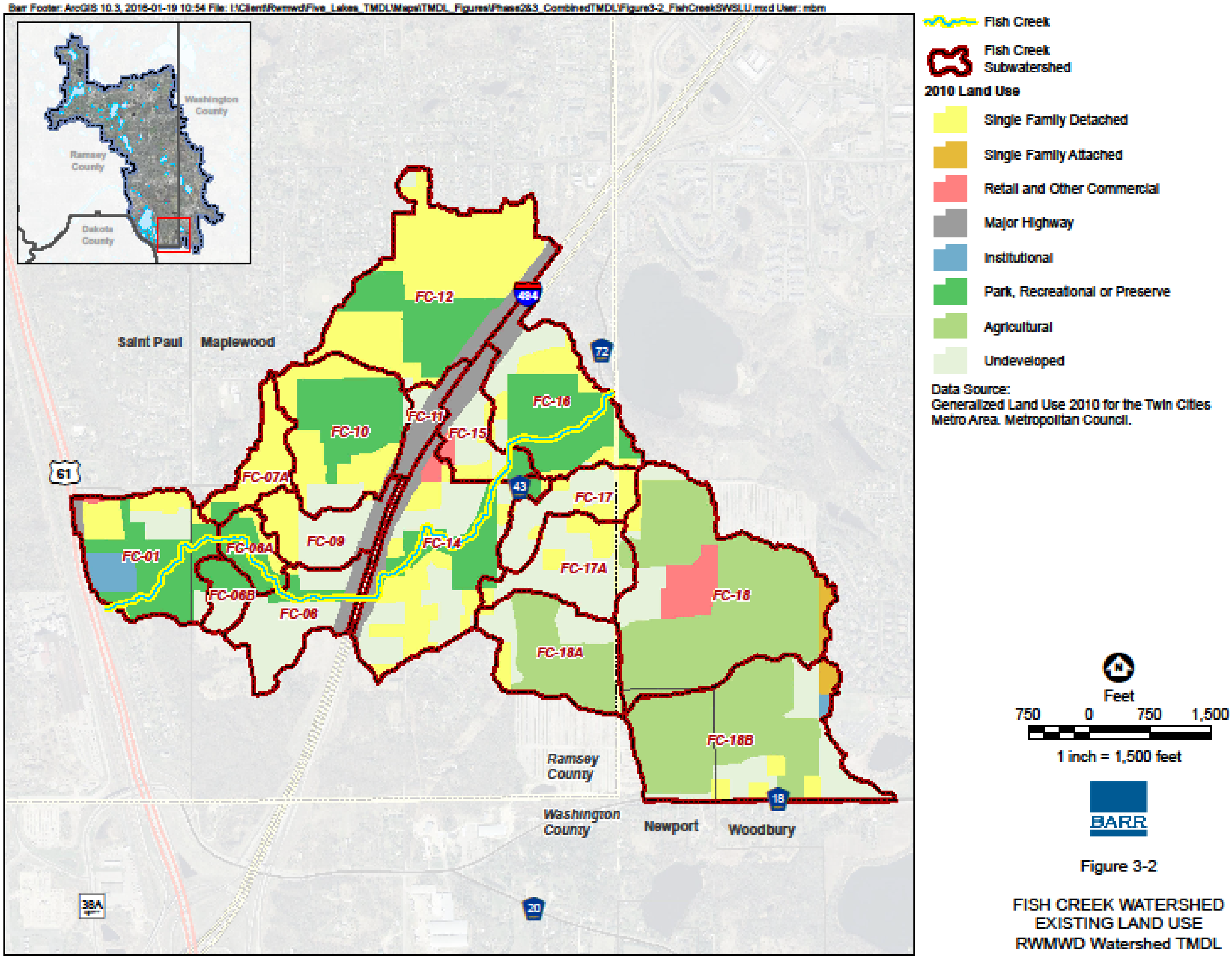

Figure 3-2 Fish Creek Watershed existing land use

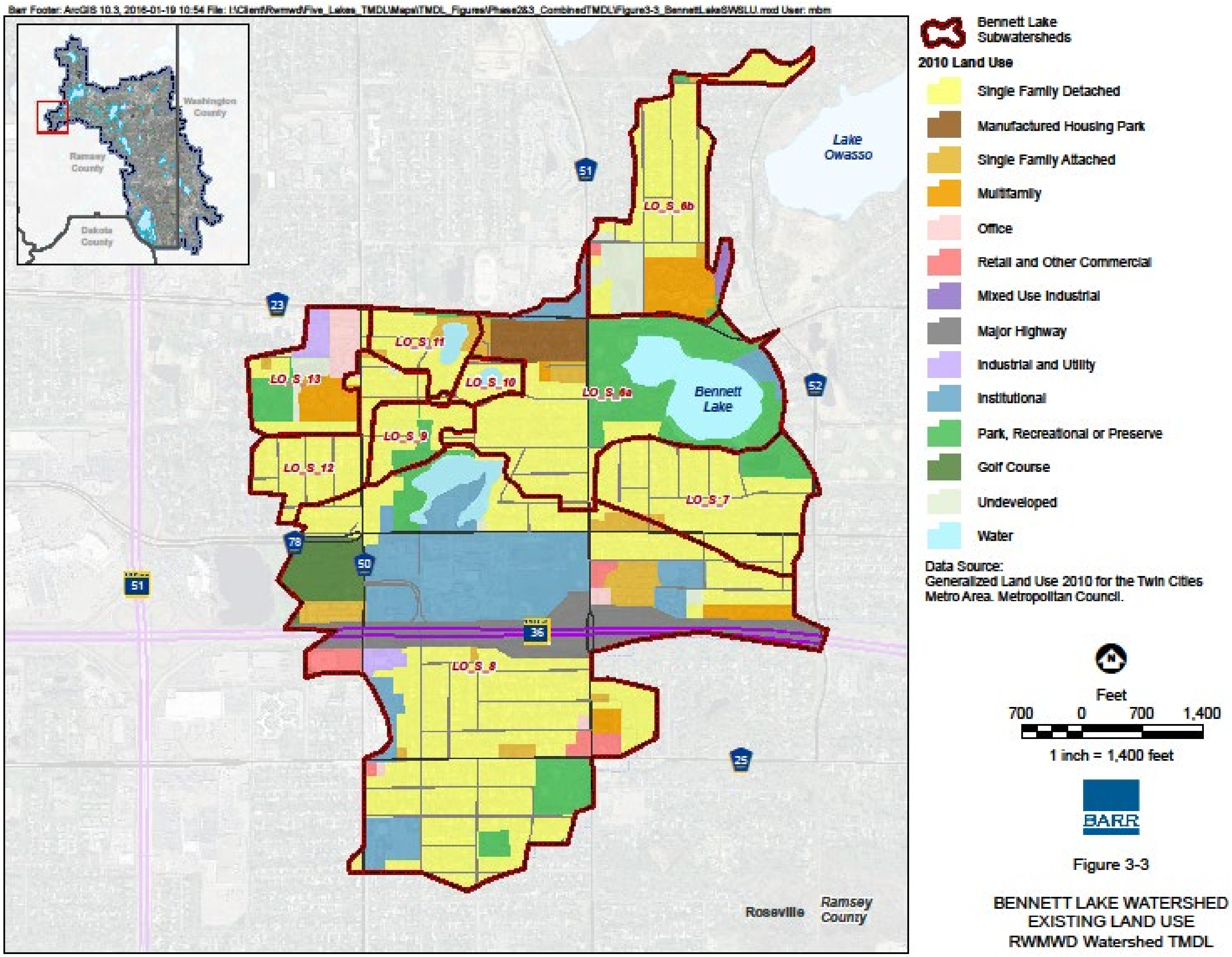

Figure 3-3 Bennett Lake Watershed existing land use

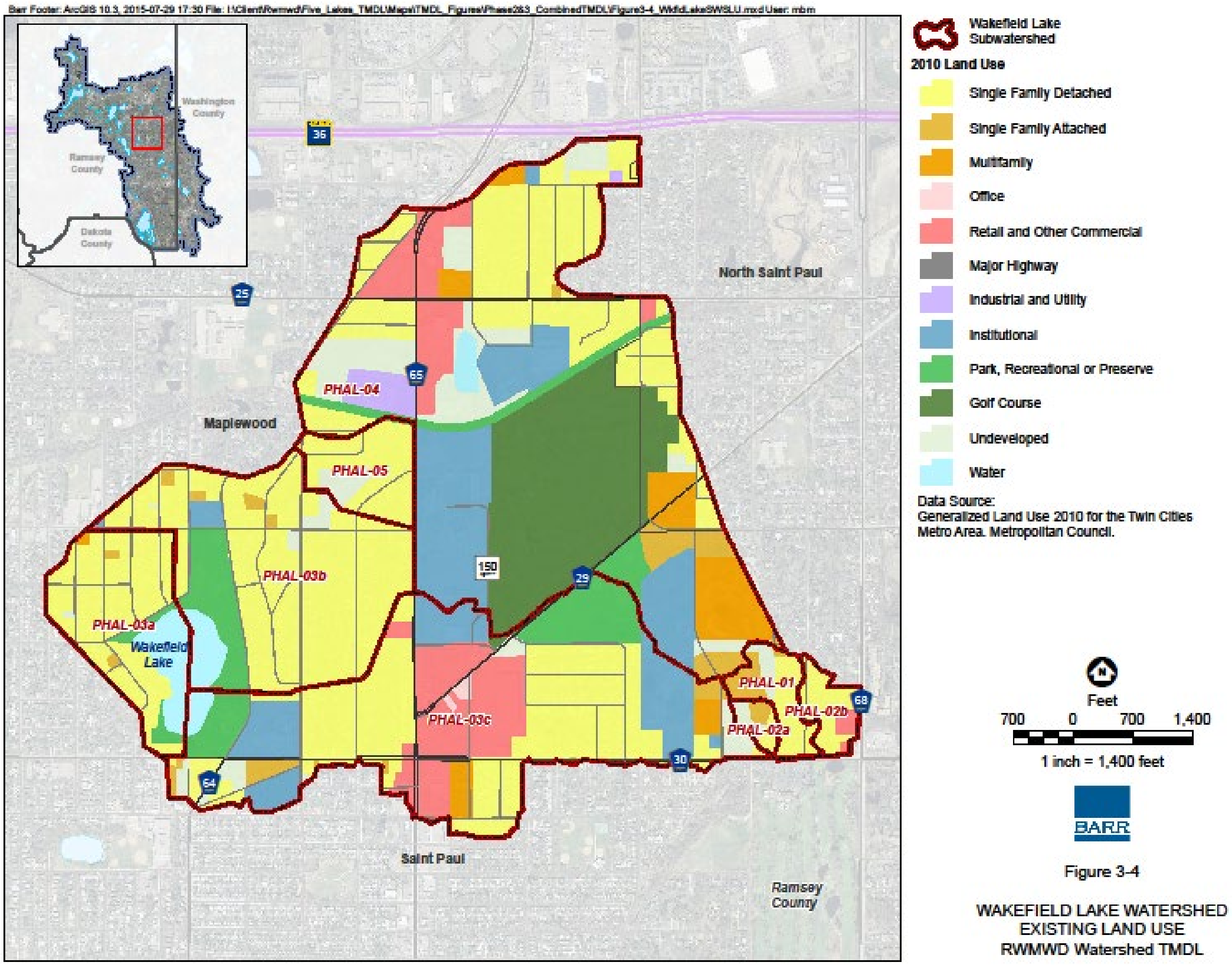

Figure 3-4 Wakefield Lake Watershed existing land use

Table 3-2 Met Council 2010 Land Use Classification of the RWMWD TMDL study areas

	Land Use Area (acres)					
2010 Generalized Land Use	**Battle Creek**	**Fish Creek**	**Bennett Lake**	**Wakefield Lake**	Total (ac)	Percent of Study Area (%)
Agricultural	62.5	183.4	--	--	245.8	5%
Golf Course	0.2	--	15.1	105.5	120.7	2%
Institutional	208.5	7.2	93.7	114.2	423.6	8%
Major Highway	112.1	46.5	47.3	0.6	206.5	4%
Manufactured Housing Parks	--	--	12.6	--	12.6	0%
Park, Recreational, or Preserve	661.2	153.7	76.5	65.5	956.8	18%
Retail and Other Commercial	168.0	15.2	20.2	80.2	283.6	5%
Mixed Use Industrial and Utility	277.7	--	9.3	9.1		
Mixed Use Residential and Multifam	122.4	--	28.0	37.3		
Single Family	1053.2	191.0	414.5	447.7	2106.3	39%
Undeveloped	170.6	186.3	15.4	58.8	431.1	8%
Water	66.8	--	39.6	25.7	132.2	2%
Total (ac)	2903	783	772	945	5403	100%

[1] Green bars indicate the relative percent of total land area within each generalized land use group.

3.5 Water Quality

3.5.1 Biological Integrity

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

Fish and macroinvertebrate IBI scores developed from all biological surveys performed on Battle Creek are summarized in Table 3-3. As can be seen, every observed IBI score falls below the defined threshold IBI scores, indicating that the fish and macroinvertebrate assemblages within Battle Creek are impaired. Analysis shows no longitudinal or temporal trends in observed IBI scores. Biological monitoring stations are shown in Figure 3-5.

Table 3-3 Battle Creek IBI scores by biological survey station

Fish IBI summary				Macroinvertebrate IBI summary			
Date	**Station ID**	**Threshold IBI[1]**	**Observed IBI**	**Date**	**Station ID**	**Threshold IBI[1]**	**Observed IBI**
8/18/1998	97UM008	51	16	97UM008	8/23/2010	36	28
9/23/1997	97UM008	51	21	04UM011	9/2/2004	47	9
6/17/2010	97UM008	51	33	99UM075	8/13/2012	36	25
7/13/2010	97UM008	51	28	00UM071	9/11/2000	47	34
7/23/2012	97UM008	51	6				
6/14/1999	99UM076	51	42				
6/14/1999	99UM075	51	23				
7/31/2012	99UM075	51	39				
8/21/2000	00UM071	45	30				

[1] Threshold IBI scores correspond to stream classification at each station.

The Battle Creek Stressor Identification (SID) Report (SID) (Barr 2015) was completed in in the spring of 2015 to identify the primary cause(s) of biological impairments to the fish and macroinvertebrate populations in Battle Creek. The SID process is a critical part of TMDL development as it identifies factors, which are primarily responsible for the biological impairment observed within the stream. The SID report prepared as part of this TMDL study was completed using the EPA's Causal Analysis/ Diagnoses Decision Information System (CADDIS) (EPA 2010a). CADDIS, a methodology for conducting a stepwise analysis of candidate causes of impairment, characterizes the potential relationships between candidate causes and stressors, and identifies the probable stressors based on the strength of evidence from available data.

Potential candidate causes of the biological impairments that were either ruled out or inconclusive based on review of available data include: temperature, nickel, chromium, nitrate, pH, and altered hydrology. Potential candidate causes were eliminated when water quality was found to be within Minnesota water quality standards or there was found to be a lack of biological response. Candidate causes were deemed inconclusive when water quality data or collected biological monitoring data was insufficient to relate the candidate cause to biological impairment.

Excess sediment (TSS), chloride, low dissolved oxygen (DO), TP, altered habitat, habitat fragmentation, and four heavy metals (zinc, cadmium, copper, and lead) were all found to impact stream biology to varying extents, and were therefore identified as candidate causes of biological stress. A summary of evidence for each of the identified candidate causes is provided in the following subsections. As a result of the SID process, TSS and chloride were found to be the primary stressors to the fish and macroinvertebrate communities. A summary for each candidate stressor is provided below; more detailed information can be found in the Battle Creek Stressor Identification (SID) Report.

3.5.1.1 Excess Sediment (TSS)

Excess TSS was identified as a primary stressor to both the fish and macroinvertebrate assemblages in Battle Creek. Water quality measurements indicate that TSS and turbidity routinely exceed the MPCA standards (see Section 4.1.2). Excess TSS loading can adversely affect biota by four main pathways: (1) impairment of filter feeding, by filter clogging or reduction of food quality; (2) reduction of light penetration and visibility in the stream, which may alter interactions between visually-cued predators and prey, as well as reduce photosynthesis and growth by submerged aquatic plants, phytoplankton, and periphyton; (3) physical abrasion by sediments, which may scour food sources (e.g., algae) or directly abrade exposed surfaces (e.g., gills) of fishes and invertebrates; and (4) increased heat absorption, leading to increased water temperatures (Cormier 2007).

Biological metric and Tolerance Indicator Value analyses both show a clear response to TSS stress, with both fish and macroinvertebrate communities being dominated by species and taxa highly tolerant to stress related to suspended sediment.

3.5.1.2 Chloride

Chloride was identified as a primary stressor to the macroinvertebrate community in Battle Creek. Battle Creek was listed on the 303(d) list for chloride impairment in 2008. Review of collected chloride data shows that exceedance of the MPCA standard (230 mg/L) are common. Additionally, review of historic water quality monitoring of Battle Creek (1977 through 2013) shows a significant increase in average growing season concentrations of chloride. The increase in baseline concentration of chloride over the historic dataset is likely driven by anthropogenic sources, including the application of chloride-containing deicers on paved surfaces. Because chloride is a conservative pollutant, anthropogenic application of chloride has elevated chloride concentrations in water bodies throughout the TCMA. To address this issue, the MPCA has developed a Chloride TMDL and Management Plan for the entire TCMA. Battle Creek is included in the TCMA Chloride TMDL.

Ephemeroptera (mayflies) have been shown to be particularly sensitive to chloride (MPCA 2010; MPCA 2014b; Piscart et al. 2005; Echols et al. 2009). Although the exact mechanism by which elevated chloride concentrations affect stream biota is not well understood, it is likely related to osmotic and ionic regulation. An analysis of the ephemeroptera population in Battle Creek over a 40-year period showed that total ephemeroptera counts and relative ephemeroptera abundance declines as average annual chloride concentration in the stream increases. The impact of chloride on fish was also evaluated, but it was found that chloride is likely not a primary driver of stress to the fish assemblage in Battle Creek.

3.5.1.3 Low Dissolved Oxygen

Low DO was determined to be a secondary stressor to the fish assemblage, and an inconclusive stressor to macroinvertebrates in Battle Creek. The DO concentrations in Battle Creek have not been extensively monitored. The modern (post-2000) DO data set consists of two synoptic surveys, one performed in 2012 and one performed in 2013, and 12 days of continuous DO monitoring completed by the MPCA in the late summer of 2012. The synoptic survey and continuous DO monitoring data suggest that DO concentrations are at their lowest, and possibly below the MPCA standard, at monitoring stations immediately downstream of Battle Creek Lake and McKnight Basin, although the small dataset is insufficient to make a determination of impairment. Low DO immediately downstream of detention areas may be attributed to (a) low dissolved-oxygen content in outflows from upstream waterbodies caused by eutrophication, or (b) attenuation in stream flow caused by upstream waterbodies. Future DO monitoring efforts will help determine whether low DO is a persistent problem for Battle Creek's biota.

3.5.1.4 Excess Total Phosphorus (TP)

Excess TP loading was determined to be a secondary stressor to fish and an inconclusive stressor to macroinvertebrates in Battle Creek. The TP measured in Battle Creek has routinely exceeded the eutrophication criteria concentration for streams in the Central River Nutrient Region (0.10 mg TP/L; MPCA 2013) over the period of record (1977 through 2013). Analysis of the water quality dataset shows that TP concentrations in the stream are highly positively correlated to TSS concentrations, suggesting TP concentrations are driven by phosphorus associated with sediment delivery. This finding also suggests that steps taking to reduce sediment loading will also reduce TP concentrations in the stream.

Although TP is not a proximate stressor, excessive phosphorus loading to a waterbody can lead to accelerated primary production (a process known as eutrophication), which can effect stream ecology by (a) altering food resources; (b) altering habitat structures; and (c) allowing for growth of toxic algae and bacteria (EPA 2010a). Future TP monitoring efforts will help determine whether efforts to decrease TSS loadings to Battle Creek have been successful in lowering TP concentrations concurrently.

3.5.1.5 Altered Habitat

Altered habitat was determined to be a secondary stressor to macroinvertebrates and an inconclusive stressor to fish in Battle Creek. Watershed urbanization has had significant impacts on the geomorphology of Battle Creek. To resolve routine flooding issues and address major erosion issues within the channel, a large restoration project was completed on Battle Creek in 1982. The project included the installation of several sheet pile drop structures and step weir structures, a major flood detention basin (McKnight Basin), and a flood-flow diversion structure, which routes high flows into an underground pipe. Since completion of the project, bank erosion and channelization have been significantly reduced. In-stream habitat in Battle Creek has been monitored using the MPCA Stream Habitat Assessment (MSHA) methodology. The MSHA scoring at stations along Battle Creek generally found in stream habitat to by "fair" or "good". There are few clear trends in the dataset, with the exception that scoring of substrate and the overall MSHA score tends to decrease from upstream to downstream.

3.5.1.6 Habitat Fragmentation

Habitat fragmentation was determined to be a secondary stressor to fish and an inconclusive stressor to macroinvertebrates in Battle Creek. As discussed in Section 3.5.1.5, many gradient control structures were installed along the length of Battle Creek during the 1981 through 1982 Battle Creek restoration project. Beginning at Century Avenue North (just east of station 12UM148) a total of 23 drop structures and 6 step-weir structures were installed. The height of gradient control structures along Battle Creek eliminates the potential for upstream movement of fish and most macroinvertebrate species between many biological survey stations. Instream structures can limit or reduce upstream migration, which can lead to changes in community structure (Brooker 1981 as cited by MPCA 2014d). These structures can also impact the physiochemical properties of the stream by altering water temperature, sediment transport and stream flow, and can affect upstream primary production and nutrient cycling (Cumming 2004).

Longitudinal analysis of fish and macroinvertebrate IBI scores shows no trend in scores from upstream to downstream; suggesting that limited upstream migration is not impacting the quality of biological communities. However, it may be the case that the biological condition of Battle Creek has been sufficiently degraded by other stressors that potential negative impacts of habitat fragmentation are overwhelmed or not currently assessable.

3.5.1.7 Heavy Metals (Cadmium (Cd), Copper (Cu), Chromium (Cr), Lead (Pb), Nickel (Ni) and Zinc (Zn))

Metal toxicity was found to be an inconclusive stressor to both the fish and macroinvertebrate populations within Battle Creek. Beginning in 2000, concentrations of six heavy metal species has been tracked within Battle Creek: Pb, Cu, Cr, Cd, Ni, and Zn. Of the metals analyzed, Cd, Cu, Pb and Zn have failed to meet chronic standards, maximum standards, or final acute values for Class 2B streams, pursuant to Minn. R. 7050.0222, subp. 4. In addition to exceeding the MPCA standards, water quality analysis showed that all four heavy metals are highly correlated to TSS concentration, suggesting that heavy metal delivery via sediment loading is the primary cause of elevated metal concentration within Battle Creek.

To determine if elevated metal concentrations are impacting aquatic communities, biological metrics sensitive to metal toxicity were evaluated. Fish species typically identified as being tolerant or sensitive to metal toxicity have not been identified in large numbers in Battle Creek, and for this reason impairment of the fish community could not be related to metal toxicity. All biological metrics were compared to monthly metal standard exceedances and average monthly metal concentrations, but no relationship could be identified. Based on the results of this analysis, a clear impact of metal toxicity on the fish and macroinvertebrate communities in Battle Creek could not be identified, and metal toxicity is therefore considered an inconclusive stressor to both communities.

3.5.1.8 Candidate Cause Summary

A summary of the probable primary, secondary, and inconclusive stressors to aquatic communities in Battle Creek is presented in Table 3-4. Identification of probable stressors was based on strength of evidence scoring as outlined in the EPA's CADDIS methodology (EPA 2010). Many of the candidate causes analyzed are interrelated, meaning that addressing one may indirectly impact another (e.g., reducing watershed sediment loading may reduce phosphorus and metal loading associated with sediment). For this reason, it is recommended that candidate causes identified as probable primary stressors be addressed with precedence over secondary and inconclusive stressors. Specific recommendations to resolve biological impairment developed in the Battle Creek SID Report are outlined in Table 3-5.

Table 3-4 Summary of probable stressors in the Battle Creek Watershed

Stream Name	AUID	Biological Impairment	Candidate Causes						
			Excess Sediment	Specific Conductance and Chlorides	Dissolved Oxygen and BOD	Excess Total Phosphorus	Altered Habitat	Habitat Fragmentation	Metal Toxicity
Battle Creek	07010206-592	Fish	●	○	●*	◐	○	◐	○
		Macroinvertebrates	●	●	○	○	◐	○	○

● = probable primary stressor; ◐ = probable secondary stressor; ○ = inconclusive stressor

●* = probable station-specific primary stressor (e.g., DO impairment immediately downstream of detention areas)

Table 3-5 Recommendations to address biological impairment developed in the Battle Creek SID

Stressor	Priority	Recommendations
Candidate Causes		
Excess Sediment	High	· Create and implement TMDL for sediment loading (TSS loading). · TMDL should focus on watershed sediment loading, as well as sediment loading from the immediate stream channel.
Specific Conductance and Chloride	High	· Implementation of recommendations from Twin Cities Metropolitan Area Chloride TMDL and Management Plan.
Dissolved Oxygen and Biological Oxygen Demand (BOD)	Medium-High	· Increase longitudinal DO and BOD monitoring efforts along Battle Creek. · Efforts should focus on determining (a) whether or not DO impairment is limited to stations immediately downstream of detention areas and (b) the source of DO impairment (BOD? TP? Temperature? In-stream detention? Low Flow? Chl-a? Etc.). · Consider (a) longitudinal deployment of continuous dissolved oxygen monitoring sensors and (b) additional pre-9 AM synoptic surveying efforts during the growing season. Simultaneous measurements of DO, BOD, TP, temperature, and flow will help determine potential sources of DO impairment.
Excess Total Phosphorus	Medium	· Continue longitudinal monitoring of TP concentrations. · TP monitoring should be conducted during TSS monitoring associated with sediment loading TMDL (to determine if reduced TSS loading also reduces TP loading).
Altered Habitat	Medium	· Continue MSHA surveying and request quantitative substrate measurements be taken during each survey. · Monitor survey results throughout sediment loading TMDL.
Habitat Fragmentation	Low	· Reassess biological metric impacts after other primary and secondary stressors addressed.
Metal Toxicity	Low	· Monitor concentrations of Cd, Cu, Pb, and Zn throughout sediment loading TMDL (to determine if reduced sediment loading reduces metal toxicity). · Reassess biological metric impacts after other primary and secondary stressors addressed.

Stressor	Priority	Recommendations
Inconclusive Causes		
pH	Unknown	· Expand pH monitoring efforts along Battle Creek. · Include pH in event based sampling at station 99UM075 (WOMP station). · Include pH in future synoptic surveys (include pH flux monitoring).
Altered Hydrology	Unknown	· Continue flow monitoring at station 99UM075, and consider installing flow monitoring stations further upstream (potentially upstream and downstream of McKnight Basin). · Continue vegetation clearing and sediment removal maintenance efforts.

3.5.2 Total Suspended Solids (TSS)

The TSS concentrations in Battle Creek were monitored from 2000 to 2013 at a Metropolitan Council WOMP Station, located roughly 1,500-feet downstream of the Highway 61 crossing (Figure 3-5). Observed TSS concentrations are compared to the TSS standard for Class 2B waters located in the Central River Nutrient Region, defined by Minn. R. 7050.0222 (see Section 2.2), in Table 3-6. As can be seen, Battle Creek exceeds the Class 2B TSS standard every year from 2000 through 2013. In the entire period of record, 53% of samples collected between April 1 and September 30 of each year (174 or 329 samples) exceed the standard of 30 mg TSS/L. Based on available data, it appears Battle Creek is impaired by TSS. For this reason, it is anticipated that when the Battle Creek TSS data are assessed it will be included in the MPCA's 303(d) impaired waters list.

To analyze the relationship between sediment loading and flow rate at the Battle Creek WOMP Station, TSS concentrations are compared to the flow duration curve developed for Battle Creek (discussed in Section 4.1.1) in Figure 3-6 and Table 3-7. As shown in Figure 3-6, TSS concentrations are strongly correlated with stream flow, with high flows generating higher TSS concentrations on average, and lower flows producing lower TSS concentrations. Table 3-7 shows that a majority of samples taken at high flow and moist conditions exceeded the MPCA standard for TSS, while only 15% of samples taken at the low flow condition, exceeded the standard. Only during low flow conditions does the average TSS concentration in the stream drop below the MPCA standard.

Longitudinal surveys conducted during 2012 and 2013 (Table 3-8) found relatively low levels of TSS. Only 3 of 52 total samples exceeded the MPCA TSS standard. The greatest exceedance recorded at the outlet of Battle Creek Lake (140 mg/L) occurred during a low flow condition at the WOMP station. For this reason, it is likely that there was low outflow from Battle Creek Lake on this sampling date, and that the elevated TSS observed was caused by algae suspended in the outflow from Battle Creek Lake. From the 13 samples collected at 4 different sites over a 2-year period, it is difficult to identify any longitudinal trends in TSS concentration. From the more robust dataset collected at the WOMP station, it is clear that TSS concentrations exceeding the MPCA standard are common at downstream portions of the stream. More data will need to be collected to determine the extent to which this degraded condition propagates upstream.

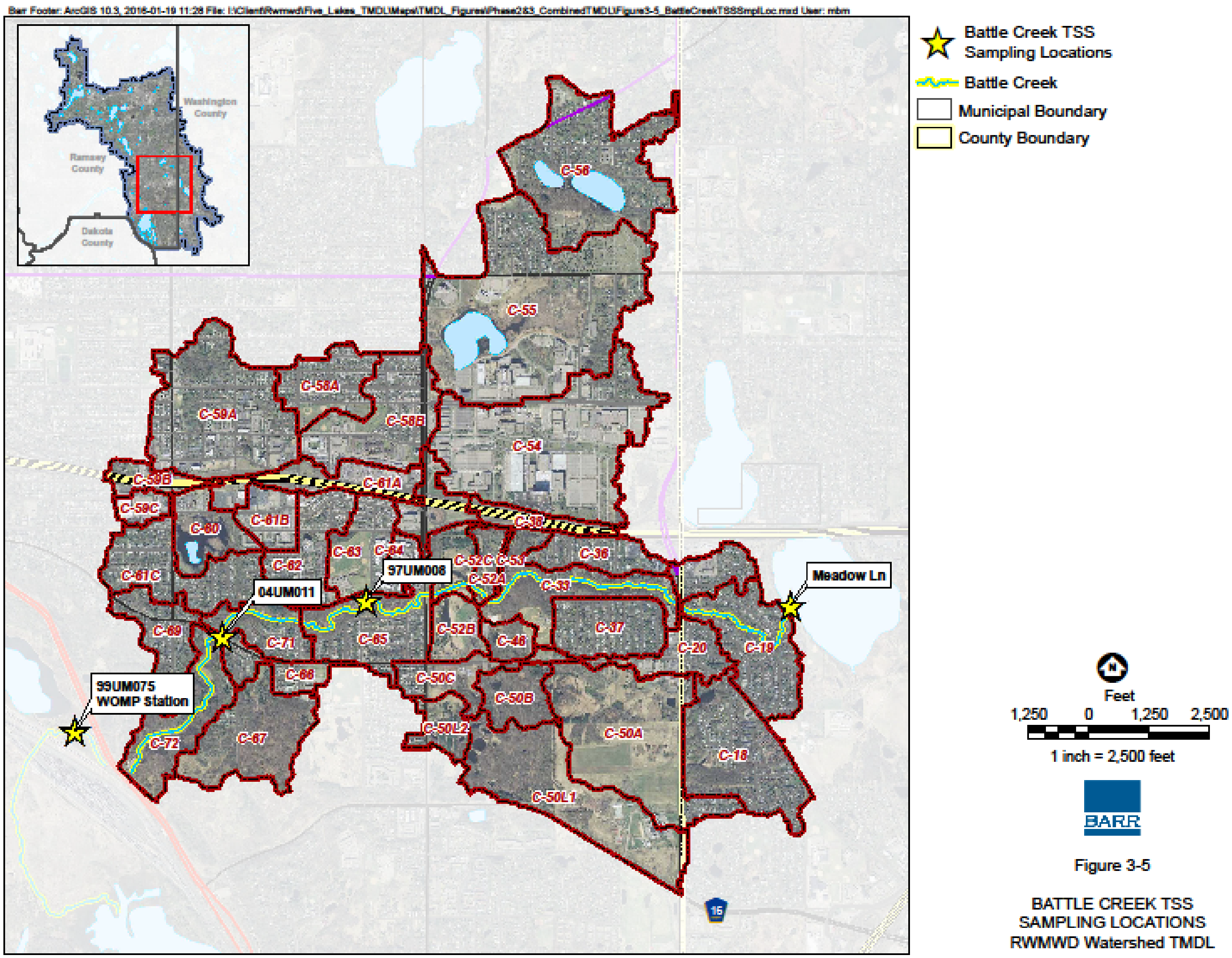

Figure 3-5 Battle Creek sampling locations

Table 3-6 Battle Creek TSS summary at WOMP station (99UM075), April 1 through September 30

	Battle Creek TSS Summary (April 1 through Sept 30 samples only)														
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Entire Dataset**
Number of Samples	13	17	20	12	32	29	25	32	26	20	35	20	26	22	329
Average TSS Concentration (mg/L)	60.5	36.4	78.6	93.1	64.9	125.9	73.6	76.3	91.8	108.7	64.5	46.1	31.6	20.4	70.2
Percentage of Samples exceeding Standard (30 mg/L)	54%	35%	70%	50%	56%	79%	44%	56%	58%	60%	60%	35%	42%	23%	53%

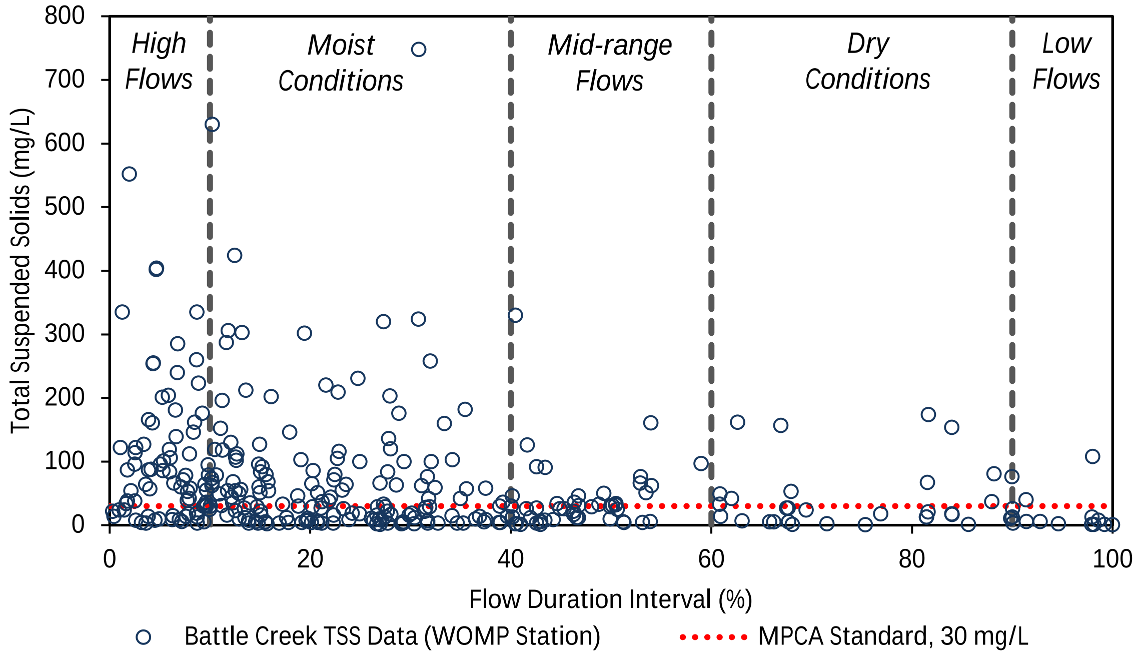

Figure 3-6 TSS water quality duration curve at WOMP station (99UM075)

Table 3-7 TSS and flow duration interval summary at WOMP station (99UM075)

Flow condition	High Flows	Moist Conditions	Mid-range Flows	Dry Conditions	Low Flows
Flow duration interval	**0-10%**	**10-40%**	**40-60%**	**60-90%**	**90-100%**
Average TSS concentration (mg/L)	103	74	40	41	17
Percentage of samples exceeding MPCA TSS standard (30 mg TSS/L)	71%	54%	42%	38%	15%

Table 3-8 Summary of TSS measurement from 2012 and 2013 longitudinal surveys

Upstream → *Downstream*

Date	Flow Condition at WOMP Station	TSS (mg/L) samples, 2012-2013 longitudinal survey			
		Meadow Lane (at the outlet from Battle Creek Lake)	97UM008	04UM011	99UM075 WOMP Station
9/20/2012	Mid-Range Flows	ND[1]	ND	ND	ND
9/26/2012	Mid-Range Flows	6.1	10.5	ND	ND
10/10/2012	Moist Conditions	6.8	9.4	11.4	ND
3/23/2013	Dry Conditions	7.5	12	7.5	7
3/28/2013	Mid-Range Flows	48[2]	15	12	9
4/25/2013	High Flows	ND	5.5	14	12
5/29/2013	High Flows	1.5	4.5	5	4.5
6/27/2013	High Flows	2	3.5	14	14
7/25/2013	Dry Conditions	4	3.5	2	ND
8/15/2013	Dry Conditions	13	16	5	3.5
8/29/2013	Moist Conditions	26	36	9.5	8
9/24/2013	Low Flows	140	6	1.5	ND
10/22/2013	Mid-Range Flows	2.5	6.5	3	4.5

[1] ND = not detectable (below laboratory detection limits).
[2] Cells highlighted in red exceed the MPCA TSS standard (30 mg/L).

3.5.3 Bacteria (*E. coli*)

The Metropolitan Council operates a Watershed Outlet Monitoring Program (WOMP) station located on Fish Creek near U.S. Highway 61 (Figure 3-7). *E. coli* data collected at the WOMP station from 2008 through 2013 were evaluated and compared to numeric *E. coli* standards for Class 2C waters defined in Minn. R. 7050.0222 (Section 2.3). In addition to the WOMP station, *E. coli* was also collected in 2012 and 2013 at the three sampling locations along Fish Creek shown in Figure 3-7. Data were collected at sites along the length of Fish Creek so that changes in *E. coli* concentrations from upstream to downstream could be tracked and analyzed. Understanding spatial differences in *E. coli* concentrations can help to identify or rule-out potential sources of bacteria.

As discussed in Section 2.3, a stream is considered impaired by bacteria if the monthly geometric mean value of one or more months (from April through October) exceeds 126 organisms per 100 mL (the MPCA chronic standard) based on a minimum of five aggregated samples, and/or if 10% of the individual samples exceed 1260 organisms per 100 mL (the MPCA acute standard). Table 3-9 summarizes monthly sample counts and the monthly geometric mean *E. coli* concentrations at each of the four sample sites along Fish Creek. Also included in the table is the summary of the available bacteria data collected in Carver Lake. The results in Table 3-9 are also shown graphically in Figure 3-8. As can be seen, *E. coli* concentration at the Fish Creek WOMP station exceeds the monthly geometric mean impairment condition for the months of June through October, meaning that the reach is impaired by bacteria. Although the other sampling sites did not contain the requisite number of monthly samples, the data indicate that *E. coli* concentrations are highest at the Fish Creek WOMP station and at the location upstream of the I-494 crossing. In general, *E. coli* levels are lower at the upstream monitoring locations and typically these locations meet the chronic monthly standard.

In addition exceeding the chronic *E. coli* standard, there were regular exceedances of the acute standard of 1,260 organisms per 100 mL in Fish Creek during the monitoring period. The acute *E. coli* standard and a summary of each of the monitoring location are summarized in Table 3-10. The WOMP station exceeded the acute *E. coli* standard in 11% of samples. No exceedances of the acute standard occurred at stations upstream of the I-494 station, again suggesting that *E. coli* concentration increase from upstream to downstream.

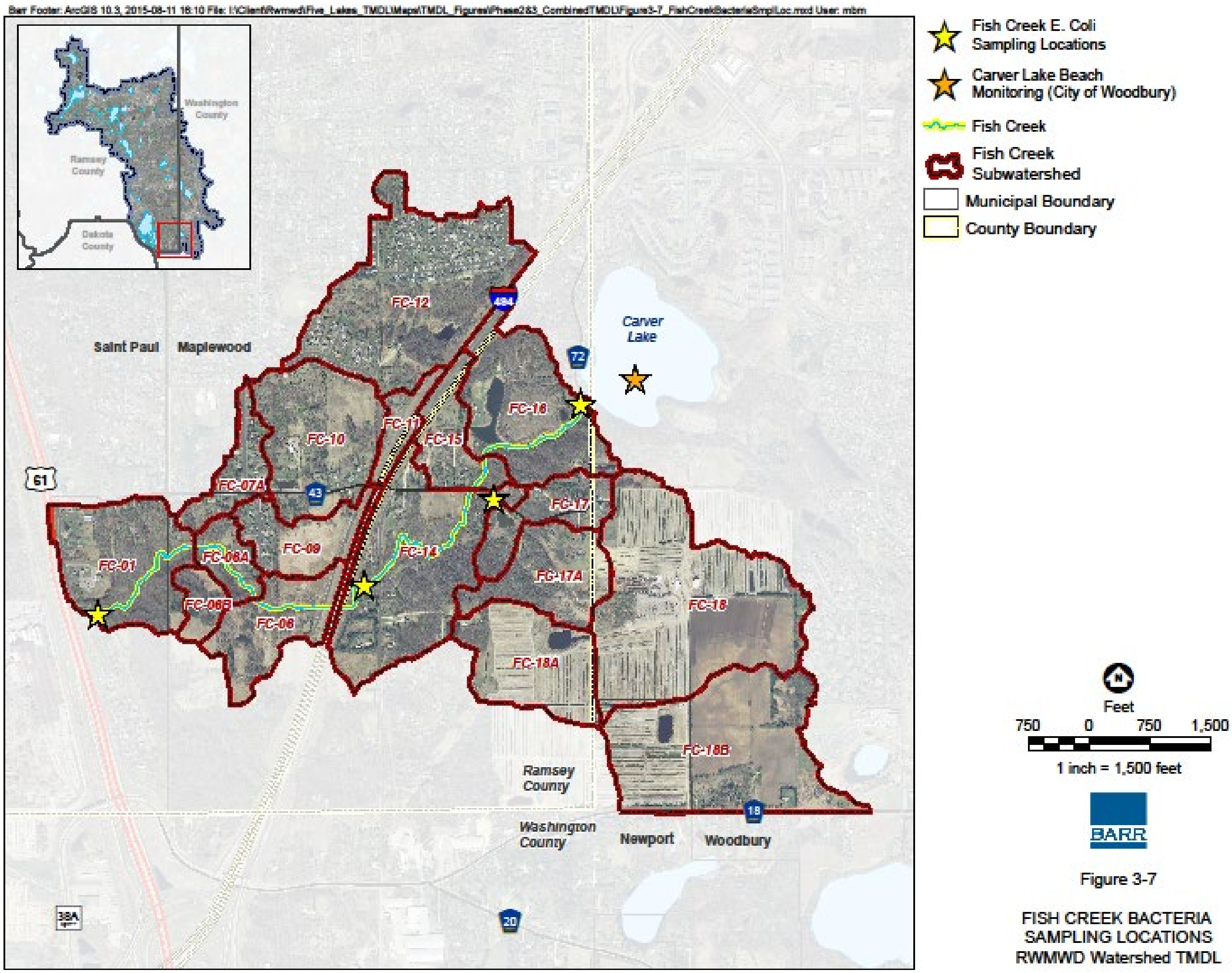

Figure 3-7 Fish Creek sampling locations

Table 3-9 Exceedances of chronic *E. coli* standard and sampling location along Fish Creek

Chronic *E. coli* standard summary	
Minimum Samples Per Month (#)	5
Monthly Geometric Mean Criterion (org/100 mL)	126

Sampling Site		Month						
		Apr	May	Jun	Jul	Aug	Sept	Oct
Fish Creek WOMP Station	Samples Per Month (#)	5	5	5	5	6	6	6
	E. coli Geometric Mean (org/100 mL)	36	74	223[1]	330	466	450	164
I-494 upstream of Highway Crossing	Samples Per Month (#)	1	1	1	1	1	3	2
	E. coli Geometric Mean (org/100 mL)	7	30	47	248	1553	150	73
Downstream of Double Driveway Pond	Samples Per Month (#)	1	1	1	1	1	1	1
	E. coli Geometric Mean (org/100 mL)	135	10	308	2	2	32	86
Century Ave at the outlet of Carver Lake	Samples Per Month (#)	0	0	0	0	0	2	1
	E. coli Geometric Mean (org/100 mL)	N/A	N/A	N/A	N/A	N/A	81	68
Carver Lake - Main	Samples Per Month (#)	0	8	12	11	6	0	0
	E. coli Geometric Mean (org/100 mL)	N/A	6	9	3	3	N/A	N/A
Carver Lake - North	Samples Per Month (#)	0	9	16	9	3	0	0
	E. coli Geometric Mean (org/100 mL)	N/A	6	6	5	4	N/A	N/A

[1] Values highlighted in red indicate the geometric mean of samples collected exceeded the monthly geometric mean criterion (126 org/100 mL).

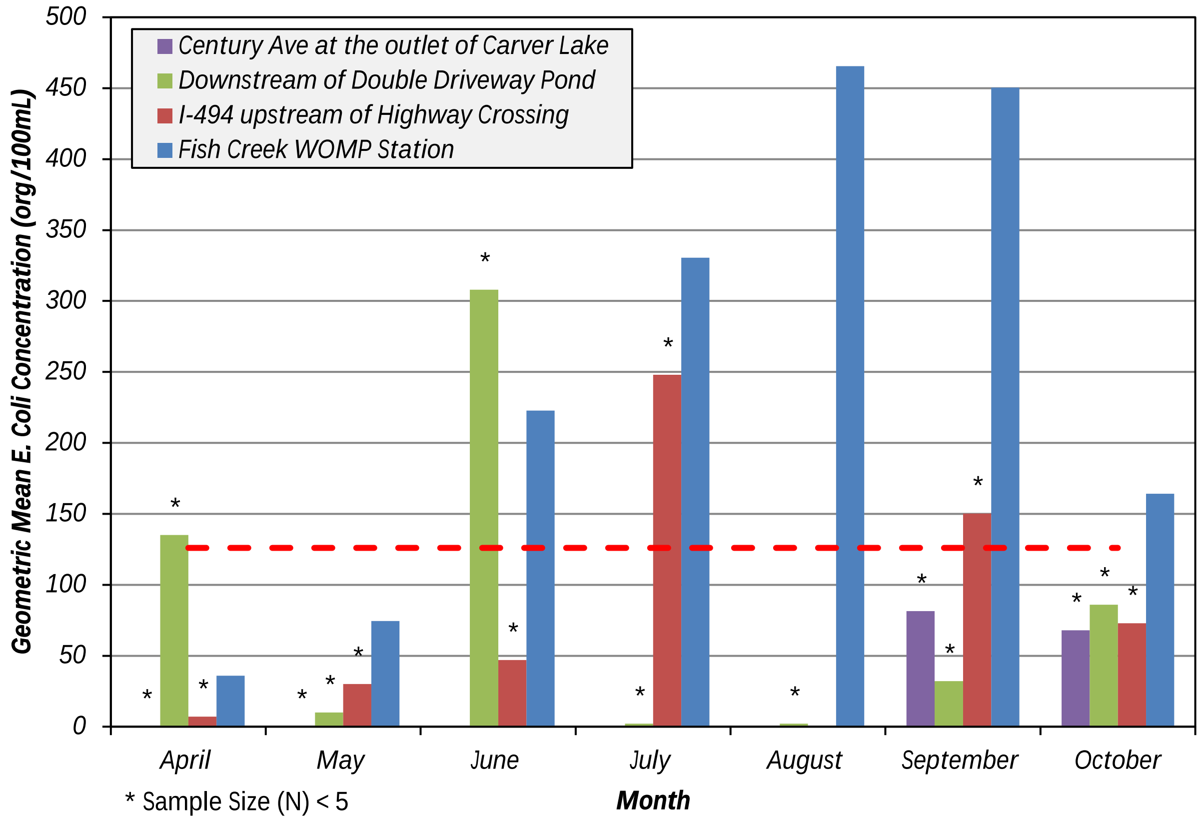

Figure 3-8 Fish Creek bacteria monthly geometric mean by monitoring station

Table 3-10 Exceedances of acute *E. coli* standard and sampling location along Fish Creek

Acute *E. coli* standard summary	
Minimum Number of Samples	**15**
Standard Exceedance Threshold (Exceeds 1,260 orgs/100 mL)	**> 10%**

Sampling Site	**Years Sampled**	**Total Number of Samples**	**Percent > 1,260 org/100 mL**
Fish Creek WOMP Station	2008-2013	38	11%[1]
I-494 upstream of Highway Crossing	2012-2013	10	10%
Downstream of Double Driveway Pond	2013	7	0%
Century Ave at the outlet of Carver Lake	2012	3	0%
Carver Lake - Main	2005-2008	37	0%
Carver Lake - North	2005-2008	37	0%

[1] Value(s) highlighted in red exceed the MPCA standard for maximum proportion of standard exceedances.

3.5.4 Excess Nutrients

Water quality trends in Bennett Lake and Wakefield Lake were evaluated by analyzing 10 years of water quality data from each lake (based on the start of the TMDL evaluation). For the purposes of this TMDL report, growing season (June 1 through September 30) mean concentrations of TP, Chl-*a*, and Secchi disc transparency were used to evaluate the water quality of Bennett and Wakefield Lake. Additionally, the summarized data reflects the surface samples (samples collected from 0-2 meters in depth). The growing season (GS) is often used to evaluate lake water quality, as it is the time period encompassing the months during which the water quality is most likely to suffer due to algal growth.

Table 3-11 summarizes the historical water quality information compared to the MPCA shallow lake eutrophication criteria. Historic growing season means of TP, Chl-*a*, and Secchi disc transparency for Bennett and Wakefield Lake are shown in Figure 3-9 and Figure 3-10, respectively.

Table 3-11 Bennett Lake and Wakefield Lake historic nutrient related water quality parameters

Water Quality Parameter	MPCA Shallow Lake Eutrophication Standard (NCHF Ecoregion)	Bennett Lake (2003-2012) GS Average	Wakefield Lake (2002-2011) GS Average
Total Phosphorus (µg/L)	≤ 60	138.4	106.1
Chlorophyll-*a* (µg/L)	≤ 20	37.5	29.4
Secchi disc transparency (m)	≥ 1.0	0.9	1.5

The EPA requires that during the TMDL development, the maximum allowable pollutant load or loads needed to meet water quality standards for a given water body are defined for "critical conditions". Critical conditions are represented by the combination of loading, waterbody conditions, and other environmental conditions that result in impairment and violation of water quality standards. For the purposes of this TMDL, the critical condition was determined to be equal to the year which produced the highest growing season average TP concentration during the most recent decade of analysis (2003 through 2012 for Bennett Lake, 2002 through 2011 for Wakefield Lake), as phosphorus is the causal factor for the nutrient impairment in both lakes. Growing season average water quality for the critical year of Bennett Lake (2005) and Wakefield Lake (2004) are summarized below in Table 3-12. The critical years for the waterbodies are also highlighted in Figure 3-9 and Figure 3-10.

Table 3-12 Growing season average water quality for critical year

		Critical Year Growing Season Average		
Waterbody	Critical Year	Total Phosphorus (µg/L)	Chlorophyll-*a* (µg/L)	Secchi disc transparency (m)
Bennett Lake	2005	210	56.8	0.7
Wakefield Lake	2004	154	58.1	0.6

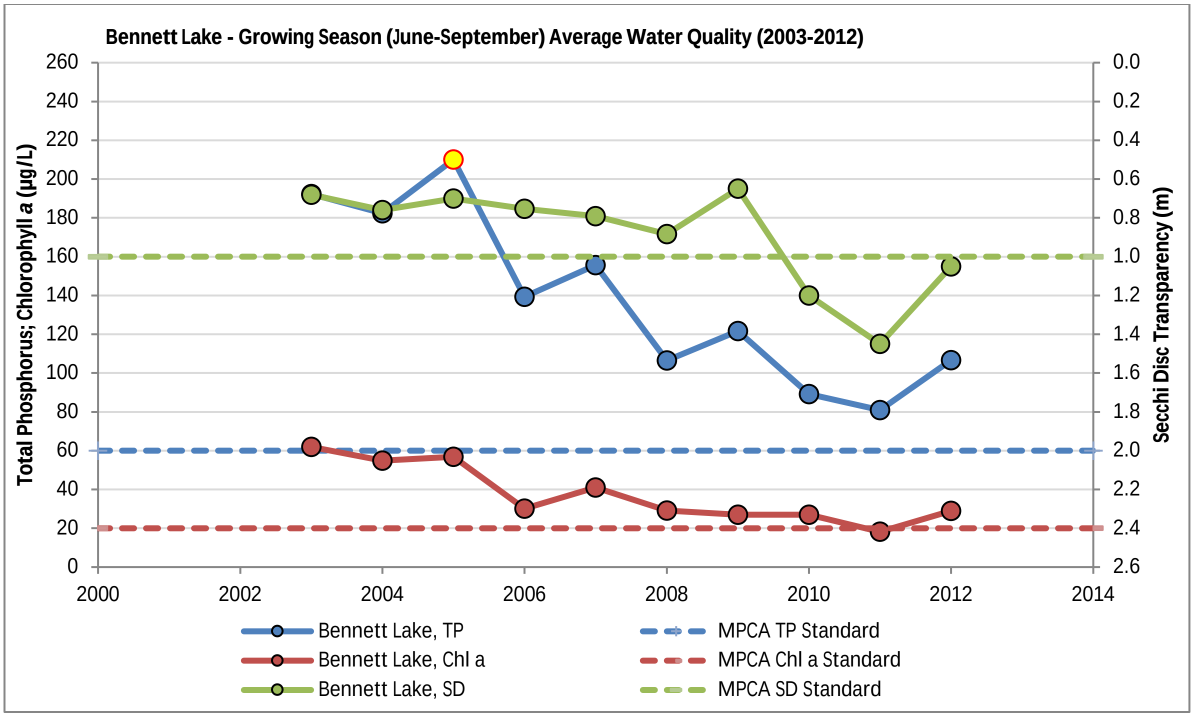

Figure 3-9 Bennett Lake Growing Season (June-September) Average Water Quality, 2003-2012

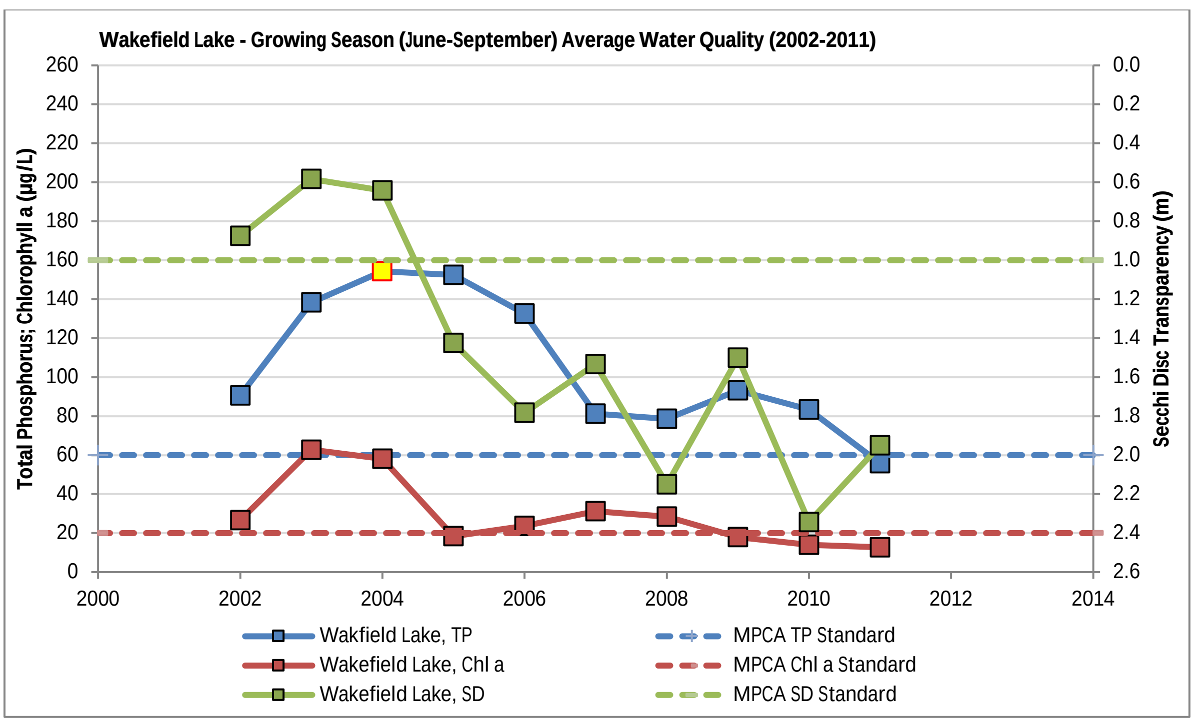

Figure 3-10 Wakefield Lake Growing Season (June-September) Average Water Quality, 2002-2011

3.6 Pollutant Source Summary

3.6.1 Total Suspended Solids (TSS)

These sections provide a brief discussion of the potential sources of sediment to Battle Creek, although the actual quantification of these sources will be further discussed in Section 4.1 of this TMDL report. The sources of sediment can be classified into permitted or non-permitted sources, which will be defined and discussed in the following sections.

3.6.1.1 Permitted Sources

Permitted sources of sediment (primarily from stormwater runoff) are those that require a National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit (Permit). Examples of typical permitted sources of sediment include the following:

- Municipal Separate Storm Sewer System (MS4) Permit (Permit) - Includes coverage of MS4s operators, which are operators of infrastructure that is used solely for stormwater and often include cities, townships, and public institutions. The goal of the MS4 Permit is to improve the water quality of urban stormwater runoff and reduce pollutants in stormwater discharges.
- Construction Stormwater NPDES/SDS General Permit – Includes coverage of any construction activities disturbing one acre or more of soil, less than one acre of soil when part of a larger development that is more than one acre, or less than one acre when the MPCA determines the activity to pose a risk to water resources. The goal of the construction stormwater permit is to control erosion and reduce the amount of sediments and other pollutants being transported by runoff from construction sites.
- Multi-Sector Industrial Stormwater NPDES/SDS General Permit – Includes coverage of stormwater discharges associated with a variety of industrial activities. The goal is to reduce the amount of pollution that enters surface and ground water from industrial facilities in the form of stormwater runoff.
- NPDES/SDS Permit – Includes coverage of facilities that discharge treated wastewater to surface or ground water of the state. The goal of the permit is to establish minimum effluent limits for a variety of constituents that protect the water quality and designated uses of waters of the state.

3.6.1.2 Non-Permitted Sources

Non-permitted sources of sediment are those that are not regulated by the NPDES/SDS program. For many streams, these sources can be significant portion of the sediment load to the stream and can be a major contributor to impairment. The following are examples of the typical non-permitted sources of sediment:

- **Internal Sources** – Includes sediment resuspension within the stream channel, erosion and bank failure within the stream corridor, and in-channel algal production can all contribute to TSS loading.
- **Loading from upstream waterbodies** – Headwater ponds and other waterbodies that discharge flow into the stream corridor can be significant sources of sediment loading.

3.6.2 Bacteria (*E. coli*)

In order to develop the linkage between watershed sources of bacteria and water quality targets, this study followed an approach that was initially developed for the Regional TMDL Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Southeast Minnesota (MPCA 2002) and utilized the bacteria production estimates from the Upper Mississippi River Bacteria TMDL (EOR 2014). The bacteria production estimates used in the Upper Mississippi River Bacteria TMDL were originally modified from daily fecal coliform production rates by animal type from Metcalf and Eddy (2003).

This section provides an inventory of the sources of bacteria within the Fish Creek Watershed. The sources of bacteria in the watershed include:

- Septic systems and human waste (Section 3.6.2.1)
- Stormwater runoff and pets (Section 3.6.2.2)
- Sanitary sewer exfiltration (Section 3.6.2.3)
- Fecal matter from wildlife (Section 3.6.2.4)
- Agricultural sources (Section 3.6.2.5)

Figure 3-11 shows the available source information in the Fish Creek Watershed.

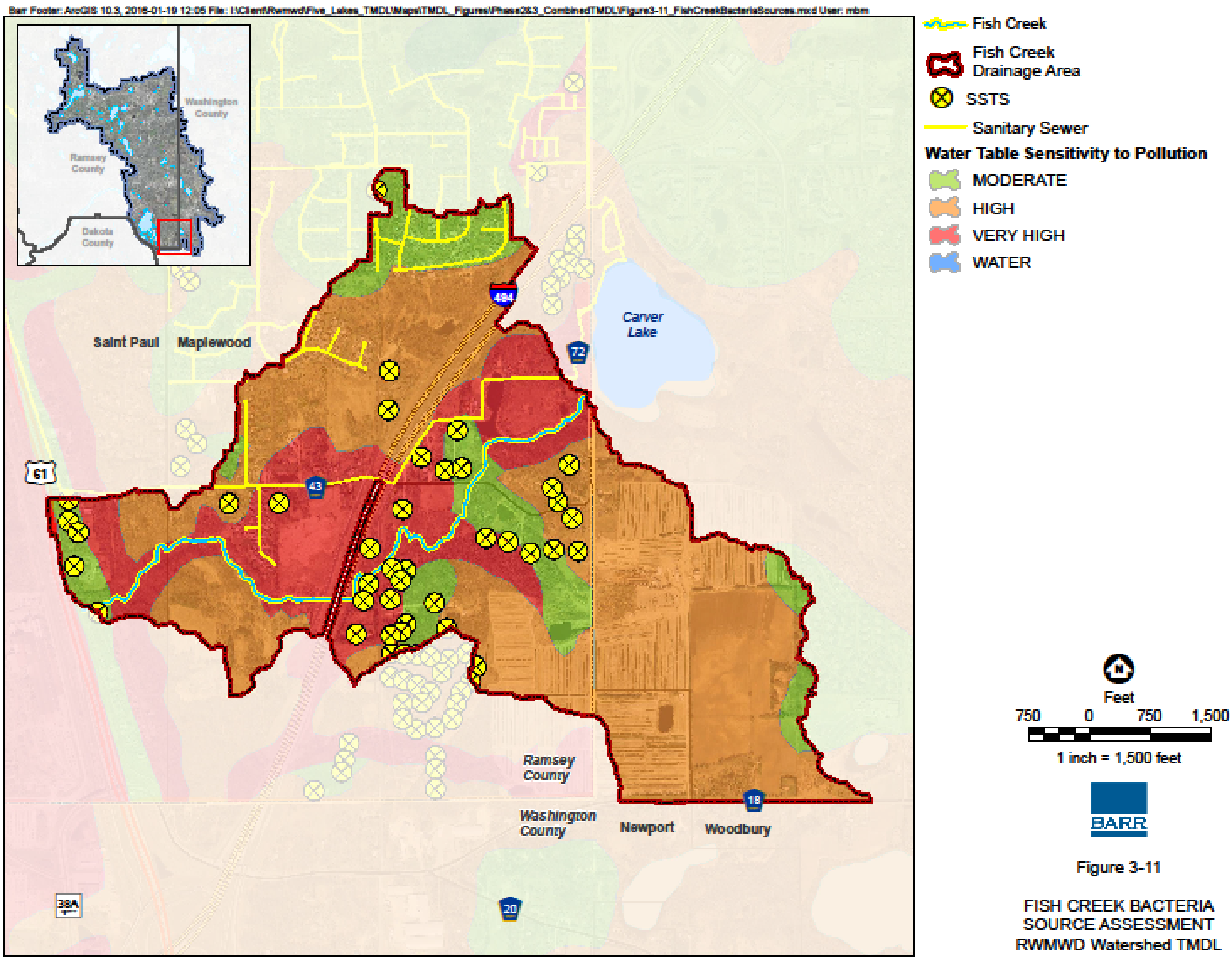

Figure 3-11 Fish Creek bacteria source assessment

3.6.2.1 Septic System and Human Waste

Human waste can be a significant source of bacteria loading to surface waters, especially during dry and low flow periods when human wastewater sources continue and there is little runoff to convey other sources to surface water bodies.

Subsurface Sewage Treatment System or Systems (SSTS) that are not properly designed or maintained can allow untreated or partially treated sewage to flow into surface waters. Minn. R. 7080.1500 establishes compliance criteria for individual subsurface sewage treatment systems, including the following:

- Minn. R. 7080.1500, subp. 4(A), states the SSTS "must be protective of human health and safety. A system that is not protective is considered an imminent threat to public health or safety. At a minimum, a system that is an imminent threat to public health or safety is a system with a discharge of sewage or sewage effluent to the ground surface, drainage systems, ditches, or storm water drains or directly to surface water…"
- Minn. R. 7080.1500, subp. 4(B), states the SSTS "must be protective of groundwater. At a minimum, a system that is failing to protect groundwater is a system that is a seepage pit, cesspool, drywell, leaching pit, or other pit; a system with less than the required vertical separation distance…, and a system not abandoned in accordance with part 7080.2500."
- Minn. R. 7080.1500, subp. 4(B), states the SSTS "must be operated, meet performance standards, and be managed according to its operating permit."

SSTS that do not meet these compliance criteria are considered non-compliant.

There are no permitted surface water discharges from municipal or industrial wastewater treatment facilities (WWTF) in the Fish Creek Watershed. Although portions of the Fish Creek Watershed are served by sanitary sewer, there are still many SSTS in the watershed. Based on SSTS data provided by the cities of Maplewood and St. Paul, there are 40 SSTSs within Fish Creek direct drainage boundary, which ultimately drains to the Fish Creek WOMP monitoring station, as well as several SSTS located just outside the watershed boundary.

Of the 40 total SSTSs within the Fish Creek Watershed, 36 are located within the city of Maplewood. Pursuant to the SSTS ordinance adopted by the city of Maplewood in 2013, residents are required to have their SSTSs inspected and submit a MPCA Septic Tank Maintenance Reporting Form every three years. Prior to the 2013 ordinance, SSTS inspection reports were processed by the city only when maintenance requests were made by homeowners. The city, on average, receives one to two maintenance requests per year, indicating an annual failure rate of about 1% of systems (Personal Communications 2014). However, information compiled for the MPCA's Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (Barr 2004a) suggests a 25% failure rate for SSTS in the Upper Mississippi River Basin.

The four SSTSs not within the city of Maplewood are located within the city of St. Paul. According to Chapter 50 of the city of St. Paul's legislative code, St. Paul SSTSs are regulated by Minn. R. 7080 (Minn. R. 7082, 2014). Residents are required to maintain their SSTSs no less frequently than once every two years. Additionally, a permit is required for any installation, alteration, or repair of an SSTS, confirming that all sizing, location, and material requirements have been met.

The 40 SSTS systems within the Fish Creek Watershed are serving an estimated population of 102 people. Assuming a 25% non-compliant/failing rate based on the information above, the number of people associated with the estimated failing SSTS system is 26 people.

Additionally, information from the Minnesota Geological Survey also indicates that the water table susceptibility to pollution ranges from moderate to very high (See Figure 3-11).

3.6.2.2 Stormwater Runoff and Pets

Untreated urban stormwater can have bacteria concentrations as high as or higher than runoff from pastures and cropland (EPA 2001), primarily sourced from pet waste.

Approximately one-third of the direct drainage area to Fish Creek is considered urban, with the primary land use in the watershed being low-density residential housing. The northern portion of the watershed is the most densely populated, while the southern and eastern portions of the watershed are predominantly commercial nursery.

The total number of pets in the contributing watershed of Fish Creek is estimated from the American Veterinary Medical Association values of 0.66 cats and 0.58 dogs per household. Based on 2009 parcel data from Ramsey and Washington counties, there are 325 residences within the direct drainage area to Fish Creek. Based on this number of households, it is estimated that there are 189 dogs and 215 cats in the Fish Creek Watershed. Waste from these animals is conservatively assumed to be conveyed to surface waters with equal likelihood, regardless of the location of the household within the watershed.

3.6.2.3 Sanitary Sewer Exfiltration

According to the MPCA's 2014 Upper Mississippi River Bacteria TMDL Study and Protection Plan (EOR 2014), 37% of the sanitary sewer infrastructure in the Fish Creek Watershed is over 50-years old. Due to changes in material and construction standards, as well as deteriorating associated with aging (corrosion and cracking), sanitary sewer over 50-years old is typically well beyond its useful life, and can pose a risk to human health. Exfiltration from aging sanitary sewer infrastructure can cause raw, untreated sewage to enter nearby storm sewers. These phenomena can lead to chronic contamination of storm sewer systems and receiving water bodies.

Based on the study linking exfiltration from the sanitary sewers to the storm sewers, exfiltration rates from sanitary sewers can range from 0.01- 2 L/second per kilometer, and at the sites evaluated sewage comprised 0.0 to 20% of the baseflow in the storm sewer systems during dry conditions (Sercu, et. al. 2011). We have estimated that 122 people are served by the sanitary sewer systems in the Fish Creek Watershed with an average wastewater flowrate of 288 liters per person per day (Metcalf and Eddy 2003). Assuming that 37% of the sanitary sewer in the Fish Creek Watershed is older than 50 years and can exfiltrate at a rate of 0.1 L/s per kilometer, the estimated sewage exfiltration volume is 3% of the total wastewater load to the sanitary sewer.

3.6.2.4 Wildlife

The Minnesota Department of Natural Resources (DNR) compiles population estimates for various native wildlife species at locations throughout Minnesota. The 2013 Farmland Wildlife Populations estimate (DNR 2013) indicated that average deer populations in the management units surrounding the Fish Creek Watershed to the north and south (as density numbers were not available for the Twin Cities Metro Area in this study) were approximately 12 deer per square mile. Based on the area of the Fish Creek Watershed contributing to the downstream monitoring station, there are approximately 13 deer within the watershed.

Based on 2000 wild turkey density estimates from the National Wild Turkey Federation, the density of wild turkeys in the Fish Creek Watershed is approximately 6 to 15 wild turkeys per square mile (NWTF 2000). At this density, there are approximately 11 wild turkeys in the Fish Creek Watershed. The total number of equivalent animal population based on this estimate is 0.2 turkeys (Minnesota Department of Agriculture (MDA) website 2014).

The DNR estimates there were 550,000 breeding ducks in Minnesota annually from 2005 to 2009 (DNR Roundtable 2010) during the common seven-month residence period (April through October). Following the procedure outlined in the MPCA's 2014 Upper Mississippi River Bacteria TMDL Study and Protection Plan (EOR 2014), it was assumed that the annual duck population was distributed evenly throughout 2006 National Land Cover Database (NLCD) Open Water and wetland land use types. Based on this distribution, it is estimated that there are 0.24 ducks residing in the direct drainage area to Fish Creek.

Based on methodology outlined in the MPCA's 2014 Upper Mississippi River Bacteria TMDL Study and Protection Plan (EOR 2014), it was assumed that there were 0.20 geese per acre of 2006 NLCD open water and wetland land use types. Based on this assumed density, it is estimated that there are 1.2 geese in the 6.0 acres of open water and wetland area within the direct drainage area to Fish Creek.

To account for all other wildlife in the Fish Creek Watershed, the total *E. coli* loads estimated for the quantified wildlife populations were doubled.

The riparian area of Fish Creek is mainly classified as forested wetlands. Additionally, the majority of forested, wetland, and open natural area in the Fish Creek Watershed is along or near the steam corridor. For this reason, it is expected that wildlife in the watershed would be most densely concentrated in the areas closest to Fish Creek, and waste from wildlife would be transported relatively quickly into the surface water.

3.6.2.5 Agricultural Sources

Runoff generated from agricultural land use can be a significant source of bacteria loading to streams in rural and predominantly agricultural watersheds. The predominant sources of bacteria loading from agricultural land use are livestock graving and land application of manure fertilizer. As discussed in Section 3.6.2.2, the southern and eastern portions of the Fish Creek watershed are predominately commercial nursery land use. Although there is no evidence of livestock grazing in this portion of the watershed, a longitudinal analysis of bacteria concentration along Fish Creek was performed to determine if this portion of the watershed is contributing elevated bacterial loading concentrations to Fish Creek.

As discussed in Section 3.5.3 and shown in Table 3-9, *E. coli* concentrations are lower at the upstream monitoring locations and typically these locations meet the chronic monthly standard. Figure 3-7 shows that the "downstream of double driveway pond" monitoring site is the first monitoring location downstream of the Bailey Nursery. Review of the spatial variability of *E. Coli* loading along Fish Creek (Figure 3-8 and Table 3-9) does not show elevated E.coli concentrations at the "downstream of double driveway pond" monitoring site compared to other monitoring sites, and data at this site are not sufficient to indicate that the site is impaired for E.coli. For this reason, there was no evidence that agricultural areas of the watershed were contributing elevated concentrations to the stream. For this reason, it was determined that no special consideration of loading from agricultural sources should be included in the bacteria TMDL developed for Battle Creek.

3.6.2.6 Bacteria Available for Runoff

In the TMDL source assessment, it is not only necessary to estimate the total bacteria production by source, but it is also necessary to: (1) estimate the amount of bacteria potentially available for runoff from each source; and (2) assess the potential for the bacteria to reach surface waters under wet and dry conditions. This analysis results in the partitioning of the stream load by source, based on the total load estimated to reach surface waters under the given conditions.

The data and assumptions discussed in the previous sections result in total populations corresponding to potential sources and estimates of total bacteria production. The total source population inventory for the contributing watershed is shown in Table 3-13, along with the estimated quantity of *E. coli* bacteria produced monthly. The *E. coli* bacteria production rates were based on animal type.

Table 3-13 Estimated population and monthly *E. coli* production by source

Category	Source	Animal Population	*E. coli* Organisms per Unit per Month (10^9 organisms)*	Total *E. coli* Organisms Available per Month (10^9 organisms)	% of Total *E. coli* Organisms Available per Month
Human	Pop. using SSTSs	102	30	3066	8%
	Pop. using sanitary sewer	123	30	3679	10%
Urban Runoff	Cats	215	75	16088	43%
	Dogs	189	75	14138	38%
Wildlife	Deer	13	5.4	69	0.2%
	Wild Turkey	0.2	3.9	1	0%
	Geese	0.02	0.3	0	0%
	Ducks	0.002	165	0	0%
	Other Wildlife	--	--	141	0.4%

* From the Upper Mississippi River Bacteria TMDL (2014), modified from daily fecal coliform loading rates from MetCalf and Eddy (1991) and EPA (2001).

Once produced, *E. coli* bacteria is made available or applied on the land surface by several different methods. Table 3-14 shows the fraction of bacteria generated by different sources and application types that are available to runoff into Fish Creek. The methodology used here was originally applied in the Southeast Minnesota Regional Fecal Coliform TMDL (MPCA 2002), and assumes that the delivery of *E. coli* would be the same as for fecal coliform. The assumed availability and distribution between various application methods represent the characteristics of the Fish Creek Watershed.

Note that this analysis makes the simplifying assumption that all bacteria produced in the watershed remains in the watershed. For some sources (e.g., wildlife) all bacteria produced is assumed available for runoff. For other sources (e.g., humans), a portion of the bacteria produced is assumed to not be available for runoff under any circumstances, such as in adequately treated rural wastewater.

Table 3-14 Assumed *E. coli* availability by application method

Category	Application Method	Assumed Availability	Notes
Human	Adequately treated SSTS	75% of humans	Not available
	Inadequately treated SSTS	25% of humans	Available
	Exfiltration from Sanitary Sewer	3% of humans	Available
	Treated Sanitary Sewer	97% of humans	Not available
Urban Runoff	Properly managed pet waste	90% of pets	Not available for runoff
	Improperly managed pet waste	10% of pets	Available for runoff
Urban Wildlife Runoff	Wildlife Waste	100% of deer, wild turkey, geese, and ducks	Available for runoff

Once the estimated total bacteria produced in the contributing portion of the Fish Creek Watershed is calculated and assigned to various application methods, final assumptions must be made on the potential for each application method to deliver bacteria to surface waters. This analysis is adapted from that used in the TMDL for the Lower Mississippi River Basin in Minnesota (MPCA 2002). The TMDL analyses ranked each application method according to its risk of bacteria delivery and assigned a corresponding delivery percentage (see Table 3-15). This risk of delivery to the water resource was translated into delivery percentages. A very low potential delivers 1%, low potential is 2%, moderate is 4%, high is 6%, and very high is 8%. The delivery percentage represents the fraction of the total available bacteria that is assumed to be transported to Fish Creek for a given condition (wet or dry).

This analysis procedure reflects the conditions in the Fish Creek Watershed. The assumed dry weather application methods are inadequately treated wastewater (SSTS), exfiltration from the sanitary sewer system, and wildlife. All application methods are assumed to contribute bacteria to the stream in wet weather.

Table 3-15 Assumed *E. coli* delivery potential by application method

Application Method	Assumed Delivery Potential*	
	Wet Conditions	Dry Conditions
Inadequately treated wastewater (SSTS)	Very High (8%)	Very High (8%)
Exfiltration from the Sanitary Sewer	Very High (8%)	Very High (8%)
Improperly managed pet waste	Moderate (4%)	None
Wildlife	Very low (1%) for all other	Very low (1%) for all other

* Adapted from values used in MPCA (2002).

3.6.2.6 Estimated Source Load Proportions

The *E. coli* loading in the contributing Fish Creek Watershed was estimated by multiplying the total number of *E. coli* organisms available per month for each source by its corresponding availability and delivery potential. A comparison of sources contributing to wet weather and dry weather loading is shown in Figure 3-12 and Figure 3-13, respectively.

Bacteria loading to Fish Creek is dominated by loading from humans, primarily from inadequately treated wastewater SSTS, and improperly managed pet waste in both wet and dry weather conditions.

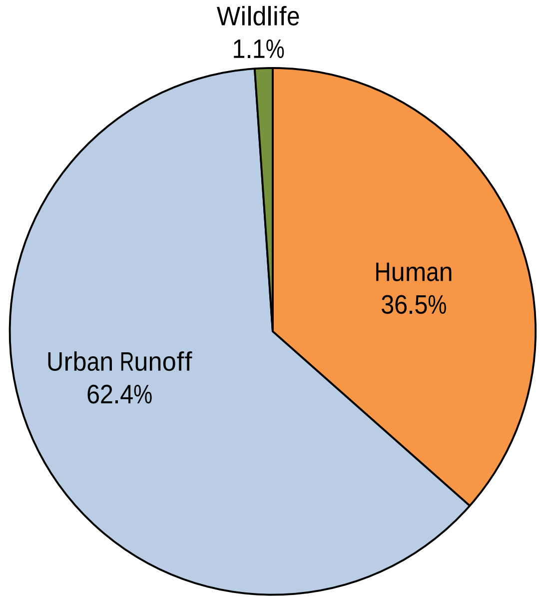

Figure 3-12 Estimated Bacteria Loading by Source for Wet Weather Conditions

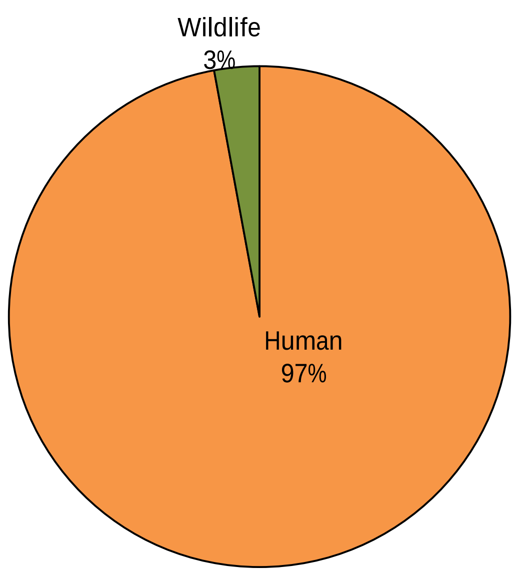

Figure 3-13 Estimated Bacteria Loading by Source for Dry Weather Conditions

3.6.3 Nutrients

These sections provide a brief discussion of the potential sources of phosphorus to Bennett Lake and Wakefield Lake, although the actual quantification of these sources will be further discussed in Section 4.3 of this TMDL report. The sources of phosphorus can be classified into permitted or non-permitted sources, which will be defined and discussed in the following sections.

3.6.3.1 Permitted Sources

Permitted sources of TSS are the same as described in Section 3.6.1.1.

3.6.3.2 Non-Permitted Sources

Non-permitted sources of phosphorus are those that are not regulated by the NPDES/SDS program. For many lakes, especially shallow lakes, these sources can be a significant portion of the TP load to the lake and can be a major contributor to impairment. The following are examples of the typical non-permitted sources of phosphorus:

- **Atmospheric Deposition** – Phosphorus can be deposited directly on the surface of the lake during precipitation events and as dry deposition of particles in between events (e.g., particles suspended by wind that settles out).
- **Watershed Loading** – Phosphorus loads from runoff from rural and/or urban portions of a watershed that are not regulated by an NPDES/SDS MS4 Permit and may also include discharges from upstream lakes (that may or may not be impaired/have an approved TMDL).
- **Internal Sources** – There are a variety of potential sources of phosphorus that can come from within the lake. Examples include release of phosphorus bound to lake bottom sediments during anoxic conditions, the senescence of certain aquatic vegetation (e.g., Curly-leaf pondweed) during the growing season, the activity of benthivorous fish such as carp, suspension of bottom sediments due to wind and/or boat traffic, and GW interaction.
- **Non-compliant SSTS** – In rural areas not served by sanitary sewer systems, non-compliant SSTS on lakeshore properties and in other locations in the watershed can contribute to nutrient impairments.

4. TMDL Development

The TMDL is defined by the loading capacity for a given pollutant, which is distributed among its components as follows:

TMDL = WLA + LA + MOS + Reserve Capacity

Where:

WLA	=	Wasteload Allocation to Point (Permitted) Sources
LA	=	Load Allocation to Nonpoint (Non-Permitted) Sources
MOS	=	Margin of Safety
Reserve Capacity	=	Load set aside for future allocations from growth or changes

A list of MS4 permittees within each impaired watershed area is included in Appendix E.

4.1 Total Suspended Sediment (TSS)

TSS was determined to be the primary stressor to aquatic life in the Battle Creek Stressor Identification (SID) Report. For this reason, a TSS TMDL for Battle Creek was developed using the load duration approach, as described in the following sections.

4.1.1 Flow Duration Curve

The applicable water quality standard for TSS applies to the months of April through September. Therefore, a flow duration curve was developed by calculating the average daily flow in Battle Creek for the months of April through September and ranking the resulting values from highest to lowest. Flow measurements were collected at the Battle Creek WOMP station (Figure 3-5) from 1996 through 2013. The flow-duration curve for Battle Creek shown in Figure 4-1 depicts the percentage of time that the average daily flow in any given month between April and September exceeds a particular flow rate value.

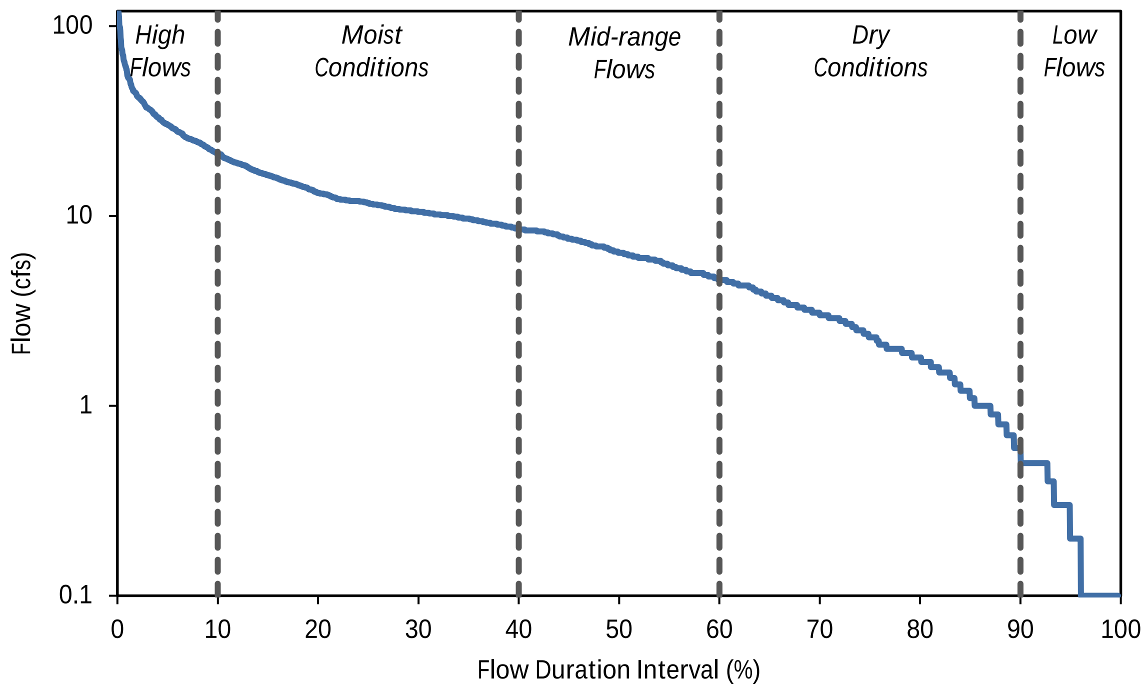

Figure 4-1 April through September Flow Duration Curve for Battle Creek

4.1.2 Load Duration Curve

Similar to the flow duration curve, the load duration curve relates TSS loading at a given flow to how often that flow value is exceeded in the stream. The load duration curve is calculated by multiplying the flow duration curve (Figure 4-1) by the MPCA TSS water quality standard for Class 2B streams (30 mg/L; see Section 2.2) and converting to a daily loading in terms of pounds (lbs) of TSS per day. The resulting TSS load is then plotted relative flow duration interval. The final TSS load duration curve (Figure 4-2) represents the TMDL for Battle Creek for any given flow rate observed in the available data set.

Figure 4-2 shows the TSS load duration curve as well as observations of TSS loading (expressed in terms of lbs. of TSS per day) collected at the Battle Creek WOMP station. Because it would be impractical to develop a TMDL for all potential flow rates in Battle Creek, the load duration curve is instead broken into the five flow conditions shown in Figure 4-2 (high flow, moist conditions, mid-range flows, dry conditions, and low flows). The median value (or midpoint) of the load duration curve within each flow condition defines the TMDL for each flow condition. Because the MPCA TSS standard states that the standard concentration (30 mg/L) may be exceeded no more than 10% of the time, the 90th percentile of observed TSS loading within each flow condition defines the existing load for each flow condition.

Figure 4-2 demonstrates that exceedances of the TSS standard in Battle Creek are common, particularly during high flows, moist conditions, and mid-range flows.

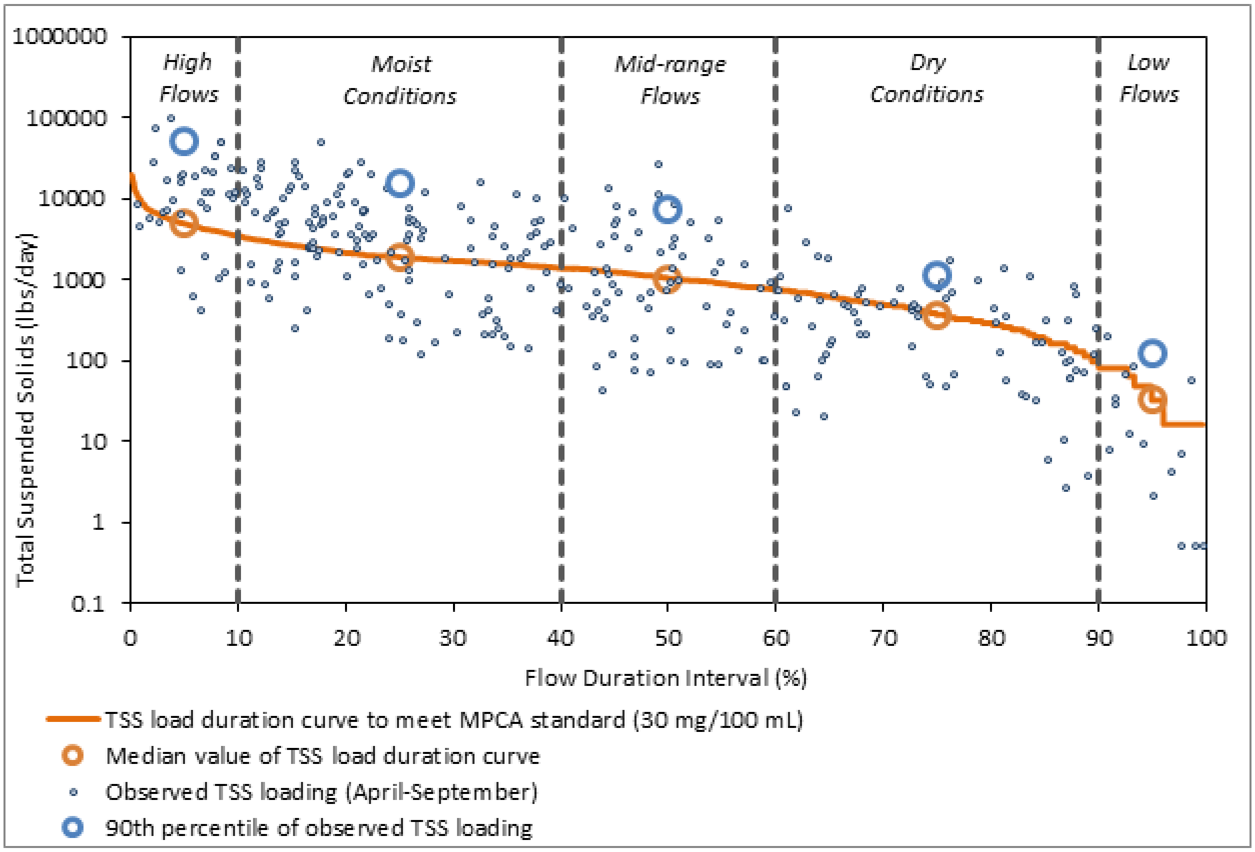

Figure 4-2 Battle Creek TSS load duration curve

4.1.3 Loading Capacity

As outlined in the TSS source assessment (Section 3.6.1), TSS loading to Battle Creek comes from a variety of sources, including point (permitted) and nonpoint (non-permitted) sources. The allowable TSS load is dependent upon flow conditions, and therefore is dynamic. The TMDL is expressed in terms of the total daily loading capacity for the various flow regimes. Because the TSS water quality standard states that the TSS water quality concentration of 30 mg/L may be exceeded no more than 10% of the time, the total daily loading capacity is compared to the 90^{th} percentile value of existing loading within each flow regime to determine required loading reductions.

Table 4-2 shows the TMDL in terms of the total load capacity for the TSS water quality standard. The load duration curve was developed by multiplying the flow-duration curve (Figure 4-1) by the TSS water quality standard (30 mg/L). The TMDL for Battle Creek is defined by the midpoint daily total loading capacity for each of the five flow intervals. Existing loading is defined by the 90^{th} percentile value of observed TSS loading within each flow interval.

4.1.4 Wasteload Allocation Methodology

The WLAs for TMDLs are typically divided into three categories: permitted MS4s, permitted point source dischargers, and construction and industrial storm water. The following sections describe how each of these allocations was estimated.

4.1.4.1 Construction and Industrial Stormwater Permits

The WLAs for the construction and industrial stormwater permits are based on estimates of the average annual percentage of the county area under an MPCA Construction Stormwater Permit, using the MPCA Construction Stormwater Permit data provided from 2007 through 2013 for Ramsey County and Washington County. From 2007 through 2013, the estimated average annual area under the MPCA Construction Stormwater Permit was 0.35% of the combined area of Ramsey and Washington County. We assumed that the same percentage for construction stormwater would apply for the MPCA Industrial Stormwater Permits, so the total percentage of the Battle Creek Watershed assumed to be under MPCA Construction or Industrial Stormwater Permits was 0.7%. The WLA assigned to construction and Industrial Stormwater Permits was calculated by applying the percent of the watershed area assumed to be under Construction or Industrial Stormwater Permit (0.7%) to the loading capacity estimated for external watershed sources. The 3M Corporate Headquarters campus is an Industrial Stormwater Permit holder within the Battle Creek Watershed. The 3M campus is entirely contained within the city of Maplewood, and comprises a significant portion of the total Maplewood drainage area within the Battle Creek Watershed. Therefor an individual WLA for 3M was not calculated separately, and was instead included within the total WLA assigned to all permitted sources.

Load reductions for construction stormwater activities are not specifically targeted in this TMDL. It should be noted that construction stormwater activities are considered in compliance with provisions of this TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all stormwater BMPs required under the permit, including any applicable additional BMPs required in the Construction General Permit for discharges to impaired waters; or meet local construction stormwater requirements if they are more restrictive than requirements of the Construction General Permit. Industrial stormwater activities are considered to be consistent with the provisions of the TMDL if they obtain an Industrial Stormwater General Permit or General Sand and Gravel General Permit (MNG49) under the NPDES program and properly select, install, and maintain all BMPs required under the permit.

4.1.4.2 Permitted MS4s

There are portions of six MS4s within the Battle Creek Watershed (Figure 4-3). Table 4-1 summarizes the total area of each MS4 within the Battle Creek Watershed. The MS4 WLAs were calculated by multiplying the municipalities' percent watershed coverage by the total watershed loading capacity after the MOS and permitted source discharge allocations were subtracted. Permitted sources of TSS include all TSS mobilized by watershed runoff and discharged into the stream through MS4 storm sewer infrastructure.

Table 4-1 MS4 summary for Battle Creek

MS4 Name	MS4 ID Number	MS4 Area within the Contributing Watershed (acres)[1]
Maplewood	MS400032	921
MnDOT Metro District	MS400170	118
Ramsey County	MS400191	552
St. Paul	MN0061263	790
Washington County	MS400160	6
Woodbury	MS400128	268

1 Open water area removed from total MS4 contributing watershed area (open water summary in Table 3-2).

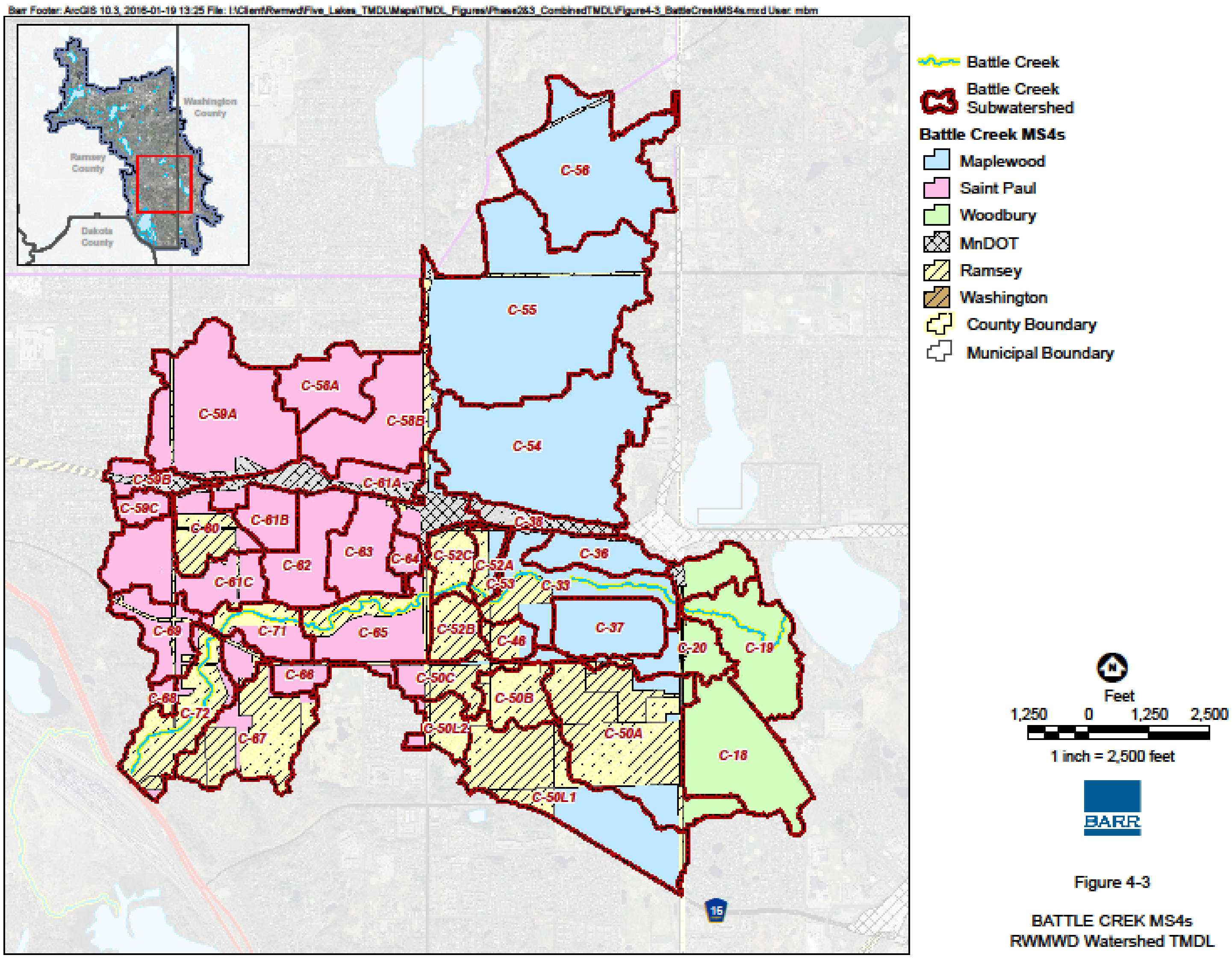

Figure 4-3 MS4s in Battle Creek Watershed

4.1.4.3 NPDES Point Source Dischargers

There are no non-stormwater NPDES permitted point source surface dischargers identified within the Battle Creek Watershed.

4.1.5 Load Allocation Methodology

The LA is the remaining load after the MOS and WLA are subtracted from the total load capacity of each flow zone. For this TMDL, the LA includes loading from upstream waterbodies (i.e., Battle Creek Lake), and loading from sources within the stream and stream corridor (e.g., sediment resuspension within the stream channel, erosion and bank failure within the stream corridor, in-channel algal production, etc.).

4.1.6 Margin of Safety

A reasonable MOS is necessary in order to account for natural variability and uncertainty in the effect that the calculated LAs will have on observed water quality. The MOS can be defined either explicitly, or implicitly, through the use of conservative assumptions. In this TSS TMDL study, an explicit 10% MOS was applied, whereby 10% of the loading capacity for each flow regime was subtracted before WLAs and LAs were calculated. A 10% MOS was considered appropriate because the load duration curve minimizes uncertainties that can arise through other approaches. Load duration curves are simply a function of average daily flow multiplied by numerical water quality standards.

4.1.7 Seasonal Variation

Seasonal variation is accounted for by the use of a load duration curve to set TMDLs over seasonal flow regimes. The in-stream data used for the source assessment and the calculation of required load reductions represents observations across the range of seasonal and annual flow variation and loading conditions. Because the TSS water quality standard only applies from April 1 through September 30, flow and loading data for the winter months were excluded from this analysis. Because several years of flow and TSS monitoring data were collected and utilized in this analysis, the TMDL accounts for both seasonal and annual variations.

4.1.8 TMDL Summary

Table 4-2 presents the TMDL for Battle Creek, expressed as pounds of pollutant loading per day, along with the WLA and LA for the creek. Also summarized in this table are the required TSS reductions, which were determined by comparing measured TSS loading data to the total daily load capacity within each flow zone. The WLAs presented in Table 4-2 is categorical, meaning that the total LAs to several permitted sources are grouped into a single WLA, with the exception of the MnDOT Metro District. The categorical WLA approach is being taken as the RWMWD is initially taking the lead role in implementing projects to achieve the WLA defined in the Battle Creek TSS TMDL.

Table 4-2 Battle Creek TMDL summary

	Flow Zone				
	Very High	High	Mid	Low	Very Low
	TSS Loading (lbs/day)				
Wasteload Allocation	**1,876**	**723**	**395**	**141**	**13**
Maplewood Ramsey County St. Paul Washington County Woodbury	1,763	679	371	133	12
Construction / Industrial	31	12	7	2	0
MnDOT Metro District	82	32	17	6	1
Load Allocation	2,551	982	537	193	17
Margin of Safety (10%)	492	189	104	37	3
Total Load Capacity (TMDL)	4,919	1,893	1,036	372	32
Existing Load, Permitted[1]	22,059	6,555	3,173	470	52
Existing Load, Non-Permitted[1]	29,992	8,912	4,314	639	70
Total Existing Load[1]	52,051	15,466	7,487	1,109	122
Required Load Reduction	47,132	13,573	6,451	737	90
Required Load Reduction (%)	91%	88%	86%	66%	73%

[1] Loading reported for all existing condition sources represents the 90th percentile of observed loading.

4.2 Bacteria (*E. coli*)

The TMDL for Fish Creek was developed using the load duration approach (MPCA 2009), as described in the following sections.

4.2.1 Flow Duration Curve

The applicable water quality standard for bacteria applies to the months of April through October. Therefore, a flow duration curve was developed by calculating the average daily flow in Fish Creek for the months of April through October and ranking the resulting values from highest to lowest. Flow measurements were collected at the Fish Creek WOMP station (Figure 3-7) from 1996 through 2013. The flow-duration curve for Fish Creek shown in Figure 4-4 depicts the percentage of time that the average daily flow in any given month between April and October exceeds a particular flow rate value.

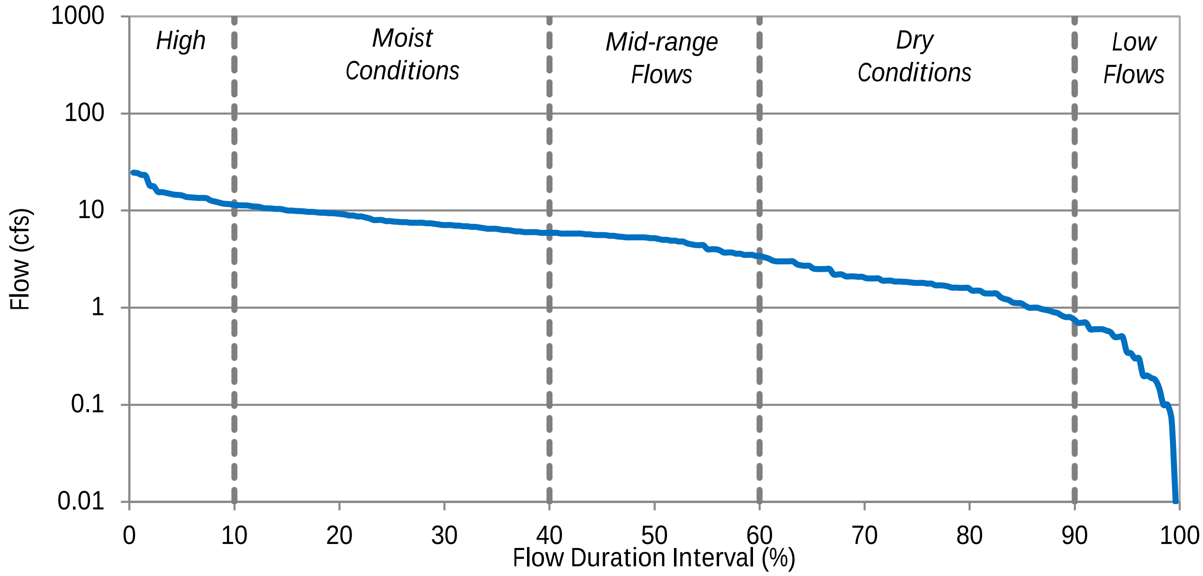

Figure 4-4 April through October Flow Duration Curve for Fish Creek

4.2.2 Load Duration Curve

Similar to the flow duration curve, the load duration curve relates bacteria loading at a given flow to how often that flow value is exceeded in the stream. The load duration curve is calculated by multiplying the flow duration curve (Figure 4-4) by the chronic *E. coli* standard for Class 2C streams (126 cfu / 100 mL) and converting to a daily loading in terms of billions of organisms per day. The resulting bacteria load is then plotted relative flow duration interval. The final chronic load duration curve (Figure 4-5) represents the TMDL for Fish Creek for any given flow rate observed in the available data set.

Figure 4-5 shows the chronic load duration curve, as well as observations of bacteria abundance (expressed in terms of *E. coli*) collected at the Fish Creek WOMP station (station ID 99UM075). Because it would be impractical to develop a TMDL for all potential flow rates in Fish Creek, the load duration curve is instead broken into the five flow conditions shown in Figure 4-5 (high flow, moist conditions, mid-range flows, dry conditions, and low flows). The median value (or midpoint) of the chronic load duration curve within each flow condition defines the TMDL for each flow condition. Because the MPCA chronic bacteria standard is developed based on the geometric mean of observed *E. coli* concentrations, the geometric mean of observed data within each flow condition defines the existing load for each flow condition.

Figure 4-5 demonstrates that *E. coli* loading in Fish Creek is typically above the loading permitted by the chronic water quality standard of 126 organisms per 100 mL, particularly during moist conditions, dry conditions, and low flows.

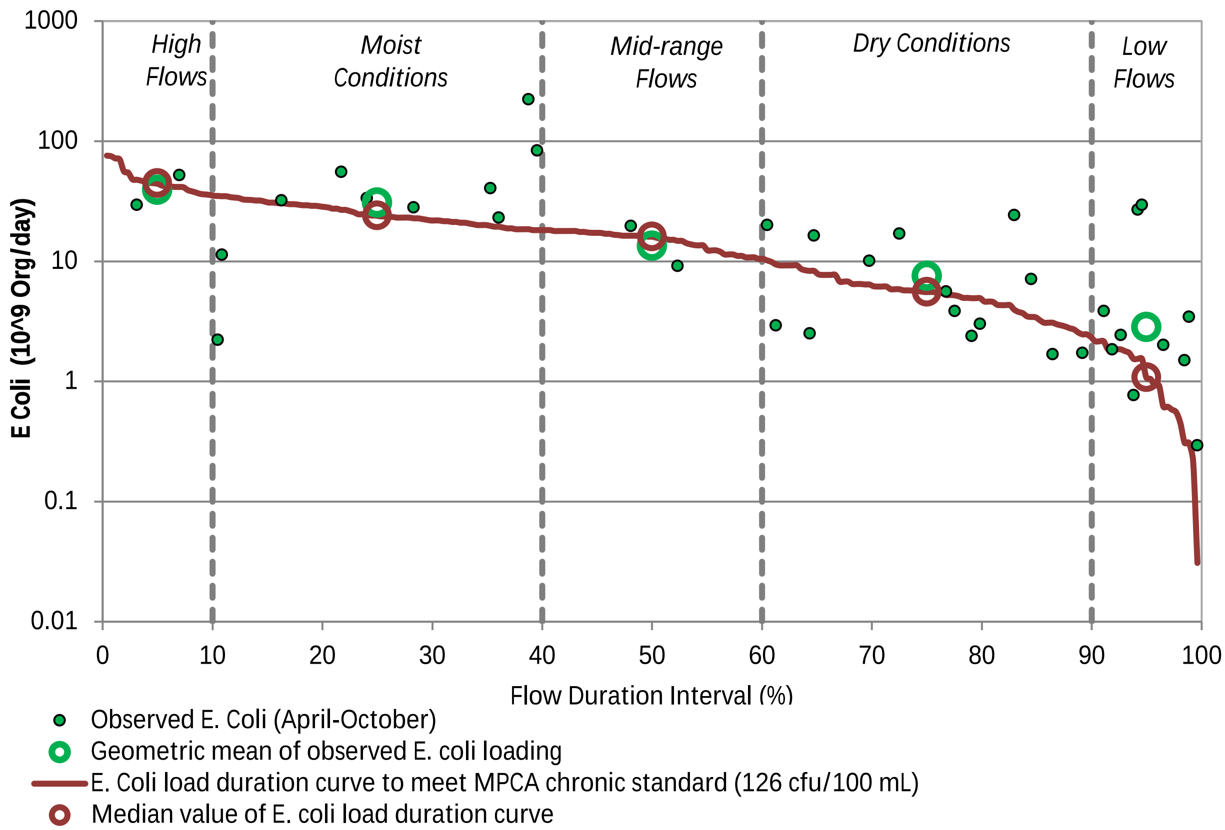

Figure 4-5 Fish Creek *E. coli* load duration data

4.2.3 Loading Capacity

As outlined in the bacteria source assessment (Section 3.6.2), bacterial loading to Fish Creek comes from a variety of sources, including point (permitted) and nonpoint (non-permitted) sources. The allowable bacteria load is dependent upon flow conditions, and therefore is dynamic. The TMDL is expressed in terms of the total daily loading capacity for the various flow regimes. The focus of this analysis is on the chronic *E. coli* standard of 126 organisms per 100 mL (applied to the monthly geometric mean) rather than the acute standard of 1,260 organisms per 100 mL Exceedances of the acute *E. coli* concentration (1,260 organisms per 100 mL) are uncommon in Fish Creek. Only 5 of 132 total samples (<4%) were found to exceed the acute standard, and the proportion of samples exceeding the acute standard was greater than 10% at only one of the six sampling locations (4 of 38 (11%) at the Fish Creek WOMP station, see Table 3-10). For this reason, it is assumed that actions taken within the Fish Creek Watershed to achieve the chronic *E. coli* standard will be sufficient to ensure that Fish Creek also meets the acute *E. coli* standard.

Table 4-4 shows the TMDL in terms of the total load capacity for the chronic water quality standard. As described in Section 4.2.2, the load duration curve was developed by multiplying the flow-duration curve (Figure 4-4) by the *E. coli* chronic water quality standard (126 organisms per 100 mL). The TMDL for Fish Creek is defined by the midpoint daily total loading capacity for each of the five flow intervals. Existing loading is defined by the geometric mean of observed *E. coli* loading within each flow interval.

4.2.4 Wasteload Allocation Methodology

The WLAs for TMDLs are typically divided into three categories: permitted MS4s, permitted point source dischargers, and construction and industrial storm water. The following sections describe how each of these WLAs was estimated. The WLAs for regulated construction stormwater (permit #MNR100001) were not developed, since *E. coli* is not a typical pollutant from construction sites. The WLAs for regulated industrial stormwater were also not developed. 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. There are no bacteria or *E. coli* benchmarks associated with any of the Industrial Stormwater Permit (Permit #MNR050000).

4.2.4.1 Permitted MS4s

There are portions of seven MS4s within the Fish Creek Watershed (Figure 4-6). Table 4-3 summarizes the total area of each MS4 within the Fish Creek Watershed. The MS4 WLAs were calculated by multiplying the municipalities' percent watershed coverage by the total watershed loading capacity after the MOS and permitted point source discharge allocations were subtracted. *E. coli* from improperly managed pet waste mobilized by stormwater runoff was the only point source of *E. coli* identified in the Fish Creek Watershed.

Table 4-3 MS4 summary for Fish Creek

MS4 Name	MS4 ID Number	MS4 Area within the Contributing Watershed (acres)[1]
Maplewood	MS400032	394
Newport	MS400040	32
MnDOT Metro District	MS400170	45
Ramsey County	MS400191	104
St. Paul	MN0061263	21
Washington County	MS400160	4
Woodbury	MS400128	182

[1] Open water area removed from total MS4 contributing watershed area (open water summary in Table 3-2).

4.2.4.2 NPDES Point Source Dischargers

There are no non-stormwater NPDES permitted point source surface dischargers identified within the Fish Creek Watershed.

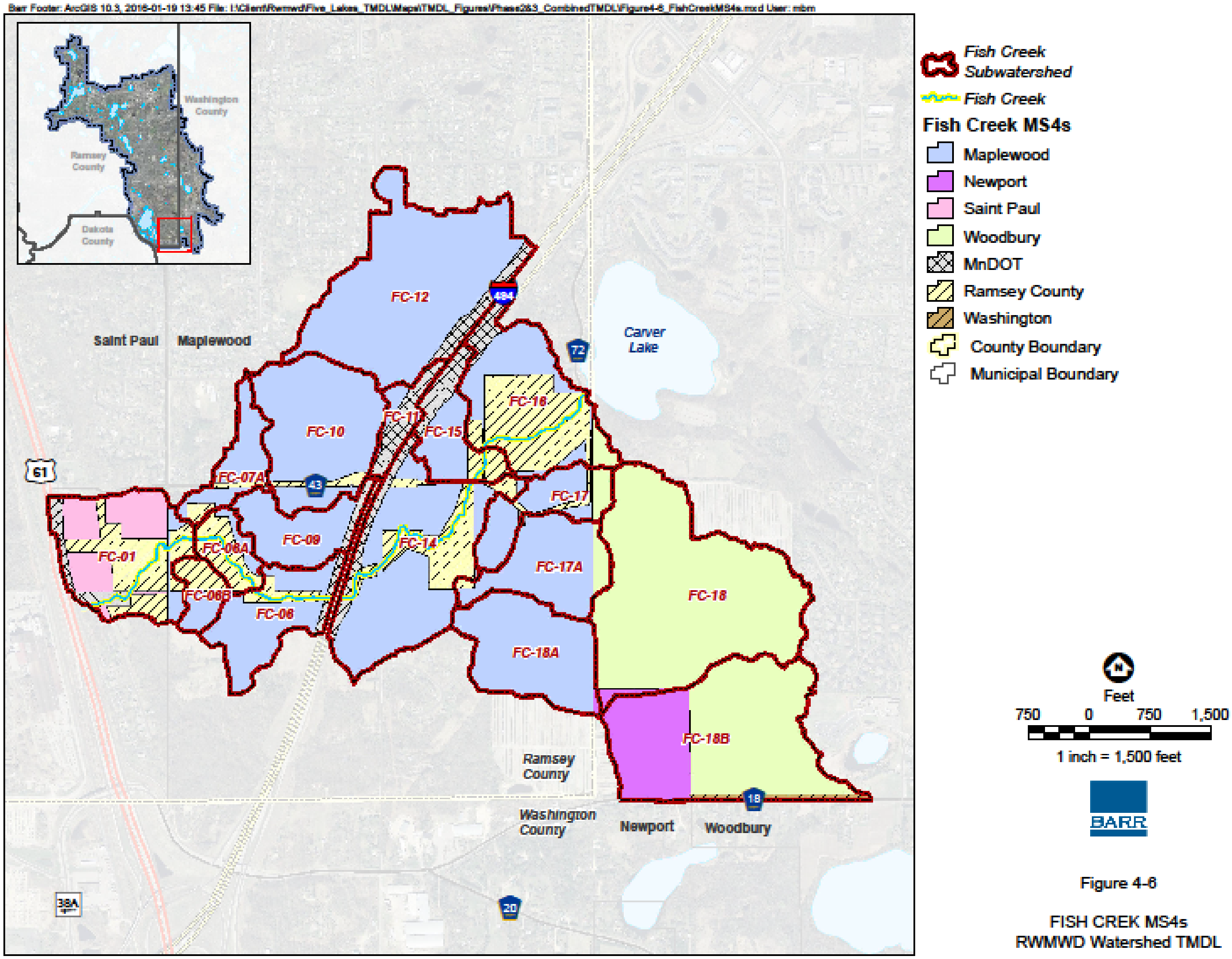

Figure 4-6 MS4s in Fish Creek Watershed

4.2.5 Load Allocation Methodology

The LA is the remaining load after the MOS and WLA are subtracted from the total load capacity of each flow zone. For this TMDL, the existing non-permitted bacterial load includes loads from non-compliant SSTS, sanitary sewer exfiltration, and bacteria loading from wildlife. By law, septic systems cannot discharge to surface waters, hence, for this TMDL, septic systems are assigned an allowable load of zero billion organisms per day. Likewise, exfiltration from sanitary sewer systems are assigned an allowable load of zero billion organisms per day.

4.2.6 Margin of Safety

A reasonable MOS is necessary in order to account for natural variability and uncertainty in the effect that the calculated LAs will have on observed water quality. The MOS can be defined either explicitly, or implicitly, through the use of conservative assumptions. In this *E. coli* TMDL study, an explicit 10% MOS was applied, whereby 10% of the loading capacity for each flow regime was subtracted before WLAs and LAs were calculated. A 10% MOS was considered appropriate because the load duration curve minimizes uncertainties that can arise through other approaches. Load duration curves are simply a function of average daily flow multiplied by numerical water quality standards.

4.2.7 Seasonal Variation

Seasonal variation is accounted for by the use of a load duration curve to set TMDLs over seasonal flow regimes. The in-stream data used for the source assessment and the calculation of required load reductions represents observations across the range of seasonal and annual flow variation and loading conditions. Because the *E. coli* water quality standard only applies from April 1 through October 31, flow and loading data for the winter months were excluded from this analysis. Because several years of flow and bacteria monitoring data were collected and utilized in this analysis, the TMDL accounts for both seasonal and annual variations.

4.2.8 MS4 Loading Considerations

Of the bacteria sources identified in this TMDL (Section 3.6.2), the only loading source that applies to MnDOT land area (MnDOT-owned road and interstate corridors, Figure 4-3) is wildlife. For this reason, existing loading from MnDOT area is below the identified WLA for MnDOT for all flow regimes, and MnDOT will not be required to reduce loading from existing conditions (noted in Table 4-4).

4.2.9 TMDL Summary

Table 4-4 presents the TMDL for Fish Creek, expressed as billion organisms per day of *E. coli,* along with the WLA and LA for the creek. Also summarized in this table are the required bacteria reductions, which were determined by comparing measured *E. coli* data to the total daily load capacity within each flow zone. The WLAs presented in Table 4-4 is categorical, meaning that the total LAs to several permitted sources are grouped into a single WLA, with the exception of the MnDOT Metro District. The categorical WLA approach is being taken as the RWMWD is initially taking the lead role in implementing projects to achieve the WLA defined in the Fish Creek bacteria TMDL. Newport is not included in the MS4s implicated in the categorical WLA, as Newport is not currently within the legal limits of RWMWD. As such, RWMWD plans to help its official member cities achieve this WLA without the involvement of the city of Newport.

Table 4-4 Fish Creek TMDL Summary

	Flow Zone				
	Very High	High	Mid	Low	Very Low
	billion organisms per day (b-org/day)				
Wasteload Allocation	**39.6**	**21.3**	**14.2**	**4.9**	**1.0**
Maplewood Ramsey County St. Paul Washington County Woodbury	37.3	20.1	13.4	4.6	0.9
MnDOT Metro District*	2.3	1.2	0.8	0.3	0.1
Load Allocation	**0.6**	**0.3**	**0.2**	**0.1**	**0.0**
Margin of Safety (10%)	**4.5**	**2.4**	**1.6**	**0.6**	**0.1**
Total Load Capacity (TMDL)	**44.7**	**24.0**	**16.0**	**5.5**	**1.1**
Existing Load, Permitted	17.8	13.9	6.1	3.4	1.3
Existing Load, Non-Permitted	21.5	16.8	7.3	4.1	1.5
Total Existing Load	39.3	30.7	13.4	7.5	2.8
Required Load Reduction	0	6.7	0	2.0	1.7
Required Load Reduction (%)	0%	22%	0%	26%	62%

* MnDOT is currently loading below its wasteload allocation, and will not be required to further reduce bacteria loading (as noted in Section 4.2.8). For this reason, no portion of the required load reduction noted in Table 4-4 applies to the MnDOT Metro District.

4.3 Nutrients

The nutrient load capacity and TMDL established for Bennett Lake and Wakefield Lake are based on the 2005 and 2004 water quality conditions, respectively. The years analyzed produced the highest growing season concentrations of TP observed in each lake over the past decade of water quality data analyzed, and were chosen to reflect the critical condition of phosphorus loading to each water body.

4.3.1 Loading Capacity Methodology

The following section outlines the water quality modeling efforts performed as part of the establishment of the Bennett Lake and Wakefield Lake nutrient TMDLs. Table 4-5 summarizes precipitation and growing season average TP concentration during the critical year in Bennett and Wakefield Lake.

Table 4-5 Summary of precipitation and water quality during critical year in Bennett Lake and Wakefield Lake

Waterbody	Critical Year	Water Year Precipitation (inches)	Growing Season Precipitation (inches)	Growing Season Average TP (µg/L)
Bennett Lake	2005	29.8	18.4	210
Wakefield Lake	2004	28.6	13.1	154

Water quality modeling provided the means to estimate the TP sources to each lake and estimate the effects on lake water quality. Water quality modeling was a two-fold effort, involving:

- A stormwater runoff computer model (P8 Urban Catchment Model) that estimated the water and TP loads from the lake's tributary watershed; and
- An in-lake mass balance model that took the water and TP loads from the lake's external and internal sources, and generated the resultant lake TP concentration.

The P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds) Urban Catchment Model and the in-lake mass balance model are described in more detail below.

4.3.1.1 Watershed Loading (P8 Modeling)

The P8 Model (Version 2.4) was used to estimate watershed runoff and TP loads from the Bennett and Wakefield Lake Watersheds. The model and its supporting information can be downloaded from the internet at http://www.wwwalker.net/p8/.

The P8 model is a useful diagnostic tool for evaluating and designing watershed improvements and BMPs because it can estimate the treatment effect of several different kinds of potential BMPs. The P8 model tracks stormwater runoff as it carries phosphorus across watersheds and incorporates the treatment effect of detention ponds, infiltration basins, flow splitters, etc. on the TP loads that ultimately reach downstream water bodies. P8 accounts for phosphorus attached to a range of particulate sizes, each with their own settling velocity, tracking their removal by treatment features accordingly.

The key inputs to the P8 model are based on the each subwatersheds total area, the fraction of each subwatershed that is directly connected imperviousness and depression storage, as well as the composite pervious area curve number (representing both pervious and unconnected impervious areas). Directly connected impervious areas create runoff that is hydraulically connected to the drainage systems, while runoff that drains from impervious surfaces to pervious surfaces is not considered directly-connected. The P8 model also requires climate data (hourly precipitation and daily average temperature), treatment device configurations information (outlets, storage volumes, seepage rates, etc.) and pollutant loading parameters to estimate pollutants in runoff and removal of those pollutants by various treatment devices.

The P8 models used in this TMDL were developed and updated for this study and reflect the natural wetlands and other stormwater management practices constructed throughout each watershed. The P8 model was used to generate a range of water and phosphorus loadings from each lake's watershed during the critical water quality period. Table 4-6 summarizes the critical year water and phosphorus loads predicted using P8 for Bennett and Wakefield Lake.

Table 4-6 Summary of P8 modeled water and phosphorus loads

Waterbody	Critical Year	Water Year Water Load (ac-ft)	Growing Season Water Load (ac-ft)	Water Year TP Load (lbs)	Growing Season TP Load (lbs)
Bennett lake	2005	436	250	113.3	70.1
Wakefield Lake	2004	536	232	254.8	127.7

A detailed discussion about the P8 modeling used for this study, along with the estimated P8 loadings to each lake for each precipitation event, is located in Appendix A.

4.3.1.2 Atmospheric Deposition

Atmospheric deposition of phosphorus directly to the lake surface throughout the year was quantified based on the estimated lake surface area (determined by the water balance model) and a deposition rate of 0.2615 kg/ha/yr (0.000639 lb/ac/d), a rate established in the Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (Barr 2005).

Table 4-7 Summary of estimated atmospheric deposition phosphorus load

		TP load from Atmospheric Deposition (lbs)	
Waterbody	**Critical Year**	**Water Year**	**Growing Season**
Bennett Lake	2005	7.0	2.3
Wakefield Lake	2004	4.8	1.4

4.3.1.3 Sediment Release

The net internal loading of phosphorus in Bennett and Wakefield Lake was calculated by deduction, using the difference between the predicted water quality using the in-lake mass balance model and the observed water quality data after all other phosphorus inputs to and losses from each lake were estimated (see Section 4.3.1.7 for additional details). To verify that the predicted internal load is reasonable, internal loading was checked against available sediment core data from Bennett and Wakefield Lake. Sediment phosphorus data are discussed below.

Four sediment cores were collected from Wakefield Lake in November 2006 and two sediment cores were collected from Bennett Lake in November of 2012. Sediment cores were analyzed for various phosphorus fractions, including mobile phosphorus and organic phosphorus fractions (Pilgrim et al. 2007). The mobile-phosphorus fraction includes loosely-sorbed phosphorus and iron-bound phosphorus, which are the portions of the sediment phosphorus pool that can most readily be released back into the water column as soluble phosphorus. The iron-phosphorus fraction is insoluble as long as the iron remains oxidized, but can become soluble again if the iron becomes reduced under anoxic conditions (i.e., absence of oxygen). The potential sediment phosphorus release rates were estimated by comparing concentrations of sediment phosphorus fractions to relationships developed by Pilgrim et al. (Pilgrim et al. 2007). The estimated mobile phosphorus release rate from the sediments ranged from 0.2 - 0.4 mg/m^2/day in Bennett Lake, and 2.4 - 3.0 mg/m^2/day in Wakefield Lake.

Lake sediments often become anoxic in summer months, and phosphorus that was previously bound to iron in the sediment becomes soluble and is released back into the water column. This newly released phosphorus is in the form of soluble reactive phosphorus, and is readily available for uptake and utilization by algae. Bennett Lake and Wakefield Lake are shallow, polymictic lakes, meaning the lakes do not experience strong thermal stratification and will mix multiple times during the growing season. However, review of DO levels collected along the profile of both lakes during various years suggests that the sediment-water interface may experience anoxic conditions intermittently. As such, enough phosphorus can be released from sediment to impact the relatively small volume of each shallow lake.

In addition to release of mobile phosphorus from sediment due to anoxic conditions, internal loading of phosphorus can also be increased by dieback and decomposition of aquatic macrophytes such as curly-leaf pondweed, as well as resuspension of lake-bottom sediments caused by wind and the activity of benthivorous fish such as carp. Curly-leaf pondweed has been observed in Wakefield Lake, but not quantified in a macrophyte survey (surveys of the lake have historically taken place after die-back of curly-leaf pondweed). A 2009 macrophyte survey found 63% coverage of curly-leaf pondweed over the surface area of Bennett Lake. Carp have not been detected in Wakefield Lake, but have been observed in Bennett Lake as recently as 2012.

Table 4-8 summarizes the estimated phosphorus release rates over the average lake surface area during the growing season from each in-lake mass balance model. The estimated magnitude of phosphorus load due to sediment release in Wakefield Lake aligns with the estimated anoxic phosphorus release rate based on collected sediment core data. The deduced internal loading rate for Bennett Lake is slightly greater than the release rate predicted by sediment core data, with a 0.1% daily recycle rate assumed. This suggests that release from curly-leaf pondweed and resuspension caused by carp activity contribute significantly to the total internal phosphorus loading within the Lake. Because the loading rate predicted by sediment core analysis reflects only anoxic release of phosphorus from lake-bottom sediments, it seems reasonable the internal loading rate predicted by the Bennett in-lake model is higher as the in-lake model predicts loading rate from all sources, including anoxic release, curly-leaf pondweed dieback, and sediment resuspension caused by carp activity.

Table 4-8 Estimated growing season internal phosphorus release rate

Waterbody	Critical Year	Sediment Core TP Release Range ($mg/m^2/d$)	Sediment Core TP Release Range w/ 0.1% daily recycling rate ($mg/m^2/d$)	Estimated Growing Season Internal Loading Rate ($mg/m^2/d$)	Estimated Total Growing Season Phosphorus Load From Internal Sources (lbs)
Bennett Lake	2005	0.2 - 0.4	2.1 – 2.8	3.4	78.1
Wakefield Lake	2004	2.4 – 3.0	- -	3.0	60.4

4.3.1.4 Aquatic Vegetation

The RWMWD conducted qualitative macrophyte surveys on Bennett Lake in 2009 and on Wakefield Lake in 2008 and 2012. Curly-leaf pondweed (*Potamogeton crispus*), a non-native submerged aquatic macrophyte, was observed in Bennett Lake, but was not detected in Wakefield Lake (potentially due to the timing of the macrophyte survey, as anecdotal evidence indicates curly-leaf pondweed has been seen in the Wakefield Lake). Because curly-leaf pondweed dies back in the middle of summer, the invasive species can increase growing season internal phosphorus loading in a lake as it senesces. Additionally, the decaying plant matter consumes oxygen, potentially exacerbating anoxic conditions at the sediment-water interface. Estimates of phosphorus loading due to the dieback of curly-leaf pondweed were based on the coverage and density of curly-leaf pondweed in Bennett Lake (as observed in the 2009 qualitative macrophyte survey) and information presented in a study completed on Half Moon Lake in Wisconsin (James et al. 2001).

Coontail (*Ceratophyllum demersum*) was observed in all three of the macrophyte surveys performed on Bennett and Wakefield Lake. Because this macrophyte grows suspended in the water column and does not root in the sediment, it directly uptakes phosphorus from the water column and can impact the observed phosphorus concentrations. Based on the estimated areal coverage and relative density estimates from the early and late summer surveys, the amount of TP uptake by coontail was estimated based on the coverage and density from the qualitative macrophyte surveys. These densities were associated with an amount of biomass determined from data from multiple lakes in the Twin Cities (Newman 2004) and average daily phosphorus uptake information (Lombardo and Cooke 2003).

Table 4-9 summarizes the estimated phosphorus load due to the dieback of curly-leaf pondweed and the estimated phosphorus uptake by coontail.

Table 4-9 Estimate growing season curly-leaf Pondweed TP loading and TP uptake by coontail

Waterbody	Critical Year	Estimated Growing Season TP Load from Curly-leaf Pondweed (lbs)	Estimated Growing Season TP Uptake by Coontail (lbs)
Bennett Lake	2005	12.3	1.2
Wakefield Lake	2004	- -	16.9

4.3.1.5 AdH 2D Modeling in Wakefield Lake

The Adaptive Hydraulics v4.2 (AdH) model, a 2-D hydraulic model developed by the Coastal and Hydraulic Laboratory (CHL), Engineer Research and Development Center (ERDC) and the United States Army Corps of Engineers (USACE) was selected for the analysis of Wakefield Lake. This model was selected because of its ability to determine flow vectors to visualize mixing processes and incorporate diffusion to estimate mixing within a body of water. AdH is a 2-D model, so the computer-estimated flow velocities are depth-averaged along the water column. This was determined to be appropriate for this level of investigation because the shallow nature of Wakefield Lake prevents significant temperature stratification that would affect differential flow velocities. In addition, AdH has the ability to adapt numerical meshes to efficiently compute a solution. The numerical mesh is the 2-D surface, with associated elevations, used to perform the model calculations. Preprocessing of model inputs, including developing the mesh, was completed using AquaVeo's Surface-Water Modeling System Version 11.1 (SMS).

There are three storm sewer inlets to Wakefield Lake, including discharges from the subwatersheds PHAL-03a (northwest inlet), PHAL-03b (northeast inlet), and PHAL-03c (southeast inlet, also known as the "Larpenteur Avenue storm sewer", see Figure 3-4). However, during the development of the Wakefield Lake Strategic Lake Management Plan (Barr 2008), it was suspected that much of the runoff coming from the area drained by the Larpenteur Avenue storm sewer (including subwatersheds PHAL 03c and upstream PHAL 01, PHAL 02a and PHAL 02b) may not significantly influence the observed water quality of Wakefield Lake. Because the flows from Larpenteur Avenue enter on the southeast end of the lake directly across from the lake's outlet on the southwest corner of the lake, it was suspected that flow may be effectively bypassing the lake (short-circuiting). Water quality in the southern part of the lake has not historically been monitored (historic monitoring location is in the center of the lake, see Appendix D), so the impact of PHAL-03c flows on Wakefield Lake's water quality in the southern end of the lake are unknown. However, if short-circuiting occurs, it must be accounted for as part of the in-lake modeling to appropriately quantify the watershed phosphorus loads to Wakefield Lake that influence the water quality (as observed) and to deduce the lake's internal phosphorus loads (see Section 4.3.1.7 for additional discussion of the in-lake mass balance modeling). In order to better understand the mixing dynamics of Wakefield Lake and to estimate the contribution of the runoff from the Larpenteur Avenue storm sewer to the observed water quality in the main body of the lake, a 2-dimensional (2D) hydraulic model of inflows and mixing patterns in Wakefield Lake was developed. For further details on 2D modeling of Wakefield Lake, refer to Appendix D.

As a result of this hydrodynamic analysis, it is likely that the watershed inflows to Wakefield Lake do not fully-mix within the lake and that the majority of the phosphorus load from the watershed along Larpenteur Avenue does not directly influence the observed water quality. Flows from the southeast portion of the watershed primarily influence the water quality in Wakefield Lake, due to diffusion of the soluble fraction of phosphorus from the southern portion of the lake to the main basin of the lake (where the historic water quality data has been collected) during storm events and after an event (for any runoff remaining in the lake). The degree of flow-induced mixing during any given runoff event will be variable; however the primary mechanism governing the influence of the Larpenteur Avenue storm sewer runoff on the observed lake water quality in Wakefield Lake is diffusion. Based on the scenarios run in AdH, the predicted P8 watershed phosphorus loads used in the in-lake mass balance modeling were reduced to reflect the "effective" watershed load from the Larpenteur Avenue storm sewer. We assumed that only 30% of the soluble phosphorus load from the runoff coming through the Larpenteur Avenue storm sewer (southeast inlet) to Wakefield Lake actually influences the observed water quality. Because the P8 model tracks the movement of five different particle sizes (with a certain amount of phosphorus associated with each particle size fraction), we were able to estimate the amount of soluble phosphorus coming from the Larpenteur Avenue Watershed, and reduce the effect of the particulate loading from the Larpenteur Avenue storm sewer used in the in-lake mass balance model, to represent the main body of Wakefield Lake.

4.3.1.6 In-Lake Mass Balance Model

In-lake modeling for Bennett and Wakefield Lake was accomplished through the creation of mass balance models that track flow of water and phosphorus through each lake for the critical water quality growing season as well as the previous year. The mass balance models, referred to throughout as in-lake models, consider influent water and phosphorus loads (as discussed in the sections above) for a 17-month period.

The estimated water and phosphorus loads of the year prior to the critical year (12 months from May through end of April of the following year) were used to establish the steady-state phosphorus concentration in each lake at the beginning of the water quality calibration period, using published empirical models, which predict lake phosphorus concentrations. The influent water and phosphorus loads from the remaining five months were then used in the in-lake mass balance model to evaluate the period of May 1 through September 30 of the critical year. Modeling results from June 1 through September 30 of the critical year were used to estimate the growing season average water and phosphorus loading.

The key input parameters for the in-lake mass balance model include direct precipitation data, evaporation data, runoff loads from the lake's watershed (as predicted by the P8 model), the lake storage and outlet rating curve, and in-lake water quality monitoring data. Additional data, including sediment core data and macrophyte survey information, were used to verify that model estimates of internal phosphorus loading were reasonable.

Prior to conducting the phosphorus mass balance modeling for each lake, a daily water balance model was calibrated to observed historical lake level data in Bennett and Wakefield Lake. The daily water balance model developed for each lake was used in conjunction with lake level data to calibrate P8-predicted watershed loading to provide the best fit between the predicted and observed water levels.

Once the water balance was calibrated, the phosphorus mass balance modeling was performed in two phases. The first step was to predict the steady-state phosphorus concentration in the lake at the beginning of the calibration period. As previously mentioned, the P8 model was used to not only estimate the watershed loads for the critical water quality year/calibration period (e.g., May 1 through September 30 of the critical year), but also for the year prior. These annual loads for the year prior to the calibration period were used to estimate the steady-state concentration at the beginning of the calibration period. Several published empirical models were evaluated for Bennett and Wakefield Lake, and the model that provided the best fit to the observed early season phosphorus data was selected. By selecting the empirical model that provides the best fit, the in-lake water quality model can be used to predict the impact of changes in water and phosphorus loads to the lake on the steady-state spring phosphorus concentrations in the lake and through the subsequent growing season.

The following empirical relationships were used to estimate the steady state phosphorus concentration in Bennett Lake and Wakefield Lake. Note that different empirical relationships were used to define the phosphorus retention coefficient between Bennett and Wakefield Lake.

Empirical Model (Dillon and Rigler, 1974):

$$P = L(1 - Rp)/(z * p)$$

Where:

L = Areal loading rate ($mg/m^2/yr$)

z = Mean depth (m)

p = Flushing rate (1/yr)

Rp = Phosphorus Retention Coefficient

Bennett Retention Coefficient (Larsen and Mercier, 1976):

$$Rp = 1/(1 + p^{\frac{1}{2}})$$

Wakefield Retention Coefficient (Chapra, 1975):

$$Rp = 16/(16 + q_s)$$

Where:

q_s = Overflow Rate (m/yr)

The second step to the calibration of the phosphorus mass balance model was to predict the observed TP concentrations in each lake during the respective calibration periods (May through September) for the critical water quality conditions. Calibration was performed at intervals coinciding with the water quality monitoring dates for each lake. Calibrating to these intervals allows for internal loading to be evaluated at multiple points throughout the growing season.

Phosphorus loads from the watershed predicted in P8 were combined with estimated phosphorus loading from atmospheric deposition and curly-leaf pondweed dieback and compared to estimated phosphorus losses due to flushing and uptake by coontail. To calibrate the in-lake models, phosphorus loads and losses were compared to the observed in-lake water quality data on each water quality sampling date. The magnitude of the internal phosphorus load to each lake's surface water was deduced by comparing the observed water quality in each lake to the water quality predicted by the in-lake models using the following general mass-balance equation for each time step:

P Adjustment = Observed P + Settling P + Coontail Uptake P + Groundwater Loss P – Runoff P – Atmospheric P – Curly-leaf P –Groundwater Inflow P - P Initial

The key calibration parameter for both of the in-lake models was this estimation of the internal phosphorus loading rate. As previously discussed, this internal loading rate was verified against available sediment and macrophyte data. Table 4-10 summarizes the results of the in-lake water quality model calibration for Bennett Lake and Wakefield Lake during the spring steady state condition and during the growing season.

Table 4-10 In-Lake Water Quality Model Calibration

Waterbody	Critical Year	Water Quality Monitoring Data		Calibration Conditions	
		Observed Spring TP (µg/L)	Observed Growing Season Average TP	Model-Predicted Spring TP	Model-Predicted Growing Season Average TP
Bennett Lake	2005	73[1]	210	71[3]	210
Wakefield Lake	2004	66[2]	154	67[4]	154

[1] Observed spring steady-state phosphorus concentrations based on earliest sampling date collected from Bennett Lake in May of each respective year. Earliest observed concentrations were taken as the average TP concentration from 0 to 2 meters depth on 5/4/2005, 5/3/2006, and 5/6/2008, respectively.

[2] Observed spring steady-state phosphorus concentrations based on earliest sampling date collected from Wakefield Lake in May of each respective year. Earliest observed concentrations were taken as the average TP concentration from 0 to 2 meters depth on 5/12/2004, 5/16/2006, and 5/21/2008, respectively.

[3] Predicted spring steady-state phosphorus based on the empirical equation Dillon and Rigler (1974) with Larsen and Mercier (1976) phosphorus retention coefficient.

[4] Predicted spring steady-state phosphorus based on the empirical equation Dillon and Rigler (1974) with Chapra (1975) phosphorus retention coefficient.

The growing season TP loads for the calibrated Bennett Lake and Wakefield Lake in-lake mass balance models are summarized in Figure 4-7 and Figure 4-8. Appendix A includes details of the in-lake mass balance model methodology, and Appendix B and Appendix C include tables summarizing the mass balance for critical year modeling of Bennett and Wakefield Lake used to establish each lake's nutrient TMDL.

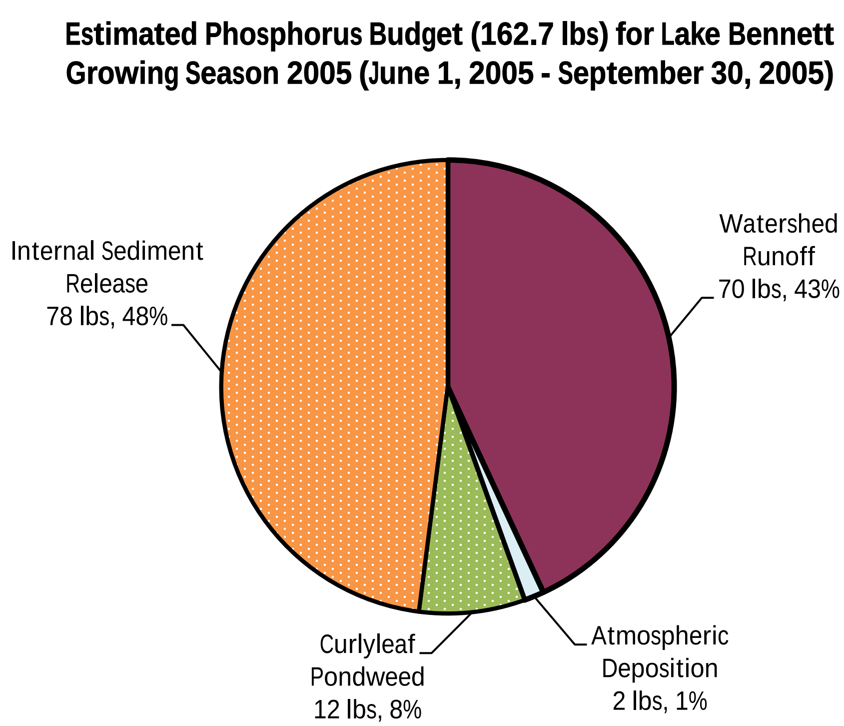

Figure 4-7 Bennett Lake 2005 growing season total phosphorus budget

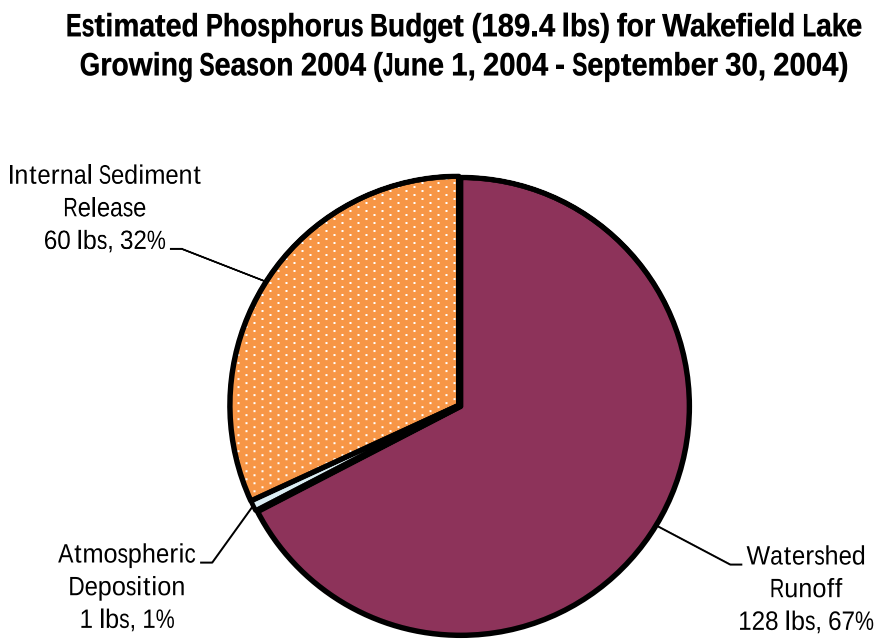

Figure 4-8 Wakefield Lake 2004 growing season total phosphorus budget

4.3.1.7 Load Capacity Summary

The existing conditions in-lake mass balance models were used to estimate the TP load to Bennett Lake and Wakefield Lake that would achieve the MPCA's shallow lake eutrophication TP standard (≤ 60 µg/L). The maximum allowable load is referred to as the lake's loading capacity. The estimated phosphorus load reduction (both internal and external) that would be required to achieve the MPCA shallow lake eutrophication TP standard for the critical year are defined for Bennett Lake and Wakefield Lake below in Table 4-11.

Table 4-11 Growing season load capacity for Bennett Lake and Wakefield Lake

Waterbody	Critical Year	Watershed Runoff	Atmospheric Deposition	Internal Loading[1]	Curly-leaf Pondweed	Total
Existing Conditions Total Phosphorus Load (lbs)						
Bennett Lake	2005	70.1	2.3	78.1	12.3	162.8
Wakefield Lake	2004	127.7	1.4	60.4	--	189.5
Estimated Load Capacity Total Phosphorus Load (lbs)						
Bennett Lake	2005	27.4	2.3	15.6	2.5	47.8
Wakefield Lake	2004	106.7	1.4	12.1	--	120.2

1 Residual internal loading from all internal sources excluding P release from Curly-leaf Pondweed.

Estimated load capacity to Bennett and Wakefield Lake was determined reducing internal and external sources during critical year modeling to achieve the MPCA's shallow lake growing season eutrophication standard of 60 µg TP/L. The following assumptions were applied when evaluating phosphorus reductions to meet the MPCA water quality standards:

- The water loads and lake volumes would not change from existing conditions as a result of the phosphorus reductions.
- Atmospheric deposition was unchanged from existing conditions.
- Because the watersheds of both Bennett and Wakefield Lake are nearly fully developed, our approach was to begin with internal sources of phosphorus (e.g., Curly-leaf pondweed and sediment release). A 60% reduction in internal load was targeted for Wakefield Lake, and an 80% reduction in internal load was targeted for Bennett Lake). After applying these internal load reductions, the required reduction of the external load from each lake's watershed was calculated based on the required total reduction to meet the MPCA's water quality standard.

4.3.2 Load Allocation Methodology

This section describes the methodology used to assign LAs to non-permitted phosphorus sources in the Bennett Lake and Wakefield Lake TMDLs. Existing phosphorus loads from non-permitted sources to Bennett and Wakefield Lake include direct atmospheric deposition to the lake surface and internal loading. The phosphorus LA for direct deposition to the lake surface and groundwater inflows is the same as existing conditions. Internal loading of phosphorus is a large proportion of TP load to both lakes. Based on identified implementation options, attainable percent reductions were applied to the internal load of Bennett Lake and Wakefield Lake. The resulting LAs for direct atmospheric deposition and internal loading for both waterbodies are discussed in greater detail in Section 4.3.1.

4.3.3 Wasteload Allocation Methodology

4.3.3.1 Construction and Industrial Stormwater Permits

The WLAs for the construction and Industrial Stormwater Permits are based on estimates of the average annual percentage of the county area under a MPCA Construction Stormwater Permit, using the MPCA Construction Stormwater Permit data provided from 2007 through 2013 for Ramsey County. From 2007 through 2013, the estimated average annual area under the MPCA Construction Stormwater Permit was 0.62% of Ramsey County. We assumed that the same percentage for construction stormwater would apply for the MPCA Industrial Stormwater Permits, so the total percentage of the Bennett and Wakefield Lake watersheds assumed to be under the MPCA Construction or Industrial Stormwater Permits was 1.24%. The WLA assigned to construction and industrial stormwater permits was calculated by applying percent watershed area assumed to be under construction or Industrial Stormwater Permit (1.24%) to the estimated loading capacity estimated for external watershed sources.

Load reductions for construction stormwater activities are not specifically targeted in this TMDL. It should be noted that construction stormwater activities are consistent with provisions of this TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all stormwater BMPs required under the permit, including any applicable additional BMPs required in the Construction General Permit for discharges to impaired waters; or meet local construction stormwater requirements if they are more restrictive than requirements of the Construction General Permit. Industrial stormwater activities are considered consistent with provisions of the TMDL if they obtain an Industrial Stormwater General Permit or General Sand and Gravel General Permit (MNG49) under the NPDES program and properly select, install, and maintain all BMPs required under the permit.

4.3.3.2 Permitted MS4s

There are three MS4s located within the Bennett Lake watershed, and four within the Wakefield Lake Watershed. Table 4-12 summarizes the total MS4 area within each watershed.

Table 4-12 MS4 summary for Bennett Lake and Wakefield Lake

Waterbody	MS4 Name	MS4 ID Number	MS4 Area within the Contributing Watershed (acres)[1]
Bennett Lake	City of Roseville	MS400047	632
	Ramsey County	MS400191	45
	MnDOT Metro District	MS400170	55
Wakefield Lake	City of Maplewood	MS400032	664
	Ramsey County	MS400191	181
	City of St. Paul	MN0061263	47
	City of North St. Paul	MS400041	27

1 Open water area removed from total MS4 contributing watershed area (open water summary in Table 3-2).

Figure 4-9 and Figure 4-10 show the MS4s in the Bennett Lake and Wakefield Lake Watersheds, respectively. To determine the WLAs assigned to each individual MS4 in the Bennett Lake Subwatershed, the fraction of the watershed phosphorus wasteload for each MS4 was allocated proportional to the area of each MS4's contributing watershed. For example, the city of Roseville comprises 86% of the total land area in Bennett Lake, and receives 86% of the estimated load capacity for watershed sources of phosphorus.

The WLA calculation for MS4s in the Wakefield Lake Watershed was based on a similar methodology, but accounts for the fact that 2D modeling in AdH (see Section 4.3.1.5) showed that subwatersheds PHAL-03a, PHAL-03b, and PHAL-03c located in the southern portion of the watershed short-circuit, and only 30% of the soluble phosphorus load from these subwatersheds contributes to water quality in Wakefield Lake. To account for short-circuiting, the portion of the WLA assigned to subwatersheds PHAL-03a, PHAL-03b, and PHAL-03c was adjusted based on the effective loading of 30% of the total soluble phosphorus loads from these areas. The WLA allocation for all other subwatersheds was based on the total contributing area of each MS4 within each subwatershed.

4.3.3.3 NPDES Point Source Dischargers

There are no non-stormwater NPDES permitted point source surface dischargers identified within the Bennett Lake or Wakefield Lake Watersheds.

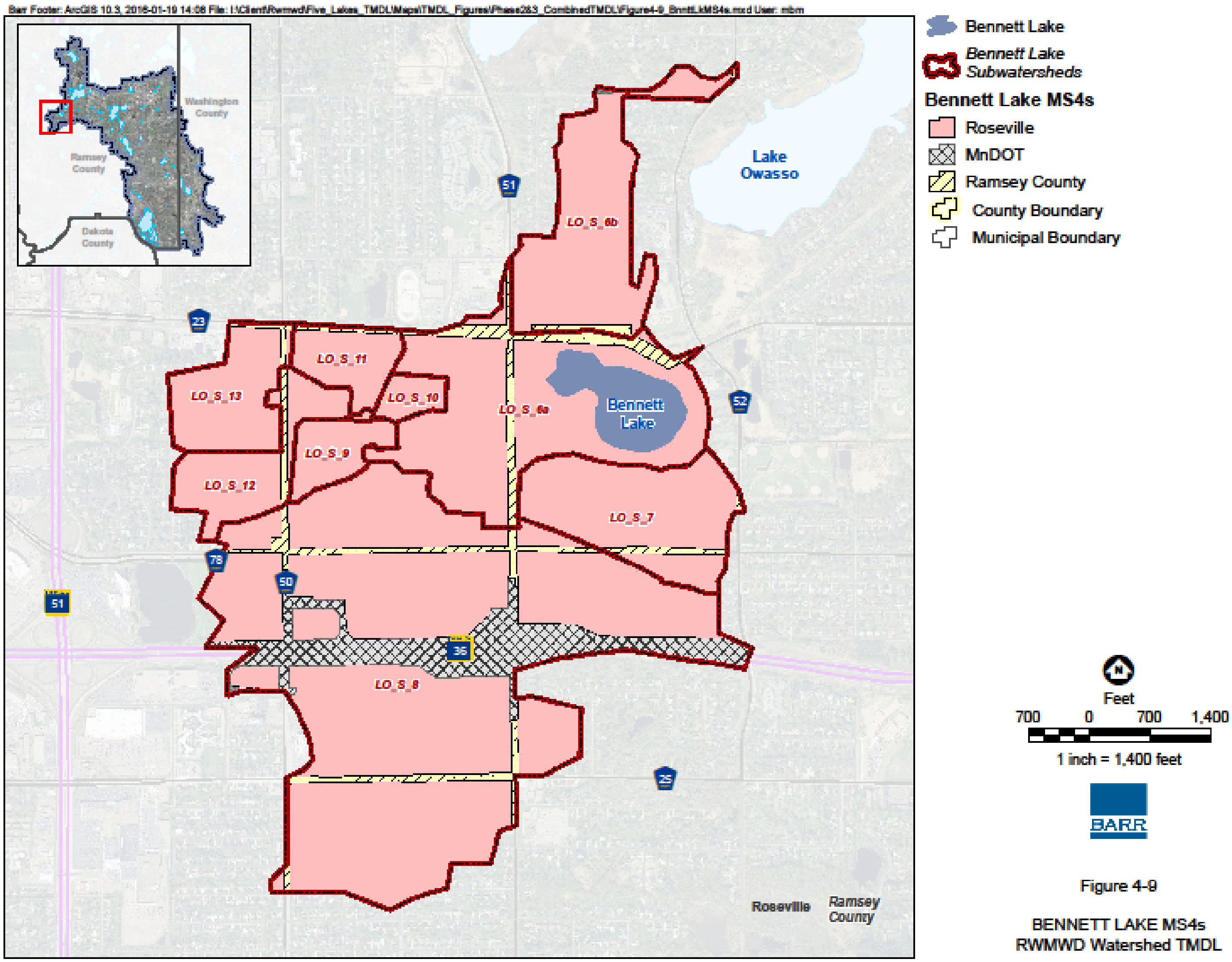

Figure 4-9 MS4s in Bennett Lake Watershed

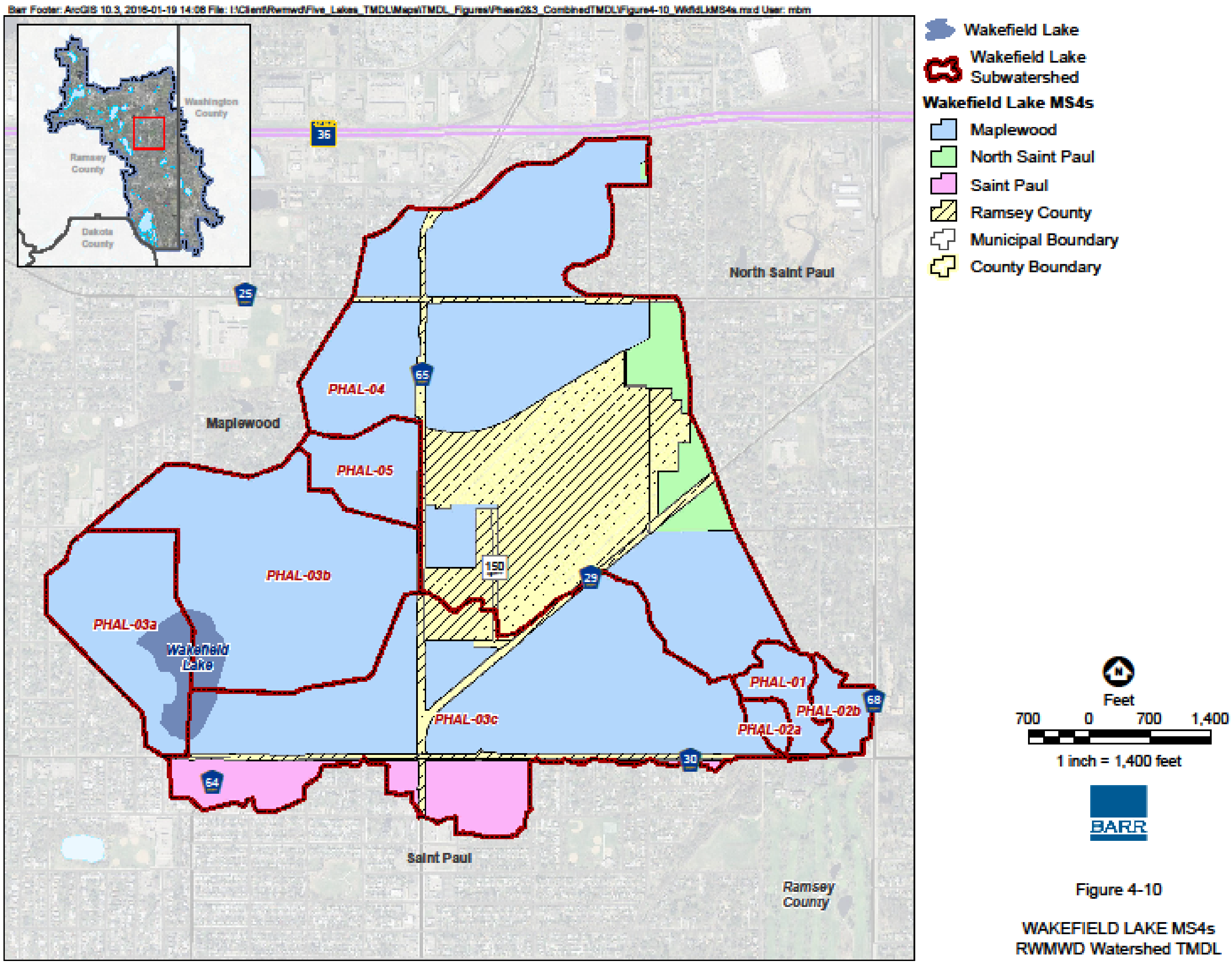

Figure 4-10 MS4s in Wakefield Lake Watershed

4.3.4 Margin of Safety

When modeling a natural system such as Bennett and Wakefield Lake, there can be some uncertainty associated with how the system will respond to changes in watershed loading. Therefore, a MOS is included to account for some of the unknowns associated with the behavior of the natural lake system.

For the Bennett and Wakefield TMDLs, an explicit 10% MOS was applied, whereby 10% of the total load capacity was subtracted before WLAs and LAs were calculated.

4.3.5 Seasonal Variation

The TP concentrations in Bennett Lake and Wakefield Lake vary during the growing season, typically peaking in late summer. The TMDL guideline for TP is defined as the growing season (June through September) mean concentration (MPCA 2014a). This critical period (growing season) was used to estimate the required reduction of watershed and internal sources of phosphorus so that the predicted growing season average would meet the MPCA lake standard (see additional discussion in Section 4.3.1.7) for the critical year.

Additionally, the WLAs and LAs for Bennett and Wakefield Lake were developed for the year that produced the worst water quality in each lake over the last 10 years of data analyzed (i.e., the critical year) rather than the average water quality condition over the last 10 years.

4.3.6 TMDL Summary

The phosphorus load and WLAs for Bennett Lake and Wakefield Lake are described in Table 4-13 and Table 4-14, respectively. The load and WLAs are described in terms of the pounds of phosphorus per growing season (lbs/growing season), as well as pounds of phosphorus per day (lbs/day). Phosphorus loading under existing conditions during the growing season of the critical year is outlined, as well as the phosphorus loading reduction required to achieve the MPCA lake eutrophication standard (TP < 60 µg/L). The WLAs presented in Table 4-13 and Table 4-14 are categorical, meaning that the total LAs to several permitted sources are grouped into a single WLA, with the exception of the MnDOT Metro District. The categorical WLA approach is pursued for these TMDLs, as the RWMWD is initially taking the lead role in implementing projects to achieve the WLA defined in the Bennett Lake and Wakefield Lake nutrient TMDLs.

Table 4-13 Bennett Lake TMDL Summary

Total Phosphorus Source	Existing Conditions (lbs/GS[2])	Existing Conditions (lbs/day)	TMDL Allocation (lbs/GS[2])	TMDL Allocation (lbs/day)	Required Load Reduction (lbs/GS[2])	Percent Reduction (%)
Wasteload Allocation (Permitted Sources)						
City of Roseville *MS400047*; Ramsey County *MS400191*	60.0	0.4915	20.1	0.1650	39.8	66%
NPDES-Permitted Construction and Industrial Stormwater	0.9	0.0071	0.9	0.0071	0	0%
MnDOT Metro District *MS400170*	9.2	0.0758	1.6	0.0133	7.6	82%
Total Wasteload Sources	70.1	0.5744	22.6	0.1854	47.4	67.7%
Load Allocations (Non-Permitted Sources)						
Atmospheric Deposition	2.3	0.0191	2.3	0.0191	0	0%
Internal Sources[3]	90.3	0.7405	18.1	0.1481	72.3	80%
Total Load Sources	92.7	0.7596	20.4	0.1672	72.3	78%
Margin of Safety[1]			4.8	0.0392		
Total	162.7	1.3339	47.8	0.3918	119.7	74%

1 Margin of safety implicitly included in modeling assumptions (see Section 4.3.4).

2 GS = Growing Season of 2005 (June 1 through September 30).

3 Reflects the sum of all internal sources of phosphorus (e.g., Curly-leaf Pondweed, sediment release, sediment resuspension due to wind and carp activity, etc.).

Table 4-14 Wakefield Lake TMDL Summary

Total Phosphorus Source	Existing Conditions (lbs/GS[2])	Existing Conditions (lbs/day)	TMDL Allocation (lbs/GS[2])	TMDL Allocation (lbs/day)	Required Load Reduction (lbs/GS[2])	Percent Reduction (%)
Wasteload Allocation (Permitted Sources)						
City of Maplewood *MS400047* City of St. Paul *MN0061263* City of North St. Paul *MS400041* Ramsey County *MS400191*	126.1	1.0335	93.1	0.7629	33.0	26%
NPDES-Permitted Construction and Industrial Stormwater	1.6	0.0130	1.6	0.0130	0.0	0%
Total Wasteload Sources	127.7	1.0465	94.7	0.7759	33.0	26%
Load Allocations (Non-Permitted Sources)						
Atmospheric Deposition	1.4	0.0115	1.4	0.0115	0	0%
Internal Sources[3]	60.4	0.4947	12.1	0.0989	48.3	80%
Total Load Sources	61.8	0.5062	13.5	0.1104	48.3	78%
Margin of Safety[1]			12.0	0.0985		
Total	189.4	1.5527	120.2	0.9848	81.3	43%

1 Margin of safety implicitly included in modeling assumptions (see Section 4.3.4).

2 GS = Growing Season of 2004 (June 1 through September 30).

3 Reflects the sum of all internal sources of phosphorus (e.g., Curly-leaf Pondweed, sediment release, sediment resuspension due to wind, etc.).

4.4 Future Growth Consideration / Reserve Capacity

For all TMDLs in the RWMWD, the following applies to determining the impact of future growth on allocations.

4.4.1 New or Expanding Permitted MS4 LA Transfer Process

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

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES Permit. In this situation, a transfer must occur from the LA.

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

4.4.2 New or Expanding Wastewater

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

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

5 Reasonable Assurances

Reasonable assurance activities are programs that are in place to assist in attaining the TMDL allocations and applicable water quality standards. The reasonable assurance evaluation provides documentation that the TMDLs WLAs and LAs are properly calibrated and the TMDL loads will ultimately meet the applicable water quality targets. Without such calibration, a TMDLs ability to serve as an effective guidepost of water quality improvement is significantly diminished. The development of reasonable assurance includes both state and local regulatory oversight, funding, implementation strategies, follow-up monitoring, progress tracking and adaptive management. (Note: Some of these elements are described in Sections 6 and 7). The following sections outline programs and policies that will provide reasonable insurance that TMDL objectives will be met.

5.1 Municipal Separate Storm Sewer System (MS4) Permits

The MPCA is responsible for applying federal and state regulations to protect and enhance water quality within the RWMWD. The MPCA oversees all regulated MS4 entities in stormwater management accounting activities. All regulated MS4s in the RWMWD fall under the Stormwater Phase I or Phase II category. The MS4 NPDES/SDS Permits require regulated municipalities to implement BMPs to reduce pollutants in stormwater runoff to the Maximum Extent Practicable.

All owners or operators of regulated MS4s (also referred to as "permittees") are required to satisfy the requirements of the MS4 General Permit. The MS4 General Permit requires each permittee to develop a Stormwater Pollution Prevention Plan (SWPPP) that addresses all permit requirements, including the following six minimum control measures:

- Public education and outreach
- Public participation
- Illicit Discharge Detection and Elimination Program
- Construction-site runoff controls;
- Post-construction runoff controls; and
- Pollution prevention and municipal good housekeeping measures

A SWPPP is a management plan that describes the MS4 permittee's activities for managing stormwater within their jurisdiction or regulated area. In the event a TMDL study has been completed, approved by EPA prior to the effective date of the general permit, and assigns a WLA to an MS4 permittee, that permittee must document the WLA in their application and provide an outline of the BMPs to be implemented in the current permit term to address any needed reduction in loading from the MS4.

The MPCA requires applicants submit their application materials and SWPPP document to the MPCA for review. Prior to extension of coverage under the general permit, all application materials are placed on 30-day public notice by the MPCA, to ensure adequate opportunity for the public to comment on each permittee's stormwater management program. Upon extension of coverage by the MPCA, the permittees are to implement the activities described within their SWPPP, and submit annual reports to the MPCA by June 30 of each year. These reports document the implementation activities, which have been completed within the previous year, analyze implementation activities already installed, and outline any changes within the SWPPP from the previous year.

In the Wakefield Lake, Bennett Lake and Battle Creek Subwatersheds, the District will initially take the lead role in implementing projects to achieve the categorical WLA defined in this TMDL. However, cities and other MS4s in these watersheds are expected to fulfill their existing responsibilities in storm water management to help meet the goals of these TMDLs. Specifically, cities and other MS4s in the Wakefield Lake, Bennett Lake, and Battle Creek Subwatersheds will:

- Continue to implement volume reduction BMPs on all City projects to comply with District rules.
- Look for opportunities to implement voluntary projects to reduce runoff wherever possible, taking advantage of the District's cost-share program for water quality improvements.
- Continue to implement their SWPPPs and to improve their public works maintenance practices wherever possible. This work is facilitated through the District Public Works Forum and District sponsored and cosponsored training and education programs.

The District will keep record of District projects implemented in these subwatersheds and will assist the MS4s in their TMDL reporting to the MPCA. After the first 10 years, an analysis of the program will be conducted to determine if the implemented projects are achieving the required reductions in phosphorus to Wakefield Lake and Bennett Lake, and in TSSs to Battle Creek. If the goals laid out in this report are not reached within the required time frame, the District will meet with city and county governmental units to determine future direction and if additional participation by these groups is needed.

In the Fish Creek Subwatershed, it is expected that the MS4s will take the lead role in implementing projects to achieve the categorical WLA defined in this TMDL. However, the District plans to assist in these activities by documenting progress toward reaching the *E. coli* WLA, and supporting the MS4s' efforts through educational assistance and creek monitoring, where needed.

This TMDL assigns TSS, TP, and *E. coli* WLAs to all regulated MS4s in the study and as previously discussed in Section 4. Regulated MS4s are required to develop compliance schedules for EPA approved TMDL WLAs not already being met at the time of permit application. A compliance schedule includes BMPs that will be implemented over the permit term, a timeline for their implementation, and a long term strategy for continuing progress towards assigned WLAs. For WLAs being met at the time of permit application, the same level of treatment must be maintained in the future. Regardless of WLA attainment, all permitted MS4s are still required to reduce pollutant loadings to the Maximum Extent Practicable.

The MPCA's stormwater program and its NPDES Permit program are regulatory activities providing reasonable assurance that implementation activities are initiated, maintained, and consistent with WLAs assigned in this study.

5.2 Regulated Construction Stormwater

Construction and industrial stormwater discharges in this TMDL study were included in the categorical WLAs for stormwater discharges. All construction activities disturbing one acre or more are required to obtain a Construction General Permit through the MPCA. Conditions in the Construction General Permit assure that stormwater discharged from the construction site will comply with TMDL standards. It is assumed that construction sites will comply with conditions outlined in the State General Permit or with local construction stormwater requirements when those requirements are more restrictive.

5.3 Regulated Industrial Stormwater

As stated in Section 5.2, WLAs for industrial stormwater were included in the categorical WLA developed for each TMDL. All industrial stormwater dischargers are required to obtain permit coverage under the State's NPDES/SDS Industrial Stormwater Multi- Sector General Permit (MNR050000), or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). Compliance with permit standards assures that stormwater discharge will also be consistent with WLAs established in this study.

5.4 RWMWD Comprehensive Management Plan

The RWMWD was established in 1975 under the Minnesota Watershed District Act to effect the protection and provident use of the District's water resources. The RWMWD adopted its first rules and regulations in 1976 and the first overall plan was adopted in 1977. Over the past 40 years, there have been several versions of the WMP. The most current version of the plan was adopted in 2007: RWMWD WMP (2017 through 2026) (Barr 2017).

The 2007 WMP outlines a partnership between the RWMWD and local government units (LGUs), which include all cities and townships, within the boundary of the District. The RWMWD's main role in partnering with LGUs has been establishing a consistent regulatory framework throughout the RWMWD and through implementation efforts from the RWMWD's WMP or local water resource management plans.

Prior to the development of this TMDL, the RWMWD has pursued water quality improvement projects within the TMDL study area boundaries. These efforts include various watershed studies, establishment of consistent and protective regulations, and targeted load reduction strategies. Additionally, in 2006 the District adopted volume reduction rules for all development and redevelopment within the watershed. The RWMWD plans to continue these types of efforts, and use this TMDL study to help strengthen targeted load reduction efforts throughout the RWMWD, including the reduction of internal phosphorus loads to impaired lakes.

With the completion of the TMDLs, the RWMWD will serve to coordinate implementation efforts among LGUs and help ensure progress toward the TMDL targets. Adaptations will be made by the RWMWD and LGUs to ensure implementation efforts are having the desired effect on water resources. The RWMWD will take the lead role in tracking attainment of water quality standards will be a role primarily held by the RWMWD. Reductions for the non-regulated (LA) portions of the TMDLs will also be needed. These loads include non-MS4 runoff, which includes some agricultural land as well as shoreline and streambank erosion, and internal loading. The RWMWD, with assistance and cooperation from LGUs and other groups, will take the lead on efforts to reduce loading from these non-regulated sources.

5.5 Funding

Funding for water resource projects throughout the RWMWD generally comes from a combination of the following sources: general tax revenue (generated from a property tax levy); grant funds; and local cost-share funding. Historically, approximately 95% of the RWMWD's funds for implementing capital projects, programs, and other operations are raised through the property tax levy. The RWMWD utilizes this funding base to sponsor cost-share and grant programs to assist municipal partners with local water quality improvement projects.

There are other funding mechanisms that the RWMWD and LGUs may apply for in the state of Minnesota. Some of these sources include grants under the state Clean Water Fund (CWF) and loan funding through the state Clean Water Partnership program. The RWMWD will also explore the funding mechanisms provided through the federal Clean Water Act Section 319 grant program, which provides cost share dollars to implement voluntary activities in the watershed to address nonpoint source pollution.

The Clean Water, Land, and Legacy amendment was passed by Minnesota voters in 2008 for the purposes of protecting, restoring, and preserving Minnesota water and providing significant funding to do so. The Clean Water Legacy Act (CWLA) of 2006 discusses how the MPCA and the involved public agencies and private entities will coordinate water quality efforts regarding land use, land management, water management, etc. Cooperation is also expected between agencies and other entities regarding planning efforts, and various local authorities and responsibilities. This would also include informal and formal agreements to jointly use technical, educational, and financial resources.

The CWLA also provides details on the overall TMDL process and follow-up implementation strategy development, and how the funding will be used. The Minnesota Board of Soil and Water Resources administers most of the portion of the CWF for restoration and protection grants, and has developed a detailed grants policy explaining what is required to be eligible to receive CWF money (FY15 Clean Water Fund Competitive Grants Policy; Minnesota Board of Soil and Water Resources 2014).

The various programs and sponsoring agencies related to clean water funding and others are:

- Agriculture BMP Loan Program (MDA)
- Clean Water Fund Grants (BWSR)
- Clean Water Partnership (MPCA)
- Environment and Natural Resources Trust Fund (Legislative-Citizen Commission on Minnesota Resources)
- Environmental Assistance Grants Program (MPCA)
- Phosphorus Reduction Grant Program (Minnesota Public Facilities Authority)
- Section 319 Grant Program (MPCA)
- Small Community Wastewater Treatment Construction Loans & Grants (Minnesota Public Facilities Authority)
- Source Water Protection Grant Program (Minnesota Department of Health)
- Surface Water Assessment Grants (MPCA)
- TMDL Grant Program (Minnesota Public Facilities Authority)
- Wastewater and storm water financial assistance (MPCA)

- Minnesota Agricultural Water Quality Certification Program (MAWQCP)

5.6 Schedule and Tracking

After the approval of this TMDL report by the EPA, the RWMWD will work with LGUs to develop a general timeline and strategy for implementation activities to be conducted within each permit cycle and/or plan cycle. It is likely that interim goals will be established within many LGUs, as immediate changes within the watershed to fully address any one or more impairment is unlikely. The RWMWD adopted an updated Watershed Plan in March of 2017. Within the plan, the long-term goal of removal of waters from the impaired waters list may be projected out beyond the 10-year life of the plan. Five and 10-year goals will likely be established within the implementation plan as reasonable benchmarks to achieve towards water quality standard attainment. Progress toward the TMDL targets will be assessed as part of the implementation of the updated Watershed Plan. Future Watershed Plan revisions and updates will also look at establishing new targets to attain water quality standards, if they have not yet been met. Progress will also be assessed through the reporting requirements of the MPCA's stormwater program and NPDES Permit requirements.

6 Monitoring Plan

The RWMWD measures lake water quality, monitors biology (macrophytes, macroinvertebrates, and sometimes zooplankton and phytoplankton), lake levels, stream water quality, stream flow, and weather conditions at multiple locations throughout the entire RWMWD, and has collected a large amount of water quality data over its history. In addition, other agencies have collected data for RWMWD waterbodies, including the MPCA, Metropolitan Council, and others. The amount of data currently available varies by waterbody.

Continued water quality data collection is necessary for the RWMWD to track water quality improvement or degradation, detect trends, better understand water quality processes, and ultimately determine if there are water quality problems (e.g., impaired uses). This information is critical for RWMWD to identify and prioritize water quality improvement projects, and to determine appropriate methods for preventing water quality degradation. Detection of trends, specifically improvements, is critical to determining the effectiveness of actions implemented by the RWMWD.

The RWMWD will continue to monitor the Battle Creek, Fish Creek, and Bennett Lake and Wakefield Lake Watersheds. The following sections outline specific monitoring goals for each TMDL study area.

6.1 Battle Creek Monitoring Plan

TSS data has historically been collected at the downstream WOMP station, owned and operated by the Metropolitan Council. To assess water quality trends as well as the impacts of implementation options identified in Section 7.3.1, it is important that continuous monitoring of water quality be maintained at the WOMP station. The RWMWD plans to continue to collect water chemistry and flow data from continuous monitoring at this station. Additionally, the RWMWD plans to perform a detailed sediment study to more accurately identify sources of sediment to the stream (Section 7.3.1).

Due to the biological impairment addressed in this study, continued monitoring of the fish and macroinvertebrate assemblage within Battle Creek will be required to track impairment as TMDLs and associated activities are implemented. Historically, fish and macroinvertebrate populations in Battle Creek have been assessed by several agencies, including the RWMWD, the United States Geological Survey (USGS), DNR, and the MPCA. More recent surveys (2004, 2010, and 2012) were performed by the MPCA. The MPCA is required to asses 10% of waters in the state annually, resulting in 100% coverage over a 10-year period. For this reason, it is anticipated that biological monitoring of Battle Creek will be performed every 10 years.

6.2 Fish Creek Monitoring Plan

For the purposes of this TMDL, the most important data is that from the downstream monitoring station on Fish Creek (Figure 3-7). The RWMWD plans to continue to collect water chemistry, *E. coli* and flow data through a continuous water monitoring station, in cooperation with other entities and will report the results of its stream monitoring. The continued collection of flow and monthly *E. coli* data will be essential to track water quality trends, assess progress towards implementation goals, and make adaptive management decisions.

6.3 Bennett Lake and Wakefield Lake Monitoring Plan

The RWMWD plans to continue the regular collection of water quality and macrophyte data for Bennett Lake and Wakefield Lake. Water quality measurements include Secchi disc transparency depth, TP, chlorophyll-*a* (Chl-*a*), and other lake eutrophication parameters at the lake surface. Several measurements will likely be collected each year over the course of the growing season, as well as in the spring. When degrading water quality trends are identified, the RWMWD may collect more detailed water quality data, including evaluation of phosphorus concentrations, DO, specific conductance, turbidity, and pH data at depth, which can be used to help assess the problems.

According to the RWMWD WMP, the RWMWD water quality monitoring program tracks water quality and quantity in lakes within the watershed, including Wakefield Lake and Bennett Lake, on an annual basis. The annual monitoring program includes in-lake monitoring in collaboration with the Ramsey County Environmental Services Office. In this partnership, Ramsey County collects samples and RWMWD sends the samples to local laboratories for analysis and reports the results. The RWMWD plans to continue District-wide monitoring efforts into the future.

7 Implementation Strategy Summary

7.1 Implementation Framework

This section provides implementation strategies designed to help meet the required pollutant load reductions that are required as a result of this TMDL study. These strategies are potential actions that will help reduce nutrient, bacteria, and TSS loading in the RWMWD Watershed and are incorporated into the separate RWMWD Watershed Restoration and Protection Strategies (WRAPS) Report.

7.1.1 Adaptive Management

The proposed implementation strategies will typically follow the adaptive management approach (Figure 7-1). Proposed projects will be implemented in a phased manner, selecting specific projects for construction/implementation followed by a period of monitoring to evaluate the impact of the projects on the water quality of the impaired resources. Depending on the resulting water quality, additional projects may be evaluated and selected for implementation, or it may be determined that the water quality meets the MPCA standards and the management approach may change from improvement to anti-degradation/protection.

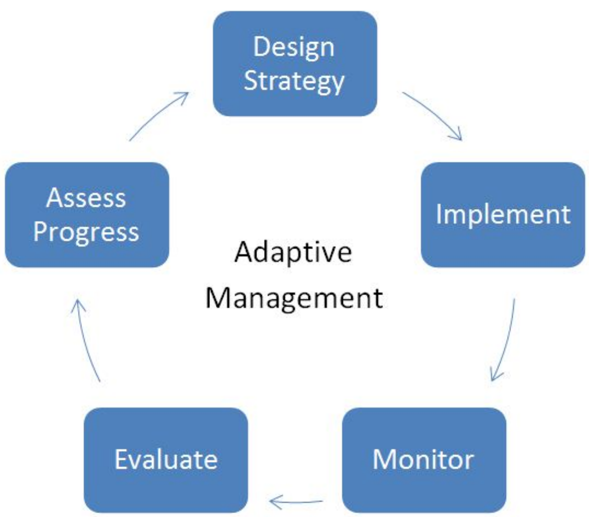

Figure 7-1 Adaptive Management

7.2 Permitted Sources

7.2.1 MS4s

The NPDES Permit requirements must be consistent with the assumptions and requirements of an approved TMDL and associated WLAs. For the purposes of this TMDL, the baseline year for implementation will be the critical year for the lake nutrient TMDLs and the mid-range year of the data years used for the development of the TSS and bacteria load duration curves (Table 7-1).

The rationale for establishing a baseline year is that projects undertaken recently may take a few years to influence water quality. Any point source load-reducing BMP implemented since the baseline year will be eligible to "count" toward a MS4's load reductions. If a BMP was implemented during or just prior to the baseline year, the MPCA is open to presentation of evidence by the MS4 Permit holder to demonstrate that it should be considered as a credit.

Table 7-1 Implementation Baseline Years

Water body	ID	Baseline Year
Battle Creek	07010206-592	2007
Fish Creek	07010206-606	2011
Bennett Lake	62-0048-00	2005
Wakefield Lake	62-0011-00	2004

7.2.2 Construction Stormwater

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

7.2.3 Industrial Stormwater

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

7.3 Strategies and Costs

7.3.1 Total Suspended Solids (TSS)

Potential BMPs and other implementation strategies developed to reduce TSS loading to Battle Creek are presented in Table 7-2. These potential BMPs are explored more thoroughly in the WRAPS report, using results of the sediment study to prioritize implementation strategies. Table 7-2 also shows typical cost ranges for each practice, and an estimated overall cost refined in the WRAPS report. The RWMWD and the individual MS4s within each watershed have already undertaken projects similar to those outlined in Table 7-2 since the baseline year, and will continue to implement BMPs in order to attain water quality goals outlined in this TMDL.

Table 7-2 Potential TSS reduction strategies

Reduction Target	Potential BMP/Reduction Strategy	Total Estimated Associated Cost
N/A	**Sediment Study –** sediment chemical composition study and/or particle scale analysis to help identify sources of sediment to Battle Creek.	$30,000
Permitted	**Education Programs** – Provide educational and outreach opportunities about responsible land management practices and other BMPs to encourage good individual property management practices to reduce soil loss and upland erosion.	$2,000 - $10,000
	Retrofit BMPs – A variety of BMPs may be implemented throughout the watershed. New and improved technologies will be evaluated and implemented if determined to be practicable. Examples of retrofit BMPs considered include: - Incorporation on infiltration BMPs throughout watershed, including water quality projects which take advantage of RWMWD's cost-share program. - Retrofit commercial, school, and church properties with green infrastructure practices. - Partnering with Ramsey County Parks and Recreation to retrofit stormwater management features on park properties tributary to Battle Creek. Continue enforcement of the District's Permit Program (including the volume reduction rule) in redeveloping areas.	$3,000,000 - $8,000,000
Non-Permitted	**Streambank Stabilization** – Repair and stabilize actively eroding sections of bank along the stream channel. Extend stabilization practices through stream corridor when necessary.	$50,000 - $200,000
	Dredging – dredge accumulated sediment from McKnight Basin as well as portions of the stream where sediment has accumulated.	$200,000 - $300,000

7.3.2 Bacteria (*E. coli)*

Table 7-3 lists BMPs and implementation strategies for reducing bacteria loading to Fish Creek. Due to the nature of *E. coli* loading, there are few structural BMPs, which can remove or treat bacteria within the watershed. For this reason, many of the BMPs listed in Table 7-3 are procedural. These potential BMPs are explored more thoroughly, including targeting the most appropriate BMPs by location, in the accompanying WRAPS report.

Table 7-3 Potential bacteria reduction strategies

Reduction Target	Potential BMP/Reduction Strategy	Total Estimated Associated Cost
Permitted	**Education Programs** – Provide education and outreach on proper fertilizer use and proper pet waste management.	$2,000 - $10,000
	Pet Waste Management – Review member cities' local ordinances and associated enforcement for residents who do not practice proper pet waste management.	$5,000 - $15,000
Non-Permitted	**Septic System Inspection Program Review –** Review ordinances pertaining to inspection and maintenance of septic systems in the watershed. This could include a survey to homeowners inquiring about SSTS maintenance.	$25,000 - $30,000
	Streambank Buffer Enhancement – Stabilize native vegetation to filter runoff from land adjacent to the stream. A recommended goal is buffer enhancement on 25%-50% of each impaired reach. Enhancements should include at least 50 feet of buffer on both sides of the stream.	$300,000 - $1,500,000
	Sanitary Sewer Inspection – Inspect sanitary sewer within Fish Creek Subwatershed. Identify damaged sections where exfiltration is possible.	$40,000 – $80,000
	Sanitary Sewer Repair- Repair damaged sections to prevent exfiltration.	$10,000 - $100,000

7.3.3 Nutrients

Table 7-4 lists BMPs for reducing nutrient loads and managing lake water quality in Bennett Lake and Wakefield Lake. These potential BMPs are explored more thoroughly, including targeting the most appropriate BMPs for each water body, in the accompanying WRAPS report. Table 7-4 also shows typical cost ranges for each practice that are further refined in the WRAPS report, as well as feasibility studies and design planning. The RWMWD and the individual MS4s within each watershed have already undertaken projects similar to those outlined in Table 7-4 since the baseline year, and will continue to implement BMPs in order to attain water quality goals outlined in this TMDL.

Table 7-4 Potential nutrient reduction strategies

Reduction Target	Potential BMP/Reduction Strategy	Total Estimated Associated Cost
Permitted	**Education Programs** – Provide education and outreach on proper fertilizer use, low-impact lawn care practices, installation of native shoreline buffers, etc.	$2,000 - $10,000/lake $4,000 - $20,000 total cost
	Street Sweeping Program Review/Implementation – Identify target areas for increased frequency of street sweeping and consider upgrades to traditional street sweeping equipment.	$100,000 - $200,000/lake $200,000 - $400,000 total cost
	Retrofit BMPs – A variety of BMPs may be implemented in both watersheds. New and improved technologies will be evaluated and implemented if determined to be practicable. Examples of retrofit BMPs considered include: - Outlet modification (e.g., Iron-enhanced sand or spent lime filtration, etc.). - Incorporation of infiltration BMPs throughout watershed, including water quality projects which take advantage of RWMWD's Cost-Share program. - Partnering with cities to retrofit stormwater management features on park properties tributary to lakes. - Retrofit commercial, school, and church properties with green infrastructure practices. - Continue enforcement of the District's Permit Program (including the volume reduction rule) in redeveloping areas.	$1,500,000 - $2,500,000/lake $3,000,000 - $5,000,000 total cost
Non-Permitted	**Drawdown to Consolidate Sediments –** Draw water down in the winter to consolidate sediments, and to reduce regrowth of curly-leaf pondweed and carp populations.	$10,000-$20,000
	Dredging – Dredge accumulated sediment from ponds, existing wetlands, and/or tributary grit chambers.	$1,000,000 - $2,500,000/lake $2,000,000 - $5,000,000 total cost
	Shoreline Restoration – Encourage property owners to restore their shoreline with native plants and install/enhance shoreline buffers.	$50,000 to $250,000/lake $120,000 - $350,000 total cost
	In-Lake Phosphorus Treatment – Take measures to reduce internal cycling of phosphorus within the lake: - Alum treatment to bind and remove phosphorus from the water column. - Herbicide treatment to eliminate invasive curly-leaf Pondweed from Bennett Lake. - Carp management (reduce sediment and phosphorus resuspension caused by activity of carp).	$250,000 - $1,500,000/lake $500,000 - $3,000,000 total cost

8 Public Participation

Several TMDL stakeholder meetings were held between representatives of the various stakeholders in the watershed, and other applicable local and state agencies. Public meetings were also held. The goal of this process was to discuss the development and conclusions of the TMDL study, obtain input from, review results with, and take comments from those interested and affected parties.

The official TMDL public comment period was held from April 3, 2017, through May 3, 2017. Two public comment letters were received.

8.1 "Community Conversations", "Community Confluence" Event and TMDL Meetings

During the early months of development of the RWMWD WMP update, WRAPS report, and this TMDL, nearly 100 residents came together in a series of three Community Conversations within RWMWD between mid-September and early October 2013. The Community Conversations were held on the following dates:

- September 17, 2013, at Maplewood Community Center
- September 26, 2013, at Woodbury City Hall
- October 3, 2013, at Shoreview Community Center

The goal of these Community Conversations was two-fold. The first goal was to teach residents about the history of the District, how the budget is established, and the major District initiatives and recent accomplishments. The second goal of the Community Conversations was to solicit input from participants. These gatherings were designed to begin the public input process in updating the District's WMP and to help brainstorm ideas for implementation to improve water quality, as well as to achieve other RWMWD goals.

At each Community Conversation, people reflected on how they value and interact with the District's lakes, wetlands and creeks, identified many of their concerns, and offered potential solutions to the identified watershed issues through a "brain-sprinting" exercise. In the first round of the exercise, the participants generated an expanded list of issues/concerns in the watershed such as invasive species, animal habitats, stormwater and other pollutants, water quality, water levels, aquatic vegetation (macrophytes), increased development/impervious surfaces and the need for education and maintenance. A second round of small group interchanges in the exercise then precipitated insights and suggestions to address the problems and make improvements. Each night the discussions culminated in a large group sharing of what the participants valued in the watershed and a summary of the key issues and ideas for improvement.

The culmination of all of these community meetings was a "Community Confluence" event held on January 30, 2014. Members of the public, government agencies, and city and county staff were invited to hear the results from the three community conversations meetings, and to review eight posters that represented a series of goal "themes" and ideas and/or issues that pertained to those themes. These themes were developed from the feedback received during the Community Conversations meetings. A ninth poster titled "What Did We Miss?" was included for citizens to write-in additional ideas and issues that they thought were not represented in the other eight posters.

The ideas pertaining to Battle Creek, Fish Creek, Wakefield Lake and Bennett Lake were revisited during the TMDL study, and informed the implementation strategies considered for each waterbody.

The following meetings were held to discuss the waterbodies addressed in this TMDL:

Technical Stakeholder Meetings

- December 12, 2011: Kickoff meeting presenting the project and historic water quality of Wakefield Lake
- May 16, 2013: Presentation of the source assessment and draft TMDL WLAs and LAs of Wakefield Lake and discussion of implementation ideas
- August 8, 2013: Kickoff meeting presenting the project and historic water quality of Bennett Lake
- August 13, 2013: Kickoff meeting presenting the project and historic water quality of Battle Creek and Fish Creek
- June 23, 2015: Presentation of the source assessment and draft TMDL WLAs and LAs of Battle Creek and Fish Creek and discussion of implementation ideas
- August 12, 2015: Presentation of the source assessment and draft TMDL WLA and LA for Bennett Lake and discussion of implementation ideas

Public Meetings

- March 17, 2013: A public meeting was held to inform the general public about the findings of the Wakefield TMDL and to discuss the proposed implementation strategies.

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from April 3, 2017 through May 3, 2017.

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Appendices

Appendix A: Lake (Nutrient) TMDL Modeling

Nutrient TMDL Modeling

The lake water quality modeling performed for the *RWMWD TMDL Study* (TMDL study) included three different models to estimate the TMDL phosphorus load capacity required to meet the MPCA water quality standards. The models in the P8 pollutant loading model, a daily water balance model, and a phosphorus mass balance model that included empirical steady-state phosphorus equations and GS phosphorus balance model. Figure A-1 shows a schematic of the TMDL modeling approach.

1.0 P8 Pollutant Loading Model

The P8 pollutant loading model was used to estimate the water and phosphorus loads to Bennett and Wakefield Lake. Runoff volumes predicted by the P8 model were verified using a water balance model and observed lake level data (see Water Balance Model discussion). The P8 event load file was used to extract the watershed runoff volume (acre-ft) and the predicted phosphorus associated with the different particle classes in P8 (i.e., TP loads in lbs) for each event that was modeled. Both the water and the TP loads were used in the steady state phosphorus model and the phosphorus mass balance model.

1.1 P8 Model Parameter Selection

The P8 models used to estimate the watershed loads to Bennett and Wakefield Lake were developed in P8 version 2.4 specifically for this TMDL study. The following section discusses the selected P8 model parameters used for the TMDL study. P8 parameters not discussed in the following paragraphs were left at the default setting.

1.1.2 Time Step, Snowmelt, & Runoff Parameters

Time Steps Per Hour (Integer) — 15 for Bennett Lake; 4 for Wakefield Lake. Selection was based upon the number of time steps required to minimize continuity errors.

Minimum Inter-Event Time (Hours)—10 for Bennett Lake; 6 for Wakefield Lake. The selection of this parameter was based upon an evaluation of storm hydrographs to determine which storms should be combined and which storms should be separated to accurately depict runoff from the lake's watershed. It should be noted that the average minimum inter-event time for the Minneapolis area is 6.

Passes through Storm File—5 for Bennett Lake; 10 for Wakefield Lake. The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no phosphorus. Consequently, the first pass through the storm file results in lower phosphorus loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in phosphorus concentration in the pond waters. To determine the number of passes to select, the model was run with 3 passes, 5 passes, and 10 passes. A comparison of phosphorus predictions for all devices was evaluated to determine whether changes occurred between the three scenarios.

1.1.3 Particle Selection

Bennett Lake Particle File - NURP50.PAR: The particle file reflects the values typically associated with the NURP50 particle file. To estimate pollutant loading, P8 tracks the build-up, washoff, and settling of particles of varying size classes and settling velocities (5 sizes classes, with the smallest particle size class representing non-settling particles). A mass of pollutant (e.g. phosphorus) is associated with a given mass of the particle size classes. The model uses pollutant loading values consistent with the National Urban Runoff program (NURP50 particle file). Table A-1 summarizes the particle class settling velocities as well as the mass of phosphorus associated with a given mass of each particle class.

Table A-1 Bennett Lake P8 Particle Classes and Associated Phosphorus

P8 Particle Class	Description	Settling Velocity (ft/hr)	TP (mg TP/kg Particle)
P0%	Non-Settling / Dissolved	0	99,000
P10%	10th Percentile	0.03	3,850
P30%	30th Percentile	0.3	3,850
P50%	50th Percentile	1.5	3,850
P80%	80th Percentile	15	0

Wakefield Lake Particle File - PHALEN.PAR: because Wakefield Lake is within the Phalen Lake Watershed, a calibrated particle file developed for a P8 model of Phalen Lake was applied to the P8 model of Wakefield Lake. Table A-2 summarizes the particle class settling velocities as well as the mass of phosphorus associated with a given mass of each particle class in the calibrated Phalen Lake particle file.

Table A-2 Wakefield Lake P8 Particle Classes and Associated Phosphorus

P8 Particle Class	Description	Settling Velocity (ft/hr)	TP (mg TP/kg Particle)
P0%	Non-Settling / Dissolved	0	514,000
P10%	10th Percentile	0.03	15,000
P30%	30th Percentile	0.3	15,000
P50%	50th Percentile	1.5	15,000
P80%	80th Percentile	15	0

1.1.4 Climatic Data Selection

Precipitation File - FVLKPPT.pcp: The P8 model uses long-term climatic data so that watershed runoff and BMPs can be evaluated for varying hydrologic conditions. Most of the hourly precipitation obtained from the Minneapolis-St. Paul Airport. The St. Paul Airport hourly precipitation data was used to fill in gaps in the hourly data from the Minneapolis-St. Paul Airport and was used for the period from May through September 2008. A monthly adjustment factor was applied to the hourly precipitation data to match the monthly totals from a daily precipitation gage that is part of the high density precipitation network through the Minnesota State Climatology Office.

Air Temperature File - Msp4908.tmp: Average daily temperature data was obtained from the Minneapolis-St. Paul Airport for the period from 1949 through 2008.

1.1.5 Watersheds Parameter Selection

Watershed delineation and hydrologic parameters were originally developed for the Bennett Lake and Wakefield Lake in the Lake Owasso Use Attainability Analysis (Barr 2009) and Phalen Chain of Lakes Strategic Lake Management Plan (Barr 2004b), respectively. For further information pertaining to development of watersheds and watershed hydrologic parameters, refer to the documents cited above.

1.1.6 Device Parameter Selection

The P8 models for Bennett and Wakefield Lake include devices that represent existing wetlands and constructed watershed BMPs (devices). Information for the various BMPs includes the bathymetry of ponds and wetlands within the watersheds as well as information about the outlet structures.

Detention Pond— Permanent Pool— Area and Volume—The surface area and dead storage (water quality) volume of each detention pond was determined and entered here.

Detention Pond— Flood Pool— Area and Volume—The surface area and storage volume under flood conditions (i.e., the storage volume between the normal level and flood elevation) was determined and entered here.

Detention Pond— Infiltration Rate (in/hr) — Infiltration from ponded area can be set to allow the pond volume to drop below the normal water level (control elevation), especially during periods of limited rainfall.

Detention Pond— Orifice Diameter and Weir Length— The orifice diameter or weir length was determined from field surveys, development plans, or storm sewer data provided by the city of Lake Elmo of the area for each detention pond and entered here.

Detention Pond or Generalized Device— Particle Removal Scale Factor— Particle Removal Scale Factor— 0.3 for ponds less than 2 feet deep and 1.0 for all ponds 3 feet deep or greater. For ponds with normal water depths between 2 and 3 feet, a particle removal factor of 0.6 was selected. The particle removal factor for watershed devised determines the particle removal by device.

1.2 P8 Model Results

Table A-3 and Table A-4 summarize the total event precipitation (based on the hourly precipitation and average daily temperature data, as processed by P8) for the Bennett Lake and Wakefield Lake Watersheds for the 17-month modeled period used to establish the TMDL for each lake. Also summarized in the tables are the P8 predicted event watershed runoff water load and phosphorus load to each lake, along with event TP concentrations.

Table A-3 P8 Event Water and Phosphorus Loads to Bennett Lake (5/1/2004-9/30/2005)

Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc. (µg/L)
5/5/2004	0.07	0.1	0.0	100
5/9/2004	0.63	7.1	2.5	131
5/12/2004	0.16	1.3	0.4	105
5/13/2004	0.44	4.7	1.3	103
5/16/2004	0.79	9.1	3.4	136
5/19/2004	0.22	2.0	0.6	106
5/21/2004	0.06	0.0	0.0	100
5/21/2004	0.15	1.0	0.3	102
5/22/2004	0.02	0.0	0.0	101
5/23/2004	1.03	12.1	3.4	105
5/25/2004	0.01	0.0	0.0	99
5/26/2004	0.59	6.6	2.0	114
5/28/2004	0.74	8.4	2.6	114
5/30/2004	0.47	5.0	1.5	110
5/30/2004	0.26	2.6	0.7	105
5/31/2004	1.20	24.6	7.8	118
6/5/2004	0.14	1.0	0.3	103
6/5/2004	0.38	4.0	1.2	109
6/8/2004	1.68	20.1	6.2	114
6/10/2004	0.19	1.6	0.4	103
6/11/2004	0.33	3.3	1.0	113
6/11/2004	0.47	5.4	1.9	132
6/23/2004	0.34	3.5	1.2	125
6/27/2004	0.05	0.0	0.0	100
7/3/2004	0.55	6.1	1.7	101
7/5/2004	0.71	8.1	2.3	104
7/11/2004	1.29	15.3	5.6	134
7/21/2004	0.08	0.3	0.1	101
7/28/2004	0.11	0.6	0.2	102
7/30/2004	0.07	0.2	0.0	100
7/31/2004	0.16	1.3	0.3	101
8/1/2004	0.01	0.0	0.0	99
8/3/2004	0.06	0.0	0.0	99
8/7/2004	0.15	1.1	0.3	101
8/11/2004	0.01	0.0	0.0	99
8/15/2004	0.54	6.0	1.7	102
8/22/2004	0.16	1.2	0.4	104
8/23/2004	0.20	1.7	0.5	102
8/26/2004	0.12	0.7	0.2	100
8/29/2004	0.12	0.7	0.2	100
9/5/2004	0.75	8.2	3.8	168
9/5/2004	0.99	11.9	4.0	124

Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc. (μg/L)
9/13/2004	0.12	0.8	0.2	100
9/14/2004	2.86	36.8	12.9	129
9/17/2004	0.16	1.3	0.4	106
9/21/2004	0.03	0.0	0.0	100
9/22/2004	0.03	0.0	0.0	102
9/23/2004	0.26	2.5	0.7	102
10/1/2004	0.38	4.0	1.1	104
10/7/2004	0.14	1.0	0.3	103
10/13/2004	0.06	0.0	0.0	99
10/15/2004	0.12	0.7	0.2	99
10/17/2004	0.09	0.4	0.1	101
10/22/2004	0.18	1.5	0.4	101
10/23/2004	0.04	0.1	0.0	99
10/28/2004	1.04	12.1	3.7	113
10/29/2004	0.13	0.9	0.2	102
10/30/2004	0.00	0.0	0.0	100
11/1/2004	0.09	0.4	0.1	100
11/19/2004	0.75	8.6	2.3	100
12/4/2004	0.07	0.2	0.1	99
12/7/2004	0.19	1.6	0.4	101
12/9/2004	0.18	1.6	0.4	100
12/15/2004	0.01	0.0	0.0	99
12/30/2004	0.34	3.4	0.9	99
1/25/2005	0.03	0.0	0.0	99
2/1/2005	1.08	21.5	5.8	99
2/11/2005	0.95	17.2	4.6	100
3/4/2005	0.46	5.1	1.4	99
3/10/2005	0.14	1.0	0.3	99
3/21/2005	0.53	6.3	1.7	99
3/30/2005	0.94	10.9	3.8	128
4/2/2005	0.02	0.0	0.0	100
4/11/2005	0.02	0.0	0.0	98
4/11/2005	0.32	3.3	0.9	100
4/15/2005	0.13	0.8	0.2	101
4/16/2005	0.94	11.0	3.4	115
4/19/2005	0.39	4.1	1.1	102
4/25/2005	0.06	0.1	0.0	100
4/25/2005	0.14	1.0	0.3	101
4/26/2005	0.06	0.1	0.0	99
5/2/2005	0.03	0.0	0.0	99
5/7/2005	0.00	0.0	0.0	100
5/8/2005	0.02	0.0	0.0	100
5/8/2005	0.07	0.2	0.0	100

Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc. (µg/L)
5/9/2005	0.05	0.0	0.0	98
5/10/2005	0.17	1.4	0.4	105
5/12/2005	1.08	12.7	3.5	102
5/14/2005	0.12	0.8	0.2	100
5/16/2005	0.24	2.2	0.6	103
5/17/2005	0.14	1.1	0.3	103
5/18/2005	0.89	10.3	2.9	104
5/21/2005	0.05	0.0	0.0	99
5/25/2005	0.21	1.8	0.5	100
5/26/2005	0.05	0.0	0.0	99
5/27/2005	0.25	2.4	0.7	100
5/29/2005	0.13	0.8	0.2	100
6/4/2005	0.18	1.5	0.4	101
6/5/2005	0.17	1.4	0.4	105
6/7/2005	0.03	0.0	0.0	99
6/7/2005	0.64	7.3	2.4	123
6/10/2005	0.44	4.7	1.7	129
6/11/2005	0.05	0.0	0.0	103
6/11/2005	0.08	0.2	0.1	103
6/13/2005	0.52	5.7	1.9	122
6/14/2005	0.07	0.3	0.1	104
6/15/2005	0.09	0.43	0.12	102
6/20/2005	0.62	6.96	2.51	133
6/24/2005	0.01	0.00	0.00	101
6/27/2005	0.80	9.05	4.08	166
6/27/2005	1.17	13.94	4.69	124
6/29/2005	0.19	1.64	0.47	106
6/29/2005	0.62	8.11	3.05	139
7/3/2005	0.18	1.50	0.43	106
7/17/2005	0.12	0.75	0.21	102
7/20/2005	0.51	5.60	1.98	131
7/23/2005	0.93	10.82	4.18	142
7/25/2005	1.71	21.48	7.99	137
8/3/2005	0.25	2.36	0.72	113
8/8/2005	0.06	0.05	0.01	100
8/9/2005	0.47	5.05	2.00	146
8/11/2005	0.15	1.12	0.32	104
8/16/2005	0.28	2.73	0.87	117
8/18/2005	0.44	4.73	1.34	105
8/19/2005	0.03	0.02	0.00	99
8/26/2005	2.60	31.93	11.84	137
9/2/2005	0.30	2.95	0.83	104
9/3/2005	0.34	3.51	0.97	102

Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc. (µg/L)
9/5/2005	0.01	0.00	0.00	100
9/6/2005	0.31	3.11	1.02	121
9/8/2005	0.19	1.61	0.47	108
9/9/2005	0.07	0.13	0.04	101
9/13/2005	0.83	9.58	3.58	138
9/17/2005	0.16	1.30	0.37	104
9/18/2005	0.04	0.00	0.00	100
9/21/2005	2.13	25.77	7.49	107
9/23/2005	0.13	0.89	0.25	101
9/26/2005	0.10	0.49	0.13	100
9/27/2005	0.06	0.01	0.00	100
9/29/2005	0.35	3.61	1.24	126
Steady State Year (May 1, 2004 – April 30, 2005)	30	347	108	115
Growing Season (June 1, 2005 – Sept 30, 2005)	18.4	202	70	128

Table A-3 P8 Event Water and Phosphorus Loads to Wakefield Lake (5/1/2003-9/30/2004)

Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc. (µg/L)
5/4/2003	0.95	14.7	9.6	240
5/8/2003	1.28	32.1	23.1	265
5/10/2003	1.64	58.0	25.9	165
5/13/2003	0.52	8.6	5.2	223
5/19/2003	0.88	13.6	9.7	262
5/22/2003	0.33	4.8	2.0	156
5/28/2003	0.06	0.5	0.2	183
5/30/2003	0.23	3.2	2.5	292
6/4/2003	0.17	2.2	1.4	234
6/6/2003	0.93	14.4	11.2	287
6/9/2003	0.05	0.3	0.1	114
6/12/2003	0.04	0.2	0.1	125
6/18/2003	0.13	1.6	1.5	360
6/23/2003	0.09	0.9	0.4	150
6/24/2003	4.48	101.6	70.8	257
6/28/2003	0.33	4.8	3.2	247
7/3/2003	0.65	9.9	8.8	327
7/4/2003	0.12	1.4	0.6	158
7/8/2003	0.07	0.6	0.3	169
7/9/2003	0.10	1.1	0.3	111
7/11/2003	0.04	0.2	0.1	134
7/14/2003	0.78	12.0	10.5	323
7/20/2003	0.06	0.5	0.1	93
7/22/2003	0.06	0.5	0.2	184
7/30/2003	0.05	0.3	0.1	81
7/31/2003	0.13	1.6	0.7	173
8/6/2003	0.01	0.0	0.0	51
8/19/2003	0.80	12.2	12.6	378
9/11/2003	1.43	22.4	15.7	258
9/18/2003	0.50	7.5	7.8	385
9/21/2003	0.05	0.3	0.1	114
9/26/2003	0.09	0.9	0.3	126
9/29/2003	0.08	0.8	0.3	122
10/11/2003	0.53	7.9	9.0	415
10/25/2003	0.05	0.3	0.1	153
10/27/2003	0.07	0.6	0.2	109
10/28/2003	0.07	0.6	0.1	87
10/29/2003	0.08	0.8	0.3	149
10/30/2003	0.09	1.0	0.5	195
11/10/2003	0.28	4.0	0.5	48
11/12/2003	0.17	2.2	0.7	118
11/17/2003	0.03	0.0	0.0	51

Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc. (µg/L)
11/30/2003	0.09	0.9	0.1	39
12/8/2003	0.12	1.4	0.1	38
12/26/2003	0.58	10.1	1.0	37
2/19/2004	0.41	6.0	0.6	37
2/27/2004	1.46	47.4	7.8	61
3/9/2004	0.48	7.6	0.9	42
3/13/2004	0.41	6.2	0.7	44
3/17/2004	0.43	6.6	0.7	37
3/19/2004	0.03	0.0	0.0	52
3/25/2004	0.24	3.3	2.4	269
3/27/2004	0.41	6.1	2.8	170
3/28/2004	0.02	0.0	0.0	57
4/18/2004	1.51	23.8	17.8	275
4/20/2004	0.57	9.9	3.2	118
4/24/2004	0.52	7.8	4.1	192
5/5/2004	0.07	0.6	0.2	129
5/9/2004	0.63	9.6	10.7	413
5/12/2004	0.16	2.1	1.3	234
5/13/2004	0.44	6.5	3.6	202
5/16/2004	0.79	12.2	9.6	289
5/19/2004	0.22	3.0	1.8	220
5/21/2004	0.06	0.4	0.1	70
5/21/2004	0.16	2.1	0.9	159
5/23/2004	1.03	16.1	9.3	213
5/25/2004	0.01	0.0	0.0	73
5/26/2004	0.59	10.5	7.4	262
5/28/2004	0.74	11.4	6.6	215
5/30/2004	0.73	14.9	6.0	148
5/31/2004	1.20	35.1	15.8	166
6/5/2004	0.14	1.8	0.9	194
6/5/2004	0.38	5.6	4.4	292
6/8/2004	1.68	26.8	13.7	188
6/10/2004	0.99	24.1	13.5	207
6/23/2004	0.34	4.9	7.1	534
6/27/2004	0.05	0.3	0.1	79
7/3/2004	0.55	8.3	5.6	249
7/5/2004	0.71	10.9	7.1	242
7/11/2004	1.29	20.2	13.3	242
7/21/2004	0.08	0.8	0.5	224
7/28/2004	0.11	1.2	1.1	325
7/30/2004	0.07	0.7	0.3	160
7/31/2004	0.18	2.3	1.5	243
8/3/2004	0.06	0.5	0.1	113

Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc. (µg/L)
8/7/2004	0.15	1.9	1.5	297
8/11/2004	0.01	0.0	0.0	52
8/15/2004	0.54	8.1	6.2	282
8/22/2004	0.16	2.1	1.9	348
8/23/2004	0.20	2.7	1.9	252
8/26/2004	0.12	1.4	0.7	186
8/29/2004	0.12	1.4	0.6	154
9/5/2004	1.74	27.6	18.2	243
9/13/2004	0.12	1.5	0.5	126
9/14/2004	2.86	50.5	23.6	172
9/17/2004	0.16	2.1	0.7	119
9/21/2004	0.03	0.0	0.0	52
9/22/2004	0.03	0.0	0.0	52
9/23/2004	0.26	3.7	2.5	250
Steady State Year (May 1, 2003 – April 30, 2004)	26	488	279	211
Growing Season (June 1, 2004 – Sept 30, 2004)	13	211	128	223

2.0 Water Balance Model

A daily water balance spreadsheet model was used to verify the runoff volumes predicted by P8 models as well as observed lake level data (when available) to estimate each lake's volume and discharge. Stage-area-storage-discharge curves were developed for each lake based on available bathymetry data as well as outlet geometry. Water balance was estimated using the following equation:

$$\Delta \text{ in Lake Storage} = WR + DP + US - EV - GW - D - OL$$

Where:

WR	=	Watershed Runoff
DP	=	Direct Precipitation on the surface area of the lake
US	=	Flows from Upstream Lakes/Sources (when applicable; based on water balance models and/or lake levels & rating curves for upstream lakes)
EV	=	Evaporation for lake surface based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory
GW	=	Average groundwater exchange fit to lake level monitoring data
D	=	Estimated average daily discharge based on outlet geometry
OL	=	Other losses (when applicable)

The results of the water (and phosphorus) balance model for Bennett and Wakefield Lake are included in Appendix B and Appendix C.

3.0 Phosphorus Mass Balance Model

After the P8 and water balance models were developed and checked against observed water level data, phosphorus mass balance models were calibrated to observed water quality data using a differencing methodology. This differencing method allowed the models to be used to estimate phosphorus loading sources and losses not explicitly accounted for in the mass balance modeling during the Bennett Lake and Wakefield Lake growing seasons.

The phosphorus mass balance model evaluates a period of 17 months (beginning on May 1 of a given year through September 30 of the following year), and is comprised of two phases. The first phase uses water and phosphorus loads for the first 12 months of the period (May 1 through April 30 of the following year) are used as the inputs to the empirical steady-state phosphorus equation to predict the in-lake phosphorus concentration at the beginning of the calibration period. The steady-state equations used to establish the late-spring phosphorus concentration are discussed in more detail in the main body of the report and in Appendix B and Appendix C.

The second phase of the water quality modeling considers the five-month period from May 1 through September 30, to calibrate the mass balance model to observed water quality data and estimate phosphorus sources and losses to the lakes required to match the water quality monitoring data. The phosphorus mass balance model time step is variable, based on the period of time between each of the water quality monitoring events.

The mass balance equation used to estimate the internal load and calibrate the model to observed water quality data for each time step is as follows (also discussed in the main body of the report):

P Adjusted = Observed P + Outflow P + Coontail Uptake P –

Runoff P – Upstream P - Atmospheric P – Curly-leaf Pondweed P – P Initial

The following discusses each of the components of the mass balance equation and where these numbers come from based on the data available for this study as well as the P8 and water balance modeling that was performed. Summaries of phosphorus balance modeling for Bennett Lake and Wakefield Lake are included in Appendix B and Appendix C, respectively.

Observed P

The water quality data collected for each water body was used for the calibration of the mass balance model (estimation of the internal loading/losses). Surface TP is the primary parameter used for calibration (sampled collected at a depth of 0-2 m). The observed P is the amount of phosphorus in the epilimnion based on the TP concentration and the estimated epilimnion volume (estimated in the daily water balance model) at the time of the monitoring event (the end of the current timestep).

Other water quality parameters typically used to verify the water quality model include TP measurements along the water column profile (if available), water temperature, and DO data. Some of the water quality sampling dates have monitoring data available along the depth profile of the lake. The temperature profiles help identify the depth to the thermocline and when used in conjunction with the water balance, can estimate the epilimnetic volume during each period. Additionally, the TP and DO profile data can help verify if there is internal loading from the sediments due to anoxia below the thermocline and along the bottom sediments. Some of the water quality sampling dates may have only included surface water quality measurements and therefore, parameters such as depth to the thermocline, was estimated based on interpolation between known data.

Outflow P

Outflow P typically includes losses of phosphorus through surface discharge as well as through losses to the GW. The volumes of discharge during each time step were based on the daily water balance model. The TP concentration of the discharge is assumed to be the observed surface TP data from the prior time step.

Coontail Uptake P

Qualitative macrophyte surveys were performed on Bennett Lake and Wakefield Lake. These surveys included areal coverage estimates as well as relative densities for a variety of macrophyte species including Coontail. Typically, surveys were also available in early and late summer, so changes in coverage and density could be estimated throughout the GS. The uptake of TP by Coontail was estimated based on average daily uptake rates presented by Lombardo and Cooke (2003) and the estimated density and coverage of the macrophyte.

Runoff P

The P8 model results were used to estimate the phosphorus associated with watershed runoff. To estimate pollutant loading, the P8 model tracks the build-up, wash-off, and settling of particles and a mass of phosphorus is associated with each particle size (see P8 discussion above). The phosphorus mass balance model tracks the various particle sizes estimated by the P8 model and assumes particles will settle out of the epilimnion based on their settling velocity (as used in P8). As a result, the SRO TP used by the mass balance model to predict the water quality in the lake is less than the TP load directly estimated by the P8 model due to particle settling.

Upstream P

The in-lake mass balance model accounts for loads from upstream lakes and water bodies. In the case of Bennett Lake and Wakefield Lake, there are no upstream waterbodies. However, if there were upstream waterbodies (not modeled in the P8 model), the mass balance model estimates volumes from upstream sources during each timestep were based on the daily water balance model. Typically, discharge estimates are based on lake level data and the discharge rating curves or water balance models for the upstream lakes (if available). The TP concentrations associated with upstream sources are typically based on water quality monitoring data or the phosphorus mass balance model (if available).

Atmospheric P

Atmospheric phosphorus was applied at a constant loading rate of 0.2615 kg/ha/yr (Barr 2005). This was applied to the estimated surface area of the lake at each time step.

Curly-leaf P

Qualitative macrophyte surveys were performed on Bennett Lake and Wakefield Lake. These surveys included areal coverage estimates as well as relative densities for a variety of macrophyte species including Curly-leaf pondweed. Using the late-spring or early-summer surveys, the coverage and density of the Curly-leaf pondweed could be estimated. The estimated biomass phosphorus content was based on data collected as part of a study of Big Lake in Wisconsin (Barr 2001) and compared to recent biomass measurements made for Medicine Lake (Vlach & Barten 2006). The phosphorus RR was based on the Half Moon Lake study (James et al. 2001).

P Initial

This parameter represents the amount of phosphorus that currently exists in the epilimnion at the start of the timestep. It is equivalent to the amount of phosphorus in the epilimnion at the end of the previous time step. At the beginning of the calibration period, the initial phosphorus concentration is based on the spring steady state phosphorus concentration estimated from the empirical relationship selected for Bennett Lake and Wakefield Lake. At the subsequent time steps in the model, the phosphorus concentrations are calibrated to the observed water quality in the lake throughout the GS.

P Adjusted

Once the known sources and losses of phosphorus were quantified, the required TP loading adjustment could be back calibrated so that the predicted phosphorus concentration in the epilimnion matches the observed TP data. The phosphorus adjustment can be either loading or losses of phosphorus. Losses of phosphorus are minimized through the calibration process and the estimated TP loading into the lake is verified against the results of the sediment core analysis.

Using the Calibrated Mass Balance Model

Once the in-lake mass balance model was calibrated for each lake, the models were used in a predictive manner to evaluate the impact of changes in water and phosphorus loading on the lake water quality. Additionally, the mass balance was used to estimate the TMDL load capacity and required phosphorus load reduction that would result in the expected in-lake water quality that would meet the MPCA water quality standards during the GS period.

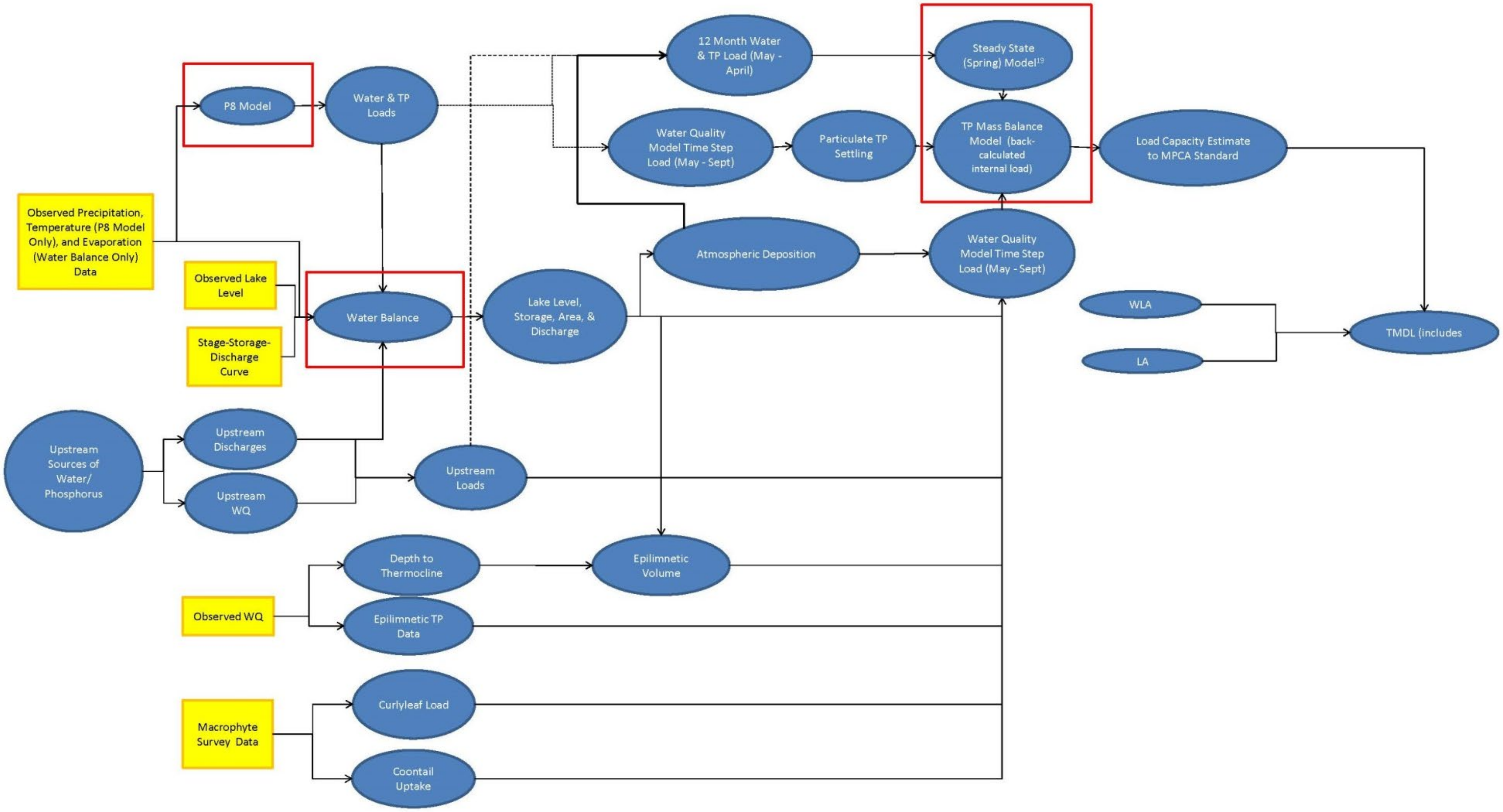

Figure A-1 TMDL modeling process flow chart

Appendix B:

Bennett Lake Water and Phosphorus Balance Model

B-1 Bennett Lake 2005 climatic conditions water balance summary

	Sample Period		A	B	C	D	E	F	G	H	I	J
			Total Lake Volume at the Start of the Period (acre-ft)	Direct Precipitation (acre-ft)	Evaporation (acre-ft)	Watershed Runoff (acre-ft)	Groundwater Inflow (acre-ft)	Surface Discharge (acre-ft)	Groundwater Outflow (acre-ft)	Change in Lake Volume (acre-ft)	Total Lake Volume at the End of the Period (acre-ft)	Lake Level at End of Period (ft MSL)
				+	-	+	+	-	-			
Steady State Year (May 1, 2004 - April 30, 2005)	5/1/2004	4/30/2005	180.4	76.9	64.7	347.1	0	372.4	0	-13.0	167.4	887.92
(Oct 1, 2004 - April 30, 2005)	10/1/2004	4/30/2005	167.1	25.5	13.5	118.7	0	130.5	0	0.3	167.4	887.92
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2005 - Sept 30, 2005)	5/1/2005	5/4/2005	167.4	0.1	1.0	0.0	0	0.8	0	-1.7	165.7	887.87
	5/5/2005	5/26/2005	165.7	7.9	5.6	30.4	0	28.1	0	4.6	170.3	888.02
	5/27/2005	6/15/2005	170.3	6.8	7.5	24.7	0	21.4	0	2.6	172.9	888.10
	6/16/2005	7/6/2005	172.9	9.2	9.4	41.2	0	43.4	0	-2.4	170.6	888.02
	7/7/2005	7/28/2005	170.6	8.4	11.2	38.6	0	28.1	0	7.7	178.2	888.27
	7/29/2005	8/22/2005	178.2	4.3	9.8	16.1	0	20.0	0	-9.4	168.8	887.97
	8/23/2005	9/9/2005	168.8	9.8	6.0	43.2	0	44.1	0	2.9	171.7	888.06
	9/10/2005	9/30/2005	171.7	9.8	6.1	41.6	0	44.5	0	0.8	172.5	888.09
Total for Growing Season (June 1, 2005 - Sept 30, 2005)	6/1/2005	9/30/2005	169.2	47.3	48.8	202.2	0	197.4	0	3.3	172.5	888.09
Total for Water Year 2005 (Oct 1, 2004 - Sept 30, 2005)	10/1/2004	9/30/2005	167.1	81.8	70.2	354.6	0	360.8	0	5.4	172.5	888.09

Annual (2005 Water Year) Water Load to Bennett Lake (acre-ft)	10/1/2004	9/30/2005	436.4	Water Load = B + D + E

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Tab "WaterBalance"
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area). See Tab "P8EventSummary".
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Tab "Evap"
D - Based on the water loads from the P8 model. See Tab "P8EventSummary"
E - Groundwater Inflow estimated in the daily water balance model.
F - Surface discharge from 24-hour average rating curve. See Tab "Lake Rating Curve"
G - Groundwater Discharge estimated in the daily water balance model.
H - Change in Lake Volume = B - C + D + E - F - G
I - Total Lake Volume @ End of Period = A + G
J - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Tab "Lake Rating Curve"

B-2 Bennett Lake 2005 climatic conditions in-lake growing season mass balance model summary[1]

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
		Epilimnion Volume	P In-Lake @ Start of Period	Total P Watershed Runoff	P Surface Runoff (after Particulate Settling)[5]	P From SSTS	P Atmospheric	P GW	P Release from Curly-leaf Pondweed[4]	P Uptake by Coontail[4]	P Loss due to Discharge	P Remaining in lake	In-Lake P before Adjustment	Observed In-Lake P	Residual Adjustment (Internal Loading / Losses)	Residual Adjustment (Internal Loading / Losses)[6]	P In-Lake @ End of Period	Predicted In-Lake P[2]
Period Start		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	µg/l	µg/L	µg/l	lbs	lbs	µg/L
Steady State Total (May 1, 2004 - April 30, 2005)[3,4,8]		159.5	N/A	108.1	92.5	0.0	7.0	0	N/A	N/A	71.8	N/A	N/A	N/A	N/A	N/A	N/A	70.9
(Oct 1, 2004 - April 30, 2005)[3,8]		159.5	N/A	33.9	29.0	0.0	4.1	0	0	0	25.2	N/A	N/A	N/A	N/A	N/A	N/A	70.9
5/1/05	5/4/05	159.8	30.8	0.0	0.0	0.0	0.1	0	0.0	0.0	0.1	30.6	70.5	77.8	7.2	3.1	33.8	78
5/5/05	5/26/05	164.1	33.8	8.5	8.2	0.0	0.4	0	0.0	0.1	5.9	36.4	81.5	128.0	46.5	20.7	57.1	128
5/27/05	6/15/05	186.5	57.1	7.9	7.1	0.0	0.4	0	0.0	0.1	7.4	57.1	112.5	173.5	61.0	30.9	88.0	174
6/16/05	7/6/05	172.2	88.0	15.2	12.7	0.0	0.4	0	6.1	0.2	20.5	86.5	184.7	190.5	5.8	2.7	89.2	191
7/7/05	7/28/05	174.4	89.2	14.4	12.1	0.0	0.4	0	5.5	0.2	14.6	92.5	194.9	279.0	84.1	39.9	132.4	279
7/29/05	8/22/05	167.5	132.4	5.3	4.4	0.0	0.5	0	0.6	0.3	15.1	122.5	269.0	239.5	-29.5	-13.4	109.1	240
8/23/05	9/9/05	167.8	109.1	15.2	11.8	0.0	0.3	0	0.0	0.2	28.7	92.3	202.4	167.5	-34.9	-15.9	76.4	168
9/10/05	9/30/05	176.0	76.5	13.0	11.7	0.0	0.4	0	0.0	0.3	20.3	68.0	142.0	167.5	25.5	12.2	80.2	168[7]
Growing Season Total (June 1, 2005 - Sept 30, 2005)[8]		N/A	N/A	70.1[9]	57.9[10]	0.0	2.3[10]	0	12.3[10]	1.2[10]	104.8[10]	N/A	N/A	N/A	N/A	78.1[11]	N/A	N/A
Total for Water Year 2005 (Oct 1, 2004 - Sept 30, 2005)[3,8]		N/A	N/A	113.3[9]	97	0.0	7.0	0	12.3	1.4	137.9	N/A	N/A	N/A	N/A	109.7[12]	N/A	N/A
Growing Season Average (6/1/2005 – 9/30/2005)[13]																		210

1 - Reflective of in-lake water quality model calibration conditions (2005 watershed conditions)
2 - Growing Season Average Reflects WQ data from June through September
3 - An empirical model (Dillon and Rigler (1974) with Larsen and Mercier (1976)) retention coefficient) was used to predict the steady state phosphorus concentration at the beginning of the phosphorus mass balance model developed for the period from May 1, 2004 - September 30, 2005.
4 - Phosphorus release from Curly-leaf pondweed and uptake by Coontail was not estimated for the Steady State year because phosphorus mass balance modeling was not performed for the period from May 1, 2004 - April 30, 2005. Also, it was assumed that during the period from October 1 - April 30 the phosphorus loading due to Curly-leaf pondweed and uptake by Coontail would be negligible due to the growth/die back cycles of these macrophytes during this season.
5 - The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2004 - April 30, 2005 reflects the total watershed runoff load multiplied by the ratio of watershed runoff P load after settling to the total watershed runoff P load.
6 - The individual TP adjustment values represent the net phosphorus load adjustment, including both phosphorus loads to the lake and losses such as sedimentation. Their algebraic sums year totals of these values will not match the growing season and water year totals below the data column nor the "internal loading from other sources" in Tab "PSourceSummary" which only summarizes the (positive) loads to the lake.
7 - Last P concentration observed (9/09/05) applied to the final growing season date (9/30/05) to establish a terminal boundary condition for growing season calculations.
8 - For Total Loads, total rounded to the nearest tenth of a lb for reporting purposes.
9 - Calculated from the P8 event loading for dates within the growing season (see Table A-3).
10 - Interpolated sum for the growing season (June 1, 2005 - Sept 30, 2005).
11 - Interpolated sum of positive loading values for the growing season (June 1, 2005 - Sept 30, 2005).
12 - Sum of positive loading values for the water year (Oct 1, 2004 – Sept 30, 2005).
13 - The growing season average TP concentration (µg/L) was calculated from values corresponding to observed growing season water quality concentrations in Bennett Lake (cells highlighted in blue).
A - See Tab "PhysicalParameters". The epilimnion volume represents the predicted epilimnion volume at the end of the time period.
B - Amount of phosphorus present in lake at the beginning of the timestep (based on spring steady state or observed TP concentration and epilimnetic volume from the previous timestep).
(Continued on following page)

(Table B-2: Continued from previous page)

C - Based on the Watershed TP Load before Particle Settling. See Tab "Particle Settling Summary"

D - Based on the Watershed TP Load after Particle Settling. See Tab "Particle Settling Summary"

E - Based on estimated load from failing SSTS in the direct watershed. See Tab "Upstream_DischargeSummary"

F - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake

G - Load from Groundwater Inflow. See Tab "Upstream_DischargeSummary"

H - Based on a phosphorus release rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Tab "Curly-leaf Decay Summary"

I - Based on average daily uptake rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Tab "Coontail Uptake Summary"

J - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the TP concentration from the previous time period. See Tab "Upstream_DischargeSummary"

K - P Remaining in Lake = B + D + E + F + G + H - I - J

L - In-Lake P before Adj = K / A / 0.00272

M - Water quality monitoring data. See Tab "WQ Data"

N - Residual Adjustment = M - L; The Residual Adjustment is the calibration parameter used to describe the internal phosphorus loads to the lake not explicitly estimated (e.g. release from bottom sediments, resuspension due to fish activity or wind, etc.), to estimate the uptake of phosphorus from the water column by algae growth, to estimate sedimentation of phosphorus from the water column, as well as to factor in possible error in the monitoring data.

O - Residual Adj Load = N*A * 0.00272. Positive values are treated as a phosphorus source to the lakes such as sediment release while negative values are handled as a sink, such as sedimentation.

P - P In-Lake at End of Period = K + O

Q - Predicted In-Lake P is a check against the Observed In-Lake P.

B-3 Bennett Lake 2005 climatic conditions in-lake growing season mass balance model allowable load estimate

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
		Epilimnion Volume	P In-Lake @ Start of Period	Total P Watershed Runoff	P Surface Runoff (after Particulate Settling)[4]	P From SSTS	P Atmospheric	P GW	P Release from Curly-leaf Pondweed	P Uptake by Coontail	P Loss due to Discharge	P Remaining in lake	In-Lake P before Adjustment	Observed In-Lake P	Residual Adjustment (Internal Loading / Losses)	Residual Adjustment (Internal Loading / Losses)	P In-Lake @ End of Period	Predicted In-Lake P
Period Start		acre-ft	lbs	lbs	Lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	µg/l	µg/L	µg/l	lbs	lbs	µg/L
5/1/05	5/4/05	160	13.2[1]	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	13.1				0.6	14	32
5/5/05	5/26/05	164	13.8	3.3	2.8	0.0	0.4	0.0	0.0	0.1	2.4	14.5				4.1	19	42
5/27/05	6/15/05	186	18.6	3.1	2.6	0.0	0.4	0.0	0.0	0.1	2.4	19.1				6.2	25	50
6/16/05	7/6/05	172	25.3	6.0	5.1	0.0	0.4	0.0	1.2	0.2	5.9	25.9				0.5	26	57
7/7/05	7/28/05	174	26.5	5.6	4.8	0.0	0.4	0.0	1.1	0.2	4.3	28.3				8.0	36	76
7/29/05	8/22/05	167	36.3	2.1	1.8	0.0	0.5	0.0	0.1	0.3	4.1	34.2				-3.7	30	67
8/23/05	9/9/05	168	30.5	5.9	5.1	0.0	0.3	0.0	0.0	0.2	8.0	27.7				-4.8	23	50
9/10/05	9/30/05	176	22.9	5.1	4.4	0.0	0.4	0.0	0.0	0.3	6.1	21.3				2.4	24	50
Growing Season Total (June 1, 2005 - Sept 30, 2005)		N/A	N/A	27.4	23.4	0.0	2.3	0.0	2.5	1.2	30.3	N/A				15.6	N/A	N/A
Growing Season Average (6/1/2005 - 9/30/2005)[5]																		60

Required load reduction (lbs / growing season) to meet MPCA standard for Bennett Lake

			Pre 10% MOS			Post 10% MOS	
P Loading Source	Existing Conditions (2005)	TMDL Condition	Loading Reduction	Loading Reduction	MOS (10%)[6]	Loading Reduction	Loading Reduction
	lbs	lbs	lbs	%	lbs	lbs	%
Watershed Runoff	70.1	27.4	42.7	61%[3]	4.8	47.4	68%
Atmospheric	2.3	2.3	0	0%	0	0	0%
Curly-leaf pondweed	12.3	2.5	9.8	80%[2]	0	9.8	80%
Internal Loading	78.1	15.6	62.5	80%[2]	0	62.5	80%
Total	**162.8**	**47.8**	**114.9**	**71%**	**4.8**	**119.7**	**74%**

1 – Based on assumed initial in lake P concentration of 30 µg/L (see Table B-9).

2 – Internal load reduction (80%) applied to internal loading sources. Cells highlighted in yellow are the result of the noted percent reduction applied to the existing loading value. The reduction applied (80%) was chosen to represent the percent reduction achievable through methods of internal phosphorus removal and control (alum and herbicide treatment).

3 – The external (watershed) load reduction applied is the reduction value required to achieve the MPCA growing season TP water quality standard (60 µg/L). The reduction value (60.9%) applied to cells highlighted in orange was calculated by solving for the external load reduction required to meet the MPCA growing season TP water quality standard after applying of the internal load reduction (see item #1).

4 – The reported phosphorus load associated with surface runoff during the steady state period reflects the total watershed runoff load multiplied by the ratio of watershed runoff P load after settling to the total watershed runoff P load.

5 – The growing season average TP concentration (µg/L) was calculated from values corresponding to observed growing season water quality concentrations in Bennett Lake (cells highlighted in blue).

6 – A MOS of 10% of the total loading capacity (47.8 lbs.) was applied to as described in Section 4.3.4.

B-4 Bennett Lake 2005 water quality

Date	Water Surface Elevation (ft msl)	Secchi Disc Depth (m)	Depth to Thermocline (m)	Sample Depth (m)	Chl-a (mg/l)	D.O. (mg/l)	Temp. (°C)	Total P (mg/L)
5/4/05	888.00	2.9	2.4	0-2				0.08
5/4/05	888.00			0	6.4	11.2	10.8	0.06
5/4/05	888.00			0.999		10.4	10.2	
5/4/05	888.00			1.6	11.4			0.09
5/4/05	888.00			1.999		10.7	9.5	
5/4/05	888.00			2.2		1.6	9.3	
5/4/05	888.00			2.4		0.8	9.3	
5/26/05	888.19	1	2.4	0-2				0.13
5/26/05	888.19			0	21.10	9.0	18.5	0.10
5/26/05	888.19			1.002		8.5	18.2	
5/26/05	888.19			1.8	4.80			0.16
5/26/05	888.19			2.005		7.0	17.0	
5/26/05	888.19			2.41		0.2	16.0	
5/26/05	888.19			2.5		0.2	16.1	
6/15/05	888.53	1	2.9	0-2				0.17
6/15/05	888.53			0	13.50	5.5	22.9	0.18
6/15/05	888.53			0.999		5.6	22.9	
6/15/05	888.53			2.004		5.6	22.8	
6/15/05	888.53			2.1	12.00			0.17
6/15/05	888.53			2.525		3.9	22.8	
6/15/05	888.53			2.9		2.6	22.7	
7/6/05	888.07	0.9	2.8	0-2				0.19
7/6/05	888.07			0	87.60	12.9	24.3	0.20
7/6/05	888.07			1.003		12.6	23.5	
7/6/05	888.07			1.9	52.60			0.19
7/6/05	888.07			2.003		10.3	23.1	
7/6/05	888.07			2.592		0.3	23.0	
7/6/05	888.07			2.8		0.1	23.0	
7/28/05	888.15	0.6	2.8	0-2				0.28
7/28/05	888.15			0	95.00	7.8	24.5	0.24
7/28/05	888.15			1.013		7.8	24.4	
7/28/05	888.15			2.009	103.00	7.6	24.3	0.32
7/28/05	888.15			2.408		0.3	24.1	
7/28/05	888.15			2.831		0.4	24.2	
8/22/05	888.21	0.4	2.5	0-2				0.24
8/22/05	888.21			0	57.70	7.9	22.5	0.24
8/22/05	888.21			1.007		7.8	22.5	
8/22/05	888.21			1.8	62.10			0.24
8/22/05	888.21			2.005		7.2	22.2	
8/22/05	888.21			2.308		3.9	22.2	
8/22/05	888.21			2.5		2.2	22.2	
9/9/05	888.35	0.6	2.4	0-2				0.17
9/9/05	888.35			0	44.50	7.8	21.9	0.17
9/9/05	888.35			1.004		6.5	21.9	

Date	Water Surface Elevation (ft msl)	Secchi Disc Depth (m)	Depth to Thermocline (m)	Sample Depth (m)	Chl-a (mg/l)	D.O. (mg/l)	Temp. (°C)	Total P (mg/L)
9/9/05	888.35			1.8	40.00			0.17
9/9/05	888.35			2.045		4.1	21.6	
9/9/05	888.35			2.306		1.4	21.5	
9/9/05	888.35			2.4		0.4	21.3	
9/30/05	888.71	0.6	2.4	0-2				0.17

B-5 Bennett Lake stage storage discharge rating curve

Elevation	Area	Cumulative Storage	Discharge[1]
(ft MSL)	(ac)	(ac-ft)	(cfs)
879.0	0.0	0.0	0.000
882.0	17.7	26.6	0.000
887.6	29.8	157.7	0.000
887.7	30.1	160.7	0.003
887.8	30.3	163.7	0.030
887.9	30.6	166.8	0.100
888.0	30.8	169.8	0.239
888.5	31.6	185.6	1.998
889.0	32.5	201.4	4.051
889.5	33.9	218.4	6.591
890.0	35.3	235.3	8.3
890.5	37.3	255.0	9.7
891.0	39.4	274.7	10.9
891.5	41.4	294.4	12.0
892.0	43.4	314.0	13.0
892.5	45.4	337.8	13.9
893.0	47.4	361.5	14.8
893.5	49.4	385.2	15.6
894.0	51.5	408.9	16.0

[1] 24-hour average discharge.

B-6 Bennett Lake historic lake level data (2004-2005)

Date	Elevation (NAVD88, feet)
1/2/2004	886.753
2/3/2004	886.643
2/26/2004	886.583
3/18/2004	887.763
4/15/2004	887.803
4/22/2004	888.433
5/11/2004	888.203
5/18/2004	888.643
5/25/2004	888.963
6/14/2004	888.383
6/22/2004	887.953
7/8/2004	888.633
7/29/2004	888.003
8/10/2004	887.843
8/24/2004	887.693
9/10/2004	887.753
9/27/2004	887.973
9/28/2004	887.973
10/5/2004	889.213
10/15/2004	886.963
11/5/2004	888.483
11/29/2004	888.323
1/11/2005	888.293
2/17/2005	888.133
3/15/2005	887.983
4/20/2005	887.893
5/24/2005	888.153
6/15/2005	888.533
7/18/2005	887.813
8/2/2005	888.313
8/17/2005	888.073
8/31/2005	888.453
9/14/2005	888.293
9/30/2005	888.713
10/17/2005	889.333
11/7/2005	888.563
11/21/2005	888.433

B-7 St. Paul Campus Monthly Pan Evaporation Data

ST. PAUL CAMPUS CLIMATOLOGICAL OBSERVATORY 21-8450-6								
Source	http://climate.umn.edu/img/wxsta/pan-evaporation.htm							
	MONTHLY PAN EVAPORATION, INCHES							
Year	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	TOTAL
2004	1.91	5.41	6.3	6.63	5.14	4.91	1.27	31.57
2005	1.2	4.35	6.96	8.82	6.49	4.81	1.2	33.83
Pan Coefficient	0.7							

B-8 Bennett Lake 2005 in-lake steady state summary

Parameter	Value[1]	Comments
L=Areal Load ($mg/m^2/yr$) From May to May	431.0	(Watershed Load + Atmospheric Load) / Surface Area
Watershed Load (mg/yr)	49,156,847	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmospheric Load (mg/yr)	3,174,787	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
V=Volume (m^3)	196,744	Lake Volume[4]
A=Surface Area (m^2)	121,407	Surface Area[4]
z = mean Depth (m) = V/A	1.6	Volume / Surface Area
Q = Outflow (m^3/yr)	443,004	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1) = Q/V	2.3	Outflow / Volume
Dillon and Rigler P=L(1-Rp)/(z*r) With Rp as follows:	Predicted TP Conc. (µg/L)	
Larsen and Mercier (1976) Rp=1/(1+r^(1/2))	70.9	

1 - Based on May 1, 2004 through April 30, 2005

2 - See Tab "P8EventSummary"

3 - See Tab "UpstreamDischargeSummary", Column G

4 - At Average Water Level; See Tab "GeneralInformation"

B-9 Bennett Lake 2005 in-lake steady state summary adjusted by external load reduction

Parameter	Value[1]	Comments
L=Areal Load (mg/m²/yr) From May to May	184.5	(Watershed Load + Atmospheric Load) / Surface Area
Watershed Load (mg/yr)	19,227,947	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmospheric Load (mg/yr)	3,174,787	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
V=Volume (m³)	196,744	Lake Volume[4]
A=Surface Area (m²)	121,407	Surface Area[4]
z = mean Depth (m) = V/A	1.6	Volume / Surface Area
Q = Outflow (m³/yr)	443,004	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1) = Q/V	2.3	Outflow / Volume
Dillon and Rigler P=L(1-Rp)/(z*r) With Rp as follows:	Predicted TP Conc. (µg/L)	
Larsen and Mercier (1976) Rp=1/(1+r^(1/2))	30.3	

1 - Based on May 1, 2004 through April 30, 2005

2 - See Tab "P8EventSummary". Watershed load reduced by external load reduction noted in Table B-3.

3 - See Tab "UpstreamDischargeSummary", Column G

4 - At Average Water Level; See Tab "GeneralInformation"

B-10 **Bennett Lake 2005 physical parameter summary**

Period		A	B	C		D	E	F	G	H
		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(ac-ft)	(acre)	(ac-ft)	(ac)
5/1/04	4/30/05	7.0	887.66	4.6	15.0	879.00	159.5	30.0	0.0	0.0
5/1/05	5/4/05	0.1	888.00	2.4	7.9	880.13	159.8	30.8	10.0	6.7
5/5/05	5/26/05	0.4	888.19	2.4	7.9	880.32	164.1	31.1	11.7	7.8
5/27/05	6/15/05	0.4	888.53	2.9	9.5	879.02	186.5	31.7	0.2	0.1
6/16/05	7/6/05	0.4	888.07	2.8	9.2	879.00	172.2	30.9	0.0	0.0
7/7/05	7/28/05	0.4	888.15	2.8	9.2	879.00	174.4	31.0	0.0	0.0
7/29/05	8/22/05	0.5	888.21	2.5	8.2	880.01	167.5	31.1	8.9	6.0
8/23/05	9/9/05	0.3	888.35	2.4	7.9	880.48	167.8	31.4	13.1	8.7
9/10/05	9/30/05	0.4	888.71	2.4	7.9	880.84	176.0	32.0	16.3	10.9

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake

B - Based on the daily water balance model. See Tab "WaterBalanceSummary", Column J

C - Estimated based on water quality profile data. See Tab "WQ Data"

D - Elevation of the Thermocline: D = B - C

E - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

F - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

G - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

H - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

B-11 Bennett Lake 2005 estimated Curly-leaf pondweed loads

Curly-leaf Pondweed survey summary

Macrophyte Area[1] (acres)	20.6
% Covered w/ Curly-leaf[1]	64%
Stem Density	150
Mat/stem	0.35
P Content	2000
Areal P load (mg/m2)	105
P Load (lbs)	12.3
Estimated Season Average Curly-leaf Release Rate Check ($mg/mg^2/d$)[2]	1.2

1 – Based on qualitative macrophyte survey

2 – Normalized over 90 days (per James et. al. 2001)

Estimated internal loading from Curly-leaf Pondweed

Sampling Dates	Cumulative P Load into Water Column (lbs)	Incremental P Load into Water Column (lbs)
4/30/05	0	0.0
5/4/05	0	0.0
5/26/05	0	0.0
6/15/05	0	0.0
7/6/05	6.07	6.1
7/28/05	11.6	5.5
8/22/05	12.2	0.6
9/9/05	12.3	0.0
9/30/05	12.3	0.0

B-12 Bennett Lake 2005 estimated uptake by Coontail

Coontail survey summary

Date Coontail uptake begins	5/1/2005
Max Coontail density (g/m^2)[1]	1324.5
Macrophyte Area (ac)	25.3
% covered w/ Coontail on uptake date	5%
Coontail Area on uptake date (ac)	1.3

1 – from LCMR, 2006; Newman, 2004

Estimated uptake by Coontail

Sampling Dates	Cumulative TP Uptake (lbs)	Incremental TP Uptake (lbs)
4/30/05	0.0	0.0
5/4/05	0.0	0.0
5/26/05	0.1	0.1
6/15/05	0.3	0.1
7/6/05	0.4	0.2
7/28/05	0.6	0.2
8/22/05	0.9	0.3
9/9/05	1.1	0.2
9/30/05	1.4	0.3

B-13 Bennett Lake 2005 summary of estimated P8 watershed runoff particle class settling from epilimnion & watershed TP loads before and after settling

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling (lbs)	Watershed TP Load after Particle Settling[2,3] (lbs)
5/1/2005	5/4/2005	15.0	20.8	2.1	0.4	0.0	0.0	0.0
5/5/2005	5/26/2005	7.9	10.9	1.1	0.2	0.0	8.5	8.2
5/27/2005	6/15/2005	7.9	10.9	1.1	0.2	0.0	7.9	7.1
6/16/2005	7/6/2005	9.5	13.2	1.3	0.3	0.0	15.2	12.7
7/7/2005	7/28/2005	9.2	12.8	1.3	0.3	0.0	14.4	12.1
7/29/2005	8/22/2005	9.2	12.8	1.3	0.3	0.0	5.3	4.4
8/23/2005	9/9/2005	8.2	11.4	1.1	0.2	0.0	15.2	11.8
9/10/2005	9/30/2005	7.9	10.9	1.1	0.2	0.0	13.0	11.7

1 Number of Days to Settle Particles = De/vs/24

2 The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles.

3 The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Tab "P8EventSummary".

4 Epilimnion Depth See Tab "PhysicalParameters"

Appendix C:
Wakefield Lake Water and Phosphorus Balance Model

C-1 Wakefield Lake 2004 climatic conditions water balance summary

	Sample Period		A	B	C	D	E	F	G	H	I	J
			Total Lake Volume at the Start of the Period (acre-ft)	Direct Precipitation (acre-ft)	Evaporation (acre-ft)	Watershed Runoff (acre-ft)	Groundwater Inflow (acre-ft)	Surface Discharge (acre-ft)	Groundwater Outflow (acre-ft)	Change in Lake Volume (acre-ft)	Total Lake Volume at the End of the Period (acre-ft)	Lake Level at End of Period (ft MSL)
				+	-	+	+	-	-			
Steady State Year (May 1, 2003 - April 30, 2004)	5/1/2003	4/29/2004	100.9	39.7	44.8	488.1	0	484.7	0	-1.6	99.3	884.72
(Oct 1, 2003 - April 30, 2004)	10/1/2003	4/29/2004	96.8	13.1	10.5	154.5	0	154.7	0	2.5	99.3	884.72
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2004 - Sept 30, 2004)	4/30/2004	5/12/2004	99.3	1.3	2.5	12.3	0	8.1	0	3.1	102.3	884.87
	5/13/2004	6/9/2004	102.3	14.1	6.3	146.3	0	151.3	0	2.8	105.1	885.01
	6/10/2004	7/1/2004	105.1	2.3	5.1	29.3	0	36.3	0	-9.8	95.3	884.50
	7/2/2004	7/22/2004	95.3	4.2	5.1	40.2	0	37.9	0	1.3	96.6	884.58
	7/23/2004	8/10/2004	96.6	0.8	3.6	6.6	0	6.2	0	-2.3	94.3	884.44
	8/11/2004	8/30/2004	94.3	1.7	3.6	15.8	0	9.9	0	4.0	98.3	884.67
	8/31/2004	9/22/2004	98.3	7.7	4.3	81.7	0	84.5	0	0.7	99.0	884.70
	9/23/2004	9/30/2004	99.0	0.4	1.5	3.7	0	4.7	0	-2.1	96.9	884.59
Total for Growing Season (June 1, 2004 - Sept 30, 2004)	6/1/2004	9/30/2004	114.6	20.9	25.5	211.4	0	224.5	0	-17.7	96.9	884.59
Total for Water Year 2004 (Oct 1, 2003 - Sept 30, 2004)	10/1/2003	9/30/2004	96.8	45.6	42.4	490.3	0	493.4	0	0.1	96.9	884.59

Annual (2004 Water Year) Water Load to Wakefield Lake (acre-ft)	10/1/2003	9/30/2004	536	Water Load = B + D + E

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Tab "WaterBalance"
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area). See Tab "P8EventSummary".
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Tab "Evap"
D - Based on the water loads from the P8 model. See Tab "P8EventSummary"
E - Groundwater Inflow estimated in the daily water balance model.
F - Surface discharge from 24-hour average rating curve. See Tab "Lake Rating Curve"
G - Groundwater Discharge estimated in the daily water balance model.
H - Change in Lake Volume = B - C + D + E - F - G
I - Total Lake Volume @ End of Period = A + G
J - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Tab "Lake Rating Curve"

C-2 Wakefield Lake 2004 climatic conditions in-lake growing season mass balance model summary[1]

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
		Epilimnion Volume	P In-Lake @ Start of Period	Total P Watershed Runoff	P Surface Runoff (after Particulate Settling)[5]	P From SSTS	P Atmospheric	P GW	P Release from Curly-leaf Pondweed[4]	P Uptake by Coontail[4]	P Loss due to Discharge	P Remaining in lake	In-Lake P before Adjustment	Observed In-Lake P	Residual Adjustment (Internal Loading / Losses)	Residual Adjustment (Internal Loading / Losses)[6]	P In-Lake @ End of Period	Predicted In-Lake P[2]
Period Start		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	µg/l	µg/L	µg/l	lbs	lbs	µg/L
Steady State Total (May 1, 2003 - April 30, 2004)[3,4,7]		102.9	N/A	279.2	93.9	0	4.8	0	N/A	N/A	88.1	N/A	N/A	N/A	N/A	N/A	N/A	66.8
(Oct 1, 2003 - April 30, 2004)[3,7]		102.9	N/A	53.7	18.1	0	3.0	0	0	0.0	28.1	N/A	N/A	N/A	N/A	N/A	N/A	66.8
4/30/04	5/12/04	85.8	18.7	12.3	6.6	0	0.2	0	0	0.1	1.5	23.9	102.5	119.3	16.9	3.9	27.9	119
5/13/04	6/9/04	87.8	27.9	80.1	29.8	0	0.4	0	0	0.9	49.1	8.0	33.3	138.5	105.2	25.1	33.1	139
6/10/04	7/1/04	71.1	33.1	20.7	3.0	0	0.2	0	0	1.7	13.7	21.0	108.3	196.5	88.2	17.1	38.0	197
7/2/04	7/22/04	76.0	38.0	26.5	4.2	0	0.2	0	0	2.6	20.3	19.5	94.4	204.5	110.1	22.8	42.3	205
7/23/04	8/10/04	82.4	42.3	4.6	1.2	0	0.2	0	0	2.8	3.4	37.4	167.0	167.5	0.5	0.1	37.5	168
8/11/04	8/30/04	83.1	37.6	11.3	3.3	0	0.2	0	0	3.4	4.5	33.3	147.2	121.0	-26.2	-5.9	27.3	121
8/31/04	9/22/04	93.4	27.3	43.0	18.3	0	0.3	0	0	4.4	27.8	13.8	54.2	98.0	43.8	11.1	24.9	98
9/23/04	9/30/04	92.0	24.9	2.5	1.2	0	0.1	0	0	1.7	1.3	23.3	93.0	98.0	5.0	1.2	24.5	98[7]
Growing Season Total (June 1, 2004 - Sept 30, 2004)[8]		N/A	N/A	127.7[9]	40.8[10]	0	1.4[10]	0	0	16.9[10]	86.7[10]	N/A	N/A	N/A	N/A	60.4[11]	N/A	N/A
Total for Water Year 2004 (Oct 1, 2003 - Sept 30, 2004)[3,8]		N/A	N/A	254.8[9]	85.7	0	4.8	0	0	17.6	149.6	N/A	N/A	N/A	N/A	81.3[12]	N/A	N/A
Growing Season Average (6/1/2004 – 9/30/2004)[13]																		154

1 - Reflective of in-lake water quality model calibration conditions (2004 watershed conditions)
2 - Growing Season Average Reflects WQ data from June through September
3 - An empirical model (Dillon and Rigler (1974) with Chapra (1975) retention coefficient) was used to predict the steady state TP concentration at the beginning of the phosphorus mass balance model developed for the period from May 1, 2003 - September 30, 2004.
4 - Phosphorus release from Curly-leaf pondweed and uptake by Coontail was not estimated for the Steady State year because phosphorus mass balance modeling was not performed for the period from May 1, 2003 - April 30, 2004. Also, it was assumed that during the period from October 1 - April 30 the phosphorus loading due to Curly-leaf pondweed and uptake by Coontail would be negligible due to the growth/die back cycles of these macrophytes during this season.
5 - The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2003 - April 30, 2004 reflects the total watershed runoff load multiplied by the ratio of watershed runoff P load after settling to the total watershed runoff P load.
6 - The individual TP adjustment values represent the net phosphorus load adjustment, including both phosphorus loads to the lake and losses such as sedimentation. Their algebraic sums year totals of these values will not match the growing season and water year totals below the data column nor the "internal loading from other sources" in Tab "PSourceSummary" which only summarizes the (positive) loads to the lake.
7 - Last P concentration observed (9/22/04) applied to the final growing season date (9/30/04) to establish a terminal boundary condition for growing season calculations.
8 - For Total Loads, total rounded to the nearest tenth of a lb for reporting purposes.
9 - Calculated from the P8 event loading for dates within the growing season (see Table A-4).
10 - Interpolated sum for the growing season (June 1, 2004 - Sept 30, 2004).
11 - Interpolated sum of positive loading values for the growing season (June 1, 2004 - Sept 30, 2004).
12 - Sum of positive loading values for the water year (Oct 1, 2003 – Sept 30, 2004).
13 - The growing season average TP concentration (µg/L) was calculated from values corresponding to observed growing season water quality concentrations in Wakefield Lake (cells highlighted in blue).
A - See Tab "PhysicalParameters". The epilimnion volume represents the predicted epilimnion volume at the end of the time period.
B - Amount of phosphorus present in lake at the beginning of the timestep (based on spring steady state or observed TP concentration and epilimnetic volume from the previous timestep).
C - Based on the Watershed TP Load before Particle Settling. See Tab "Particle Settling Summary"
D - Based on the Watershed TP Load after Particle Settling. See Tab "Particle Settling Summary"

(Continued on following page)

(Table C-2: Continued from previous page)

E - Based on estimated load from failing SSTS in the direct watershed. See Tab "Upstream_DischargeSummary"

F - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake

G - Load from Groundwater Inflow. See Tab "Upstream_DischargeSummary"

H - Based on a phosphorus release rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Tab "Curly-leaf Decay Summary"

I - Based on average daily uptake rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Tab "Coontail Uptake Summary"

J - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the TP concentration from the previous time period. See Tab "Upstream_DischargeSummary"

K - P Remaining in Lake = B + D + E + F + G + H - I - J

L - In-Lake P before Adj = K / A / 0.00272

M - Water quality monitoring data. See Tab "WQ Data"

N - Residual Adjustment = M - L; The Residual Adjustment is the calibration parameter used to describe the internal phosphorus loads to the lake not explicitly estimated (e.g. release from bottom sediments, resuspension due to fish activity or wind, etc.), to estimate the uptake of phosphorus from the water column by algae growth, to estimate sedimentation of phosphorus from the water column, as well as to factor in possible error in the monitoring data.

O - Residual Adj Load = N*A * 0.00272. Positive values are treated as a phosphorus source to the lakes such as sediment release while negative values are handled as a sink, such as sedimentation.

P - P In-Lake at End of Period = K + O

Q - Predicted In-Lake P is a check against the Observed In-Lake P.

C-3 Wakefield Lake 2004 climatic conditions in-lake growing season mass balance model allowable load estimate

Period Start		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
		Epilimnion Volume	P In-Lake @ Start of Period	Total P Watershed Runoff	P Surface Runoff (after Particulate Settling)[4]	P From SSTS	P Atmospheric	P GW	P Release from Curly-leaf Pondweed	P Uptake by Coontail	P Loss due to Discharge	P Remaining in lake	In-Lake P before Adjustment	Observed In-Lake P	Residual Adjustment (Internal Loading / Losses)	Residual Adjustment (Internal Loading / Losses)	P In-Lake @ End of Period	Predicted In-Lake P
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	µg/l	µg/L	µg/l	lbs	lbs	µg/L
4/30/04	5/12/04	85.8	15.7[1]	10.2	3.4	0.0	0.2	0.0	0.0	0.1	1.2	18.0				0.8	18.8	80
5/13/04	6/9/04	87.8	18.8	67.0	22.5	0.0	0.4	0.0	0.0	0.9	33.1	7.7				5.0	12.7	53
6/10/04	7/1/04	71.1	12.7	17.3	5.8	0.0	0.2	0.0	0.0	1.7	5.2	11.8				3.4	15.2	79
7/2/04	7/22/04	76.0	15.2	22.1	7.4	0.0	0.2	0.0	0.0	2.6	8.1	12.1				4.6	16.7	81
7/23/04	8/10/04	82.4	16.7	3.8	1.3	0.0	0.2	0.0	0.0	2.8	1.4	14.0				0.0	14.0	63
8/11/04	8/30/04	83.1	14.0	9.5	3.2	0.0	0.2	0.0	0.0	3.4	1.7	12.4				-2.2	10.2	45
8/31/04	9/22/04	93.4	10.2	35.9	12.1	0.0	0.3	0.0	0.0	4.4	10.4	7.8				2.2	10.0	40
9/23/04	9/30/04	92.0	10.0	2.1	0.7	0.0	0.1	0.0	0.0	1.7	0.5	8.7				0.2	8.9	36
Growing Season Total (June 1, 2004 - Sept 30, 2004)		N/A	N/A	106.7	37.8	0.0	1.4	0.0	0.0	16.9	37.9	69.3				12.1	79.2	N/A
																	Growing Season Average (6/1/2005 - 9/30/2005)[5]	60

Required load reduction (lbs / growing season) to meet MPCA standard for Wakefield Lake

P Loading Source	Existing Conditions (2004)	TMDL Condition	Pre 10% MOS		MOS (10%)[6]	Post 10% MOS	
			Loading Reduction	Loading Reduction		Loading Reduction	Loading Reduction
	lbs	lbs	lbs	%	lbs	lbs	%
Watershed Runoff	127.7	106.7	21.0	16.4%[1]	12.0	33	25.8%
Atmospheric	1.4	1.4	0	0%	0	0	0%
Curly-leaf pondweed	--	--	--	--	--	--	--
Internal Loading	60.4	12.1	48.3	80%[2]	0	48.3	80%
Total	**189.4**	**120.2**	**69.3**	**36.6%**	**0**	**81.3**	**42.9%**

1 – Based on assumed initial in lake P concentration of 56 µg/L (see Table C-9).

2 – Internal load reduction (80%) applied to internal loading sources. Cells highlighted in yellow are the result of the noted percent reduction applied to the existing loading value. The reduction applied (80%) was chosen to represent the percent reduction achievable through methods of internal phosphorus removal and control (alum treatment).

3 – The external (watershed) load reduction applied is the reduction value required to achieve the MPCA growing season TP water quality standard (60 µg/L). The reduction value (16.4%) applied to cells highlighted in orange was calculated by solving for the external load reduction required to meet the MPCA growing season TP water quality standard after applying of the internal load reduction (see item #1).

4 – The reported phosphorus load associated with surface runoff during the steady state period reflects the total watershed runoff load multiplied by the ratio of watershed runoff P load after settling to the total watershed runoff P load.

5 – The growing season average TP concentration (µg/L) was calculated from values corresponding to observed growing season water quality concentrations in Bennett Lake (cells highlighted in blue).

6 – A MOS of 10% of the total loading capacity (120 lbs.) was applied to as described in Section 4.3.4.

C-4 Wakefield Lake 2004 water quality

Date	Water Surface Elevation (ft msl)	Secchi Disc Depth (m)	Depth to Thermocline (m)	Sample Depth (m)	Chl-a (mg/l)	D.O. (mg/l)	Temp. (°C)	Total P (mg/L)
5/12/04	884.87	0.6	2	0-2				0.12
5/12/04	884.87		2	0		8.9	19.4	0.10
5/12/04	884.87			0.99		8.8	19.4	0.11
5/12/04	884.87			1.9				0.15
5/12/04	884.87			2		1.6	16.5	
5/12/04	884.87			2.5		1.0	14.4	
6/9/04	885.01	0.7	2	0-2				0.14
6/9/04	885.01		2	0	0.04	7.7	21.9	0.12
6/9/04	885.01			1		7.6	21.9	
6/9/04	885.01			2	0.03	2.3	20.3	0.15
6/9/04	885.01			2.7		0.6	17.2	
7/1/04	884.50	0.55	1.5	0-2				0.20
7/1/04	884.50		1.5	0	0.06	12.7	24.5	0.14
7/1/04	884.50			1		11.1	23.1	
7/1/04	884.50			1.7	0.10			0.26
7/1/04	884.50			2		0.5	17.7	
7/1/04	884.50			2		0.7	18.8	
7/22/04	884.58	0.55	1.7	0-2				0.20
7/22/04	884.58		1.7	0	0.09	10.5	27.0	0.14
7/22/04	884.58			1		9.6	27.1	
7/22/04	884.58			1.8	0.05			0.27
7/22/04	884.58			2.4		0.2	19.3	
7/22/04	884.58			2.4		0.3	20.9	
8/10/04	884.44	0.65	2.1	0-2				0.17
8/10/04	884.44		2.1	0	0.05	0.7	21.3	0.16
8/10/04	884.44			1		6.6	21.3	
8/10/04	884.44			1.5	0.06			0.18
8/10/04	884.44			2.1		0.6	21.2	
8/10/04	884.44			2.1		6.5	21.3	
8/30/04	884.67	0.6	2	0-2				0.12
8/30/04	884.67		2	0	0.06	8.3	20.3	0.12
8/30/04	884.67			0.99		7.6	20.1	
8/30/04	884.67			1.8	0.04			0.13
8/30/04	884.67			1.98		0.9	19.8	
8/30/04	884.67			1.98		1.0	19.8	
8/30/04	884.67			1.98		6.0	19.9	
9/22/04	884.70	0.8	2.5	0-2				0.10
9/22/04	884.70		2.5	0	0.05	7.3	20.2	0.09
9/22/04	884.70			1		6.9	20.1	
9/22/04	884.70			2	0.05	6.5	20.0	0.11

Date	Water Surface Elevation (ft msl)	Secchi Disc Depth (m)	Depth to Thermocline (m)	Sample Depth (m)	Chl-a (mg/l)	D.O. (mg/l)	Temp. (°C)	Total P (mg/L)
9/22/04	884.70			2.5		4.4	19.9	
9/22/04	884.70			2.5		4.6	19.9	
9/30/04	884.59	0.8	2.5	0-2				0.10

C-5 Wakefield Lake stage storage discharge rating curve

Elevation	Area	Cumulative Storage	Discharge[1]
(ft MSL)	(ac)	(ac-ft)	(cfs)
875.6	0.0	0	0.0
880.6	12.1	30	0.0
880.9	16.4	35	0.0
882.6	16.8	63	0.0
884.3	17.2	92	0.1
884.6	17.3	97	0.2
884.8	20.5	101	0.3
884.9	20.6	103	0.4
885.0	20.8	105	0.9
885.5	21.4	115	4.5
886.0	22.1	126	8.3
887.0	23.4	149	16.8
887.6	24.2	163	21.9
888.0	24.7	173	25.9
889.0	25.8	198	35.3
891.0	28.1	252	55.5
892.8	30.3	305	75.0
893.0	30.5	311	77.6
894.0	31.7	342.0	89.0

1 24-hour average discharge.

C-6 Wakefield Lake historic lake level data (2003-2004)

Date	Elevation (NAVD88, feet)
1/20/2003	884.64
2/14/2003	884.37
3/13/2003	884.12
4/2/2003	884.88
4/14/2003	884.54
5/15/2003	885.05
5/30/2003	884.68
6/12/2003	884.5
6/26/2003	885.67
7/15/2003	884.97
7/30/2003	884.74
8/15/2003	884.4
9/3/2003	884.2
9/16/2003	884.94
10/1/2003	884.83
10/14/2003	884.67
10/15/2003	884.9
10/29/2003	884.72
11/14/2003	884.67
12/10/2003	884.47
1/2/2004	884.54
2/3/2004	884.12
2/26/2004	884.34
3/18/2004	885.06
4/15/2004	884.65
4/15/2004	884.7
4/22/2004	885.07
5/11/2004	885.04
5/18/2004	885.11
5/25/2004	885.06
6/14/2004	885.19
6/22/2004	884.84
7/8/2004	885.19
7/29/2004	884.83
8/10/2004	884.73
8/24/2004	884.6
9/10/2004	884.92
9/27/2004	884.87
10/15/2004	884.75
11/5/2004	884.94
11/29/2004	884.97

C-7 St. Paul Campus Monthly Pan Evaporation Data

ST. PAUL CAMPUS CLIMATOLOGICAL OBSERVATORY 21-8450-6								
Source	http://climate.umn.edu/img/wxsta/pan-evaporation.htm							
	MONTHLY PAN EVAPORATION, INCHES							
Year	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	TOTAL
2003	2.09	5.93	6.23	6.88	6.84	5.25	1.39	34.61
2004	1.91	5.41	6.3	6.63	5.14	4.91	1.27	31.57
Pan Coefficient	0.7							

C-8 Wakefield Lake 2004 in-lake steady state summary

Parameter	Value[1]	Comments
L=Areal Load ($mg/m^2/yr$) From May to May	1546	(Watershed Load + Atmospheric Load) / Surface Area
Watershed Load (mg/yr)	126,903,306	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmospheric Load (mg/yr)	2,183,386	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
qs =Overflow Rate (m/yr)	7.1	Outflow / Surface Area
V=Volume (m^3)	126,869	Lake Volume[4]
A=Surface Area (m^2)	83,495	Surface Area[4]
z= mean Depth (m)	1.5	Volume / Surface Area
Q=Outflow (m^3/yr)	595,855	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1)	4.7	Outflow / Volume
Dillon and Rigler P=L(1-Rp)/(z*r) With Rp as follows:	Predicted TP Conc (µg/L)	
Chapra (1975) Rp=16/(16+qs)	67	

1 - Based on May 1, 2003 through April 30, 2004

2 - See Tab "P8EventSummary"

3 - See Tab "UpstreamDischargeSummary", Column G

4 - At Average Water Level; See Tab "GeneralInformation"

C-9 Wakefield Lake 2004 in-lake steady state summary adjusted by external load reduction

Parameter	Value[1]	Comments
L=Areal Load (mg/m²/yr) From May to May	1296	(Watershed Load + Atmospheric Load) / Surface Area
Watershed Load (mg/yr)	106,033,348	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmospheric Load (mg/yr)	2,183,386	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
qs =Overflow Rate (m/yr)	7.1	Outflow / Surface Area
V=Volume (m³)	126,869	Lake Volume[4]
A=Surface Area (m²)	83,495	Surface Area[4]
z = mean Depth (m) = V/A	1.5	Volume / Surface Area
Q = Outflow (m³/yr)	595,855	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1) = Q/V	4.7	Outflow / Volume
Dillon and Rigler P=L(1-Rp)/(z*r) With Rp as follows:	Predicted TP Conc. (µg/L)	
Chapra (1975) Rp=16/(16+qs)	56	

1 - Based on May 1, 2004 through April 30, 2005

2 - See Tab "P8EventSummary". Watershed load reduced by external load reduction noted in Table C-3.

3 - See Tab "UpstreamDischargeSummary", Column G

4 - At Average Water Level; See Tab "GeneralInformation"

C-10 Wakefield Lake 2004 physical parameter summary

Period		A	B	C		D	E	F	G	H
		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(ac-ft)	(acre)	(ac-ft)	(ac)
5/1/03	4/29/04	4.8	884.90	5.6	18.4	875.59	102.9	20.6	0.0	0.0
4/30/04	5/12/04	0.2	884.87	2.0	6.6	878.31	85.8	20.6	16.5	6.6
5/13/04	6/9/04	0.4	885.01	2.0	6.6	878.45	87.8	20.8	17.3	6.9
6/10/04	7/1/04	0.2	884.50	1.5	4.9	879.58	71.1	17.3	24.1	9.7
7/2/04	7/22/04	0.2	884.58	1.7	5.6	879.00	76.0	17.3	20.6	8.3
7/23/04	8/10/04	0.2	884.44	2.1	6.9	877.55	82.4	17.2	11.9	4.8
8/11/04	8/30/04	0.2	884.67	2.0	6.6	878.11	83.1	18.5	15.2	6.1
8/31/04	9/22/04	0.3	884.70	2.5	8.2	876.50	93.4	19.0	5.5	2.2
9/23/04	9/30/04	0.1	884.59	2.5	8.2	876.39	92.0	17.4	4.9	1.9

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake

B - Based on the daily water balance model. See Tab "WaterBalanceSummary", Column J

C - Estimated based on water quality profile data. See Tab "WQ Data"

D - Elevation of the Thermocline: D = B - C

E - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

F - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

G - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

H - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

C-11 Wakefield Lake 2004 estimated uptake by Coontail

Coontail survey summary

Date Coontail uptake begins	5/1/2004
Max Coontail density (g/m^2)[1]	1324.5
Macrophyte Area (ac)	17.6
% covered w/ Coontail on uptake date	5%
Coontail Area on uptake date (ac)	0.9

1 – from LCMR, 2006; Newman, 2004

Estimated uptake by Coontail

Sampling Dates	Cumulative TP Uptake (lbs)	Incremental TP Uptake (lbs)
4/29/04	0.00	0.0
5/12/04	0.04	0.1
6/9/04	0.46	1.0
7/1/04	1.24	2.7
7/22/04	2.44	5.4
8/10/04	3.71	8.2
8/30/04	5.23	11.5
9/22/04	7.22	15.9
9/30/04	7.97	17.6

C-12 Wakefield Lake 2004 summary of estimated P8 watershed runoff particle class settling from epilimnion & watershed TP loads before and after settling

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
			0.03	0.3	1.5	15		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling (lbs)	Watershed TP Load after Particle Settling[2,3] (lbs)
4/30/2004	5/12/2004	18.4	25.6	2.6	0.5	0.1	12.3	6.6
5/13/2004	6/9/2004	6.6	9.1	0.9	0.2	0.0	80.1	29.8
6/10/2004	7/1/2004	6.6	9.1	0.9	0.2	0.0	20.7	3.0
7/2/2004	7/22/2004	4.9	6.8	0.7	0.1	0.0	26.5	4.2
7/23/2004	8/10/2004	5.6	7.7	0.8	0.2	0.0	4.6	1.2
8/11/2004	8/30/2004	6.9	9.6	1.0	0.2	0.0	11.3	3.3
8/31/2004	9/22/2004	6.6	9.1	0.9	0.2	0.0	43.0	18.3
9/23/2004	9/30/2004	8.2	11.4	1.1	0.2	0.0	2.5	1.2

1 Number of Days to Settle Particles = De/vs/24

2 The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles.

3 The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Tab "P8EventSummary".

4 Epilimnion Depth See Tab "PhysicalParameters"

Appendix D: Wakefield Lake 2D Modeling

Wakefield Lake 2D Modeling

There are three storm sewer inlets to Wakefield Lake, including discharges from the subwatersheds PHAL-03a (northwest inlet), PHAL-03b (northeast inlet), and PHAL-03c (southeast inlet, also known as the "Larpenteur Avenue storm sewer", see Figure 3-4 of this TMDL study). However, during the development of the Wakefield Lake Strategic Lake Management Plan (Barr 2008), it was suspected that much of the runoff coming from the area drained by the Larpenteur Avenue storm sewer (including subwatersheds PHAL 03c and upstream PHAL 01, PHAL 02a and PHAL 02b) may not significantly influence the observed water quality of Wakefield Lake. Because the flows from Larpenteur Avenue enter on the southeast end of the lake directly across from the lake's outlet on the southwest corner of the lake, it was suspected that flow may be effectively bypassing the lake (short-circuiting). Water quality in the southern part of the lake has not historically been monitored (historic monitoring location is in the center of the lake, see Figure D-1), so the impact of PHAL 03c flows on Wakefield Lake's water quality in the southern end of the lake are unknown. However, if short-circuiting occurs, it must be accounted for as part of the in-lake modeling to appropriately quantify the watershed phosphorus loads to Wakefield Lake that influence the water quality (as observed) and to deduce the lake's internal phosphorus loads (see Section 4.3.1.7 for additional discussion of the in-lake mass balance modeling). In order to better understand the mixing dynamics of Wakefield Lake and to estimate the contribution of the runoff from the Larpenteur Avenue storm sewer to the observed water quality in the main body of the lake, a 2-dimensional (2D) hydraulic model of inflows and mixing patterns in Wakefield Lake was developed.

We selected the Adaptive Hydraulics v4.2 (AdH) model, a 2D hydraulic model developed by the Coastal and Hydraulic Laboratory (CHL), Engineer Research and Development Center (ERDC) and the United States Army Corps of Engineers (USACE) for this analysis. AdH was selected because of its ability to determine flow vectors to visualize mixing processes and incorporate diffusion to estimate mixing within a body of water. Within the AdH 2D model, computer-estimated flow velocities are depth-averaged along the water column. It was determined that this modeling approach was appropriate for this level of investigation because the shallow nature of Wakefield Lake prevents significant temperature stratification that would affect differential flow velocities. In addition, AdH has the ability to adapt numerical meshes to efficiently compute a solution. The numerical mesh is the 2D surface, with associated elevations, used to perform the model calculations. Preprocessing of model inputs, including developing the mesh, was completed using AquaVeo's Surface-Water Modeling System Version 11.1 (SMS).

To develop the 2D model of Wakefield Lake, we utilized updated bathymetry data collected by the RWMWD in 2013 to develop the bathymetry grid. To evaluate the hydrodynamics of the system, we used inflow data generated by the P8 water quality model for the critical water quality year (2003 to 2004) at the three main storm sewer inflows to the lake (on the northwest, northeast, and southeast sides of the lake). Additionally, we accounted for the outlet located on the southwest corner of the lake.

We evaluated multiple scenarios to evaluate the lake mixing dynamics including:

- Constant average inflows from the P8 model for each inlet
- Constant peak inflows from the P8 model for each inlet
- Hourly hydrographs from the P8 model for each inlet, run for a period of about 6 months including the largest storm event during the critical water quality year

Although the constant inflow for an extended period of time scenarios is not realistic given the nature of storm events, the goal of these scenarios was to help isolate the relative impacts of the main factors influencing the mixing dynamics in Wakefield Lake. Some additional variables may have short term or minor impacts on mixing within the lake, but were not incorporated into the models, including:

- Mixing due to wind
- Evaporation causing the water surface elevation to drop below the outlet elevation, which would impact how flow vectors influence mixing as the water levels increase to the lake outlet elevation.
- Full stage-discharge rating curve for the lake outlet, which would impact how quickly water leaves the lake. Available water level data indicates that the water surface bounce on Wakefield Lake is quite small, so the model assumed a constant water surface elevation.

While these variables would be important when doing a detailed analysis and model calibration, we assumed that these variables are not expected to significantly govern the mixing dynamics in the lake or the conclusions drawn from the model results,

To evaluate the impact of the Larpenteur Avenue flows on the observed water quality in Wakefield Lake, we utilized flow vectors and "dummy" concentrations with the flow inputs in AdH to evaluate relative impacts of the inflows on observed water quality. A concentration of 1 ppm was applied to the northwest and northeast inflows. A concentration of 100 ppm was applied to the southeast inflow (Larpenteur Avenue). And based on the various flow scenarios that were evaluated, the resulting concentration around the deep hole in Wakefield Lake reflects the approximate contribution (as a percentage) of the southeast inflow.

Constant inflow scenarios were run for approximately one year of model time to generate a stable modeled concentration in the north end of the lake. Average flow and high flow scenarios based on the P8 modeling results were modeled to evaluate the expected flow dynamics during these two different flow conditions. In the average flow scenario, velocities within the lake were extremely low (less than 0.01 ft/sec) and in general, the average flows into Wakefield Lake did not develop into a consistent flow pattern. In the constant flow scenario, the final concentration in the main basin on the north end of Wakefield Lake was approximately 25-30 ppm. Since the inflow concentrations for the two northern inflow locations was 1 ppm, flow vectors indicated very little mixing through the lake, and the total flow entering the main basin in the northern portion of the lake was greater than the flow entering the southern portion of the lake, the final concentration in the main basin can be attributed to diffusion of the high concentration from the southern input into the northern portion of the lake.

In the high, constant inflow scenario, a steady flow pattern developed throughout Wakefield Lake. The final concentration in the northern portion of the lake was 1.3 ppm, so the high flows prevented mixing of the flows from the southern inlet to the lake into the northern portion of the lake and prevented diffusion from having a significant impact on the expected water quality in the main basin of the lake. We performed this scenario primarily to establish the flow-based mixing patterns (as opposed to diffusion-based mixing patterns).

In addition to the constant inflow scenarios, we evaluated additional scenario using hourly time step hydrographs from the P8 model. As could be expected, the hydrograph scenario, provided results that were a mix of the two constant inflow scenarios. In general, concentrations in the main basin on the north end of the lake were low during and immediately after runoff events when higher flows governed the mixing patterns, but the concentrations went up during low flow or no flow periods when diffusion would govern the mixing, bringing TP from the south end to the main body of the lake.

Typically, the southeast inflows from Larpenteur Avenue have a higher peak rate and enter the lake before the flows from the other two inlets in the northern portion of the lake. This is because the watershed along Larpenteur Avenue is highly impervious and has very limited stormwater treatment that could temporarily detain flows, especially when compared to the watersheds of the northwest and northeast inlets. As such, during a storm event, flows from along Larpenteur Avenue enter Wakefield Lake before flows from other portions of the watershed. These flows begin moving north in the lake. However, by the time the flows from Larpenteur Avenue begin reaching the central portion of Wakefield Lake, the inflows from the northeast and northwest inlets begin to flow into the lake against the flows from Larpenteur Avenue, and preventing the flows from Larpenteur Avenue from fully-mixing into the main basin of the lake. Therefore, flows from along Larpenteur Avenue never directly reach the historic monitoring location in Wakefield Lake.

Figure D-1 shows the flow vectors and relative concentrations through Wakefield Lake for the storm event on June 25, 2003, demonstrating the mixing pattern discussed above in relation to the hourly inflow hydrograph scenarios. Also shown on the figure is the location of the historic water quality monitoring location in Wakefield Lake.

As a result of this hydrodynamic analysis, observed that Wakefield Lake likely does not fully-mix and that the majority of the phosphorus load from the watershed along Larpenteur Avenue does not directly influence the observed water quality. Flows from the southeast portion of the watershed primarily influences the water quality in Wakefield Lake due to diffusion of the soluble fraction of phosphorus from the southern portion of the lake to the main basin of the lake (where the historic water quality data has been collected) during the storm event and after an event (for any runoff remaining in the lake). The degree of flow-induced mixing during any given runoff event will be variable; however the primary mechanism governing the influence of the Larpenteur Avenue storm sewer runoff on the observed lake water quality in Wakefield Lake is diffusion. Based on the scenarios run in AdH, the predicted P8 watershed phosphorus loads used in the in-lake mass balance modeling were reduced to reflect the "effective" watershed load from the Larpenteur Avenue storm sewer. We assumed that only 30% of the soluble phosphorus load from the runoff coming through the Larpenteur Avenue storm sewer (southeast inlet) to Wakefield Lake actually influences the observed water quality. Because the P8 model tracks the movement of five different particle sizes (with a certain amount phosphorus associated with each particle size fraction), we were able to estimate the amount of soluble phosphorus coming from the Larpenteur Avenue Watershed and reduce the effect of the particulate loading from the

Larpenteur Avenue storm sewer used in the in-lake mass balance model to represent the main body of Wakefield Lake.

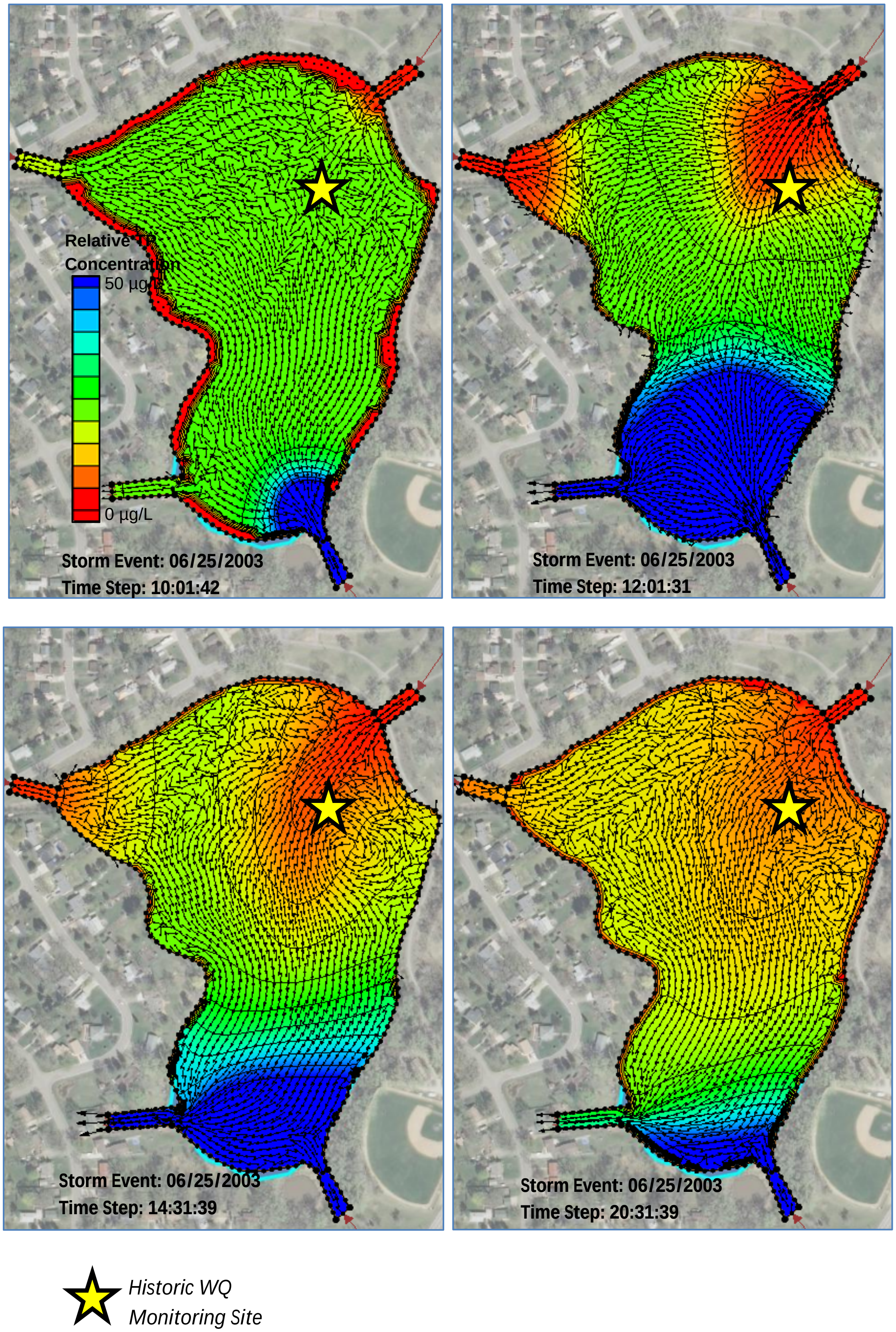

Figure D-1 Wakefield Lake 2D AdH modeling results from June 25, 2003 storm event.

Appendix E: Impaired Waterbodies by Location

E-1 Impaired lakes and streams by MS4

MS4			
MS4 Name	**MS4 ID Number**	**Impaired Lake/Stream**	**WBID**
Maplewood City	MS400032	Battle Creek Fish Creek Wakefield Lake	07010206-592 07010206-606 62-0011-00
MnDOT Metro District	MS400170	Battle Creek Fish Creek Bennett Lake	07010206-592 07010206-606 62-0048-00
North St. Paul City	MS400041	Wakefield Lake	62-0011-00
Ramsey County Public Works	MS400191	Battle Creek Fish Creek Bennett Lake Wakefield Lake	07010206-592 07010206-606 62-0048-00 62-0011-00
Roseville City	MS400047	Bennett Lake	62-0048-00
Saint Paul Municipal Storm Water	MN0061263	Battle Creek Fish Creek Wakefield Lake	07010206-592 07010206-606 62-0011-00
Washington County	MS400160	Battle Creek Fish Creek	07010206-592 07010206-606
Woodbury City	MS400128	Battle Creek Fish Creek	07010206-592 07010206-606