Minnehaha Creek E. Coli Bacteria / Lake Hiawatha Nutrients

Total Maximum Daily Load

October 2013

Prepared for

U.S. Environmental Protection Agency -- Region 5
Minnesota Pollution Control Agency
Minnehaha Creek Watershed District

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Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

BMP	Best Management Practice
CAFO	confined animal feeding operation
CIP	capital improvement program
CSO	combined sewer overflow
CWA	Clean Water Act
cfs	cubic feet per second
DMR	Discharge Monitoring Report
FDC	flow duration curve
GIS	Geographic Information System
HHPLS	Hydrologic, Hydraulic and Pollutant Loading Study
IC	impervious cover
IDDE	Illicit discharge detection and elimination
LA	Load Allocations
LDC	load duration curve
LGU	Local Government Unit
MCWD	Minnehaha Creek Watershed District
MLCCS	Minnesota Land Cover Classification System
MOS	margin of safety
Mn/DOT	Minnesota Department of Transportation
MPCA	Minnesota Pollution Control Agency
MPRB	Minneapolis Park and Recreation Board
MS	Minnesota Statutes
MS4	Municipal Separate Storm Sewer System
NCDC	National Climatic Data Center
NCHF	North Central Hardwood Forests
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NRCS	Natural Resources Conservation Service
SDS	State Disposal System
SSC	site-specific criteria
SSO	sanitary sewer overflow
SSURGO	Soil Survey Geographic Database
SWMP	Stormwater Management Program
SWPPP	Stormwater Pollution Prevention Program
TMDL	Total Maximum Daily Load
TP	total phosphorus
TSI	trophic state index
UMRB	Upper Mississippi River Basin
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WLA	Wasteload Allocations
WQS	water quality standards
WRMP	Water Resource Management Plan

TMDL Summary

EPA/MPCA Required Elements	Summary	TMDL Page Number
Location	Minnehaha Creek Watershed District in Upper Mississippi River Basin; Hennepin County, MN (HUC 07010206)	1-2
303(d) Listing Information	Minnehaha Creek: 07010206-539 Impaired Beneficial Use: Aquatic Recreation Indicator: Fecal Coliform Original Listing Year: 2008 Lake Hiawatha: 27-0018-00 Impaired Beneficial Use: Aquatic Recreation Indicator: Nutrient / Eutrophication Biological Indicators Original Listing Year: 2002 *(See Table 2-1, page 1)*	1
Applicable Water Quality Standards/ Numeric Targets	Criteria set forth in Minn. R. 7050.0222 (4). The numeric target for the reach is in terms of *E. coli:* Concentrations shall not exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies between April 1 and October 31. MPCA Lake Eutrophication Standards set forth in Minn. R 7050.0222; Subpart 2a and as modified via a site-specific standard evaluation per Minn. R. 7050.0220, Subpart 7. Growing season average (June 1 – September 30) for the following parameters: Total phosphorus < 50 μg/L Chlorophyll-a < 14 μg/L Secchi depth > 1.4 meters	14-15
Loading Capacity *(expressed as daily load)*	The duration curve framework is used as the basis to identify the appropriate flow for the bacteria TMDL. Daily average flow estimates from April through October are used to derive the duration curves. The *E. coli* TMDL for Minnehaha Creek is calculated. The loading capacities are calculated at the outlet of Minnehaha Creek to the Mississippi River by multiplying the duration curve flows based on the Met Council / MPRB gage times the monthly geometric mean *E. coli* criteria times the appropriate conversion factor (0.024463). The loading capacity for Lake Hiawatha was determined by a comparison of the in-lake site-specific target to actual monitoring data collected over the past 11 years. This analysis identified the percent reduction from current levels needed to achieve the target. This percent reduction is then applied to Minnehaha Creek cumulative TMDL study area total phosphorus loads based on MCWD water quality monitoring data collected over the same period of time.	Bacteria 55-56 Total Phosphorus 58

EPA/MPCA Required Elements	Summary	TMDL Page Number
Wasteload Allocation	The MS4 WLA for the *E. coli* TMDL is categorical (with the exception of Mn/DOT, as it specifically requested a separate WLA), which means that the WLA is assigned to all MS4 jurisdictions in the Minnehaha Creek / Lake Hiawatha TMDL study area. The MS4 WLA for Mn/DOT is based on jurisdictional area data coupled with impervious cover information. The MS4 WLAs for total phosphorus are based on a *"Combination"* approach, which averages the allocations determined through *"Area Export Coefficient"* and *"Impervious Cover"* methods. This approach recognizes the importance of both subwatershed group size and the challenges associated with implementing retro-fit controls on developed land. WLAs for individual NPDES wastewater facilities are set at the growing season average TP load based on available discharge monitoring report data.	Bacteria 56-57 Total Phosphorus 59-64
Load Allocation	Load allocations for both *E. coli* and total phosphorus include the upstream boundary load (releases from Lake Minnetonka at Grays Bay Dam) and nonpoint source loads based on the amount of wetlands, forested, and woodland area in the Minnehaha Creek / Lake Hiawatha TMDL study area. The total phosphorus load allocation also includes an estimate that accounts for atmospheric deposition on Lake Hiawatha.	Bacteria 56-57 Total Phosphorus 59-64
Margin of Safety	An explicit MOS equal to 10% of the total load was applied to the bacteria TMDL where 10% of the loading capacity for each flow regime was subtracted before allocations were made among wasteload and non-point sources. The MOS was incorporated into total phosphorus TMDL through use of conservative assumptions. Conservative assumptions utilized to account for an inherently imperfect understanding of the watershed and lake system; total phosphorus losses that occur in Meadowbrook Lake / Browndale pool reach of Minnehaha Creek; site-specific total phosphorus standard for Lake Hiawatha is a conservative in-lake water quality endpoint.	Bacteria 57 Total Phosphorus 65
Seasonal Variation	*(See Section 3.4.1, page 20)*	20
Reasonable Assurance	*(See Section 7, pages 65 - 91)*	65-91
Monitoring	*(See Section 7.7, page 73)*	73
Implementation	*(See Section 7, pages 65 - 91)*	65-91
Public Participation	*(See Section 8, page 91)*	91

Executive Summary

A Total Maximum Daily Load (TMDL) has been developed for Minnehaha Creek to address an *E. coli* bacteria impairment (originally listed as fecal coliform). A TMDL has been developed for Lake Hiawatha to address a nutrient impairment. Chlorophyll-*a* or Secchi depth observations coupled with ambient water quality monitoring data indicate that excess total phosphorus (TP) is causing the impairments in Lake Hiawatha. These TMDLs establish the allowable loadings for *E. coli* and TP through wasteload allocations for point sources and load allocations for nonpoint sources (NPS). Based on these allocations, the TMDL process identifies appropriate actions to achieve *E. coli* and TP targets that will result in attainment of Minnesota's water quality standards for Minnehaha Creek and Lake Hiawatha.

Developing TMDLs requires a combination of technical analysis, practical understanding of important watershed processes, and interpretation of watershed loadings and receiving water responses to those loadings. Key parts of the technical analysis used to support development of the Minnehaha Creek and Lake Hiawatha TMDLs include:

- Identifying targets for *E. coli* (April through October geometric mean of 126 counts per 100 milliliters) and total phosphorus (June through September growing season average of 50 µg/L), which will protect aquatic recreation uses and meet Minnesota's water quality standards for Minnehaha Creek and Lake Hiawatha **[Section 3]**.

- Using a subwatershed analysis framework to evaluate land use data coupled with information on National Pollutant Discharge Elimination System permittees to assess sources of bacteria and phosphorus in the Minnehaha Creek / Lake Hiawatha TMDL study area **[Section 4]**.

- Linking available water quality and flow data with source assessment information to analyze loading and response patterns, highlighting key areas in the Minnehaha Creek / Lake Hiawatha TMDL study area where *E. coli* and total phosphorus reductions are needed to address excess bacteria and nutrient problems **[Section 5]**.

- Calculating the bacteria and nutrient loading capacities (i.e., the greatest amount of a pollutant that a waterbody can receive and still meet water quality standards) based on the *E. coli* recreation season geometric mean of 126 counts per 100 mL and total phosphorus growing season average 50 µg/L targets **[Section 6]**.

- Establishing load and wasteload allocations **[Section 6]**.

Finally, the U.S. Environmental Protection Agency recommends that a reasonable assurance assessment be a key part of the TMDL process. Reasonable assurance activities are programs that are in place to assist in meeting the Minnehaha Creek / Lake Hiawatha TMDL allocations and applicable water quality standards. The reasonable assurance evaluation provides documentation that the nonpoint source reduction required to achieve proposed load allocations developed in point source / NPS (or mixed-source) TMDLs can and will occur over time **[Section 7]**.

1. Overview

Minnehaha Creek appears on Minnesota's draft 2012 §303(d) list of impaired waters for fecal coliform bacteria, chloride, and dissolved oxygen, as well as due to its impaired fish community. Lake Hiawatha is impaired due to excess nutrients. The Clean Water Act and U.S. Environmental Protection Agency (USEPA) regulations require that states develop Total Maximum Daily Loads (TMDLs) for waters on the §303(d) list. A TMDL is defined as *"the sum of the individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background"* such that the capacity of the waterbody to assimilate pollutant loadings without violating water quality standards is not exceeded. A TMDL is also required to consider seasonal variations and must include a margin of safety to address uncertainty.

Developing TMDLs requires a combination of technical analysis, practical understanding of important watershed processes, and interpretation of watershed loadings and receiving water responses to those loadings. An essential component of TMDL development is establishing a relationship between numeric indicators intended to measure attainment of beneficial uses and source loads that contribute to water quality problems. The TMDL report examines connections between water quality targets, available data, and potential sources. Through the TMDL linkage analysis, the relationship between watershed loadings and receiving water responses to those loadings is assessed. The report also describes the logic used to develop TMDL targets and allocations.

2. Background Information

Minnehaha Creek flows from Lake Minnetonka at the outlet of Grays Bay eastward for 22 miles to the Mississippi River *(Figure 2-1)*. It is the physical link that binds together the network of urban lakes, parks, and open space that define the southwestern Twin Cities area and south Minneapolis. Two lakes, Lake Hiawatha and Meadowbrook Lake, are in-line to the creek.

The entire length of Minnehaha Creek appears on the State of Minnesota's §303(d) list of Impaired Waters due to elevated levels of fecal coliform bacteria and chloride, as well as its impaired biotic community and low levels of dissolved oxygen. Lake Hiawatha appears due to excess nutrients and eutrophication *(Table 2-1)*.

Table 2-1. §303(d) listed segments in the Minnehaha Creek / Lake Hiawatha TMDL study area.

Reach	Description	Year	River ID#	Affected use	Pollutant or stressor
Lake Hiawatha	Lake or Reservoir	02	0701x 27-0018-00	Aquatic Recreation	Nutrient / Eutrophication Biological Indicators
Minnehaha Creek	Lake Minnetonka to Mississippi River	04	07010206-539	Aquatic Life	Fish bioassessments
Minnehaha Creek	Lake Minnetonka to Mississippi River	08	07010206-539	Aquatic Recreation	Fecal Coliform
Minnehaha Creek	Lake Minnetonka to Mississippi River	08	07010206-539	Aquatic Life	Chloride Low Dissolved Oxygen

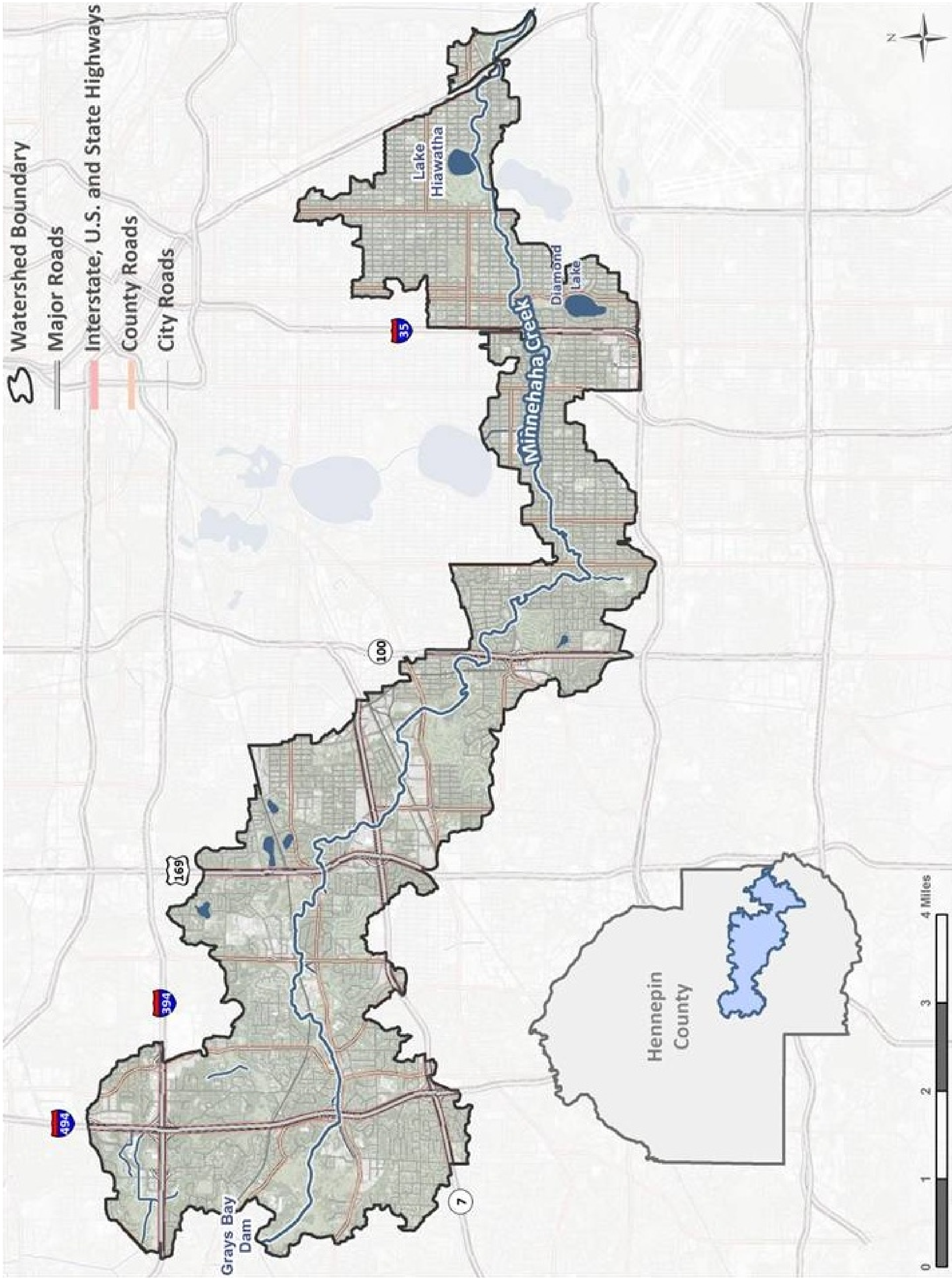


Figure 2-1. Minnehaha Creek / Lake Hiawatha phosphorus and bacteria TMDL study area.

The focus of this TMDL is on nutrients in Lake Hiawatha and bacteria in Minnehaha Creek. It is noted that the chloride listing for Minnehaha Creek is being addressed as part of the *"Twin Cities Metropolitan Area Chloride Project Phase 2"*. The dissolved oxygen and impaired fish community listings are directly related to the flow conditions of Minnehaha Creek and, therefore, are not addressed via this TMDL.

Although a formal evaluation or stressor ID process has not been done, it appears that the fish impairment is not due to a pollutant but rather is predominantly related to the flow conditions of Minnehaha Creek. TMDLs are only done to establish maximum daily loads for pollutants. In the case of Minnehaha Creek the primary source of base flow, Lake Minnetonka, is shut off at the Gray's Bay Headwaters Control Structure every winter and when Lake Minnetonka falls below the historic minimum lake level elevation of 928.6 (the management policy and operating procedures for the Headwaters Control Structure can be found at: http://minnehahacreek.org/projects/capital-projects/past-projects/headwaters-control-structure-management-policy-and-operating). This can leave much of the creek dry for a significant part of the year, limiting fish to ponded portions of the creek or tributary lakes.

In addition, development in the Minnehaha Creek / Lake Hiawatha TMDL study area has significantly changed the hydrology, resulting in increased stormwater volumes and flow peaks compounded by reduced infiltration and base flow. Wetlands and depression storage that naturally extend the period of flow have largely been eliminated in the Minnehaha Creek / Lake Hiawatha study area. Large volumes of surface runoff are produced by impervious surfaces, but are discharged over a short period leaving the creek dry at times which is detrimental to the fish population.

The low dissolved oxygen impairment has likewise not been fully evaluated, but at this time it is suspected that it too is largely related to low base flow. Lower, more shallow flowing (or stagnant) water contains less dissolved oxygen for various reasons. Low dissolved oxygen may also be caused by natural processes within the wetland complex at the head of Minnehaha Creek.

The Minnehaha Creek Watershed District (MCWD) has partnered with the University of Minnesota to study base flow in Minnehaha Creek. The purpose of the study is to determine whether stormwater runoff can be infiltrated and stored in the shallow aquifer to enhance base flow and which areas are best suited for this. This study is expected to be completed in late 2013. Thus, until and unless the base flow issue is addressed and the fish community and dissolved oxygen status is re-evaluated, the MPCA is not undertaking a TMDL for those impairments. The focus of this TMDL is instead on nutrients in Lake Hiawatha and bacteria in Minnehaha Creek.

Lake Hiawatha was a shallow wetland named Rice Lake before it was acquired by the Minneapolis Park & Recreation Board (MPRB) in 1923. The lake had stands of wild rice that grew in the shallow waters. The lake was renamed and major changes occurred to the shape and depth of Lake Hiawatha. In 1929 the Hiawatha Golf Course was constructed using over 1.25 million cubic yards of dredged material from the Rice Lake wetland area. Lake Hiawatha is now part of the Lake Nokomis - Lake Hiawatha regional park.

Lake Hiawatha has a short residence time compared to most lakes in the Minneapolis area. Conversely seasons with low creek flow cause the residence time in Lake Hiawatha to increase allowing for excess algae growth. In normal flow periods, the expected level of algae is low relative to the amount of phosphorus present in the system.

Water clarity in Lake Hiawatha is also affected by the increased sediment coming from Minnehaha Creek flow. Water level in Lake Hiawatha is directly connected to flows from Minnehaha Creek and fluctuates widely. Thermal stratification in the lake during the summer months is typically destabilized by flow from the creek and storm sewer connections (MPRB 2009).

Finally, several tributary areas within the Minnehaha Creek / Lake Hiawatha watershed either meet water quality standards or are addressed by other TMDLs. Specifically, flow to the Minnehaha Creek from Lake Minnetonka, the Chain of Lakes, and Lake Nokomis currently meet Minnesota's water quality standards for bacteria based on MCWD and MRPB ambient monitoring data. In addition, phosphorus loads from Lake Nokomis are covered under a separate TMDL. As a result, subwatersheds that flow to Lake Minnetonka, the Chain of Lakes, and Lake Nokomis are not included in this TMDL.

2.1 Population

Population data for the Minnehaha Creek / Lake Hiawatha TMDL study area is estimated based on county census data from 1990, 2000, and 2010. Portions of Hennepin County are located outside of the TMDL study area; population was estimated for portions within the TMDL study area based on the percentage of the total county area that is within the TMDL study area. The estimated population of the Minnehaha Creek / Lake Hiawatha TMDL study area is nearly 99,000 *(Table 2-2)*. The population in the TMDL study area has grown since 1990. The TMDL study area lies in the urban area of Minneapolis-St. Paul. Hennepin County has the highest population per square mile in the entire state of Minnesota. On average Minnesota has a population of 66 people per square mile, whereas the 2010 census showed that the population per square mile in Hennepin County was 2,082.

Because so much of the TMDL study area is already developed, future land use in the TMDL study area is not expected to change dramatically by 2020 or 2030 (MCWD, 2007). For this reason, an allocation for future growth is not needed in this TMDL.

Table 2-2. Hennepin County population within Minnehaha Creek / Lake Hiawatha TMDL study area.

1990 Population[a]	2000 Population[a]	2010 Population[a]	People per square mile
87,766	94,887	98,590	2,082

[a] Note that portions of Hennepin County are outside the Minnehaha Creek / Lake Hiawatha TMDL study area; therefore the population shown in the table was estimated based on the portion of the county that is located within the TMDL study area.

Source: U.S. 2010 Census and geographic information system (GIS) analysis.

2.2 Municipal Boundaries

The entire Minnehaha Creek / Lake Hiawatha TMDL study area lies within Hennepin County. Portions of seven communities lie within the Minnehaha Creek / Lake Hiawatha phosphorus and bacteria TMDL study area including: Plymouth, Wayzata, Minnetonka, Hopkins, Edina, St. Louis Park, and Minneapolis *(Figure 2-2)*. The majority of the Minnehaha Creek / Lake Hiawatha phosphorus and bacteria TMDL study area lies within Minnetonka (36.8%), Minneapolis (24.5%), Edina (13.1%), and St. Louis Park (12.5%) *(Table 2-3)*. These areas were determined by MCWD based on Geographic Information System (GIS) data layers available at the District.

Table 2-3. Municipal / MS4 jurisdictions in the Minnehaha Creek / Lake Hiawatha TMDL study area.

Municipal / MS4 Jurisdiction	Area in the TMDL Study Area		Percent of TMDL Study Area
	(acres)	*(square miles)*	
Plymouth	183	0.3	1.0%
Wayzata	98	0.2	0.5%
Minnetonka	6,574	10.3	36.8%
St. Louis Park	2,241	3.5	12.5%
Hopkins	1,123	1.7	6.3%
Edina	2,339	3.7	13.1%
Minneapolis	4,377	6.8	24.5%
Hennepin County	223	0.4	1.2%
Mn Dept. of Transportation	735	1.1	4.1%
TOTAL	17,893	28.0	100%

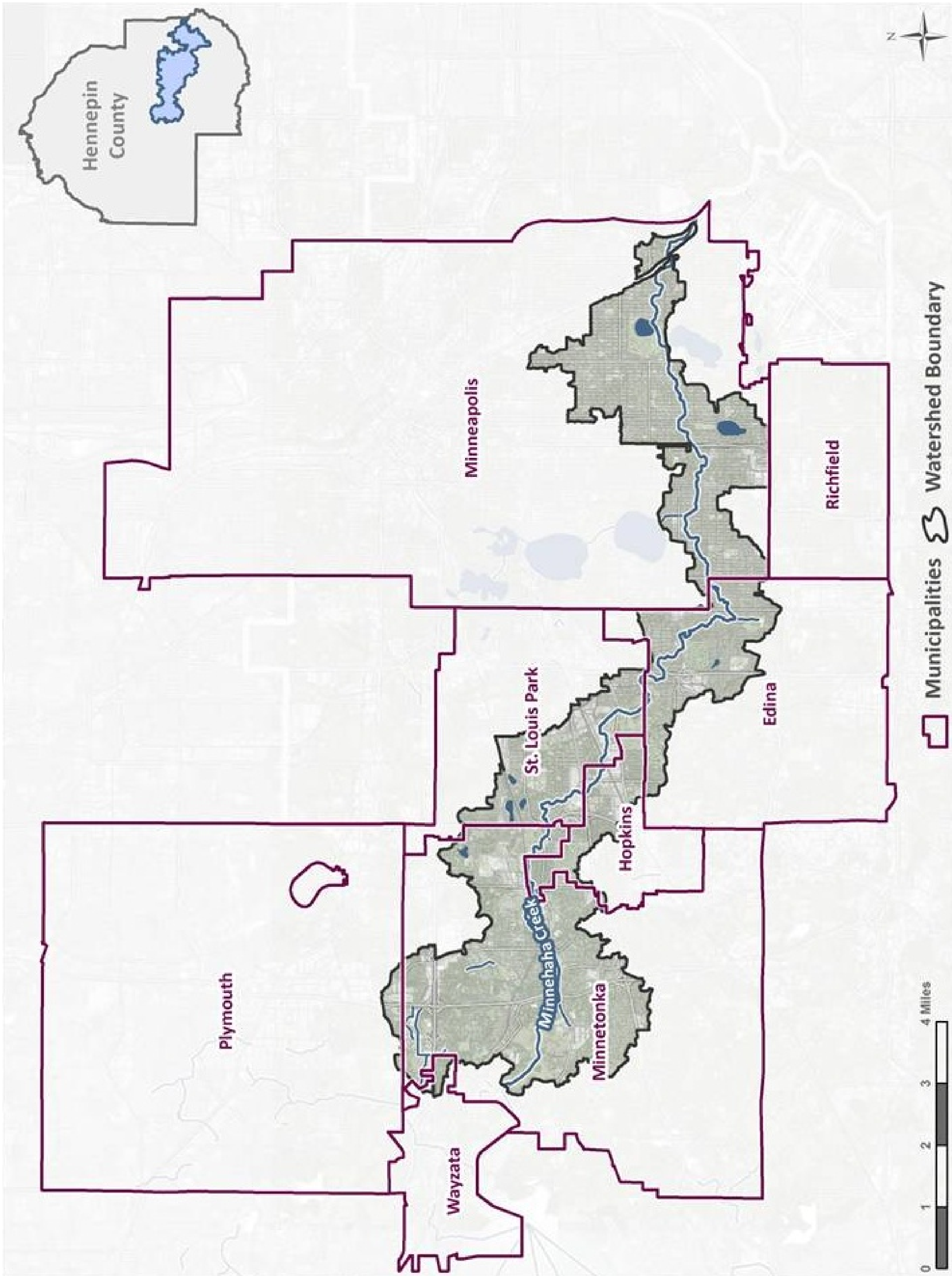


Figure 2-2. Municipal boundaries within Minnehaha Creek / Lake Hiawatha TMDL study area.

2.3 Land Use / Land Cover

Land use / land cover information for the Minnehaha Creek / Lake Hiawatha TMDL study area is available from the Minnesota Land Cover Classification System (MLCCS). Figure 2-3 displays the spatial distribution of the land use/land cover, while Table 2-4 summarizes the total areas by each category. The Minnehaha Creek / Lake Hiawatha TMDL study area consists primarily of single family residential land use (52%), parks and recreation (13%), as well as multi-family residential land use (7%) also cover significant portions of the TMDL study area. Open water makes up almost 6 percent of the TMDL study area. The percent imperviousness is higher in the eastern portion of the TMDL study area where population density is higher.

Table 2-4. Minnehaha Creek / Lake Hiawatha TMDL study area land use.

Land Use	**Area**		**Percent of Watershed**
	(acres)	*(square miles)*	
0 to 10 percent impervious cover	185	0.3	1.0%
11 to 25 percent impervious cover	258	0.4	1.4%
26 to 50 percent impervious cover	2,900	4.5	16.2%
51 to 75 percent impervious cover	5,956	9.3	33.3%
76 to 100 percent impervious cover	3,206	5.0	17.9%
Forest & Woodland	1,871	2.9	10.5%
Open Space *(including parks & golf courses)*	1,514	2.4	8.5%
Lakes, Streams, & Open Water	548	0.9	3.1%
Maintained Natural Areas	57	0.1	0.3%
Wetlands	1,399	2.2	7.8%
TOTAL	**17,893**	**28.0**	**100.0%**
Note: *Land use data calculated from MLCCS Report GIS Layer			

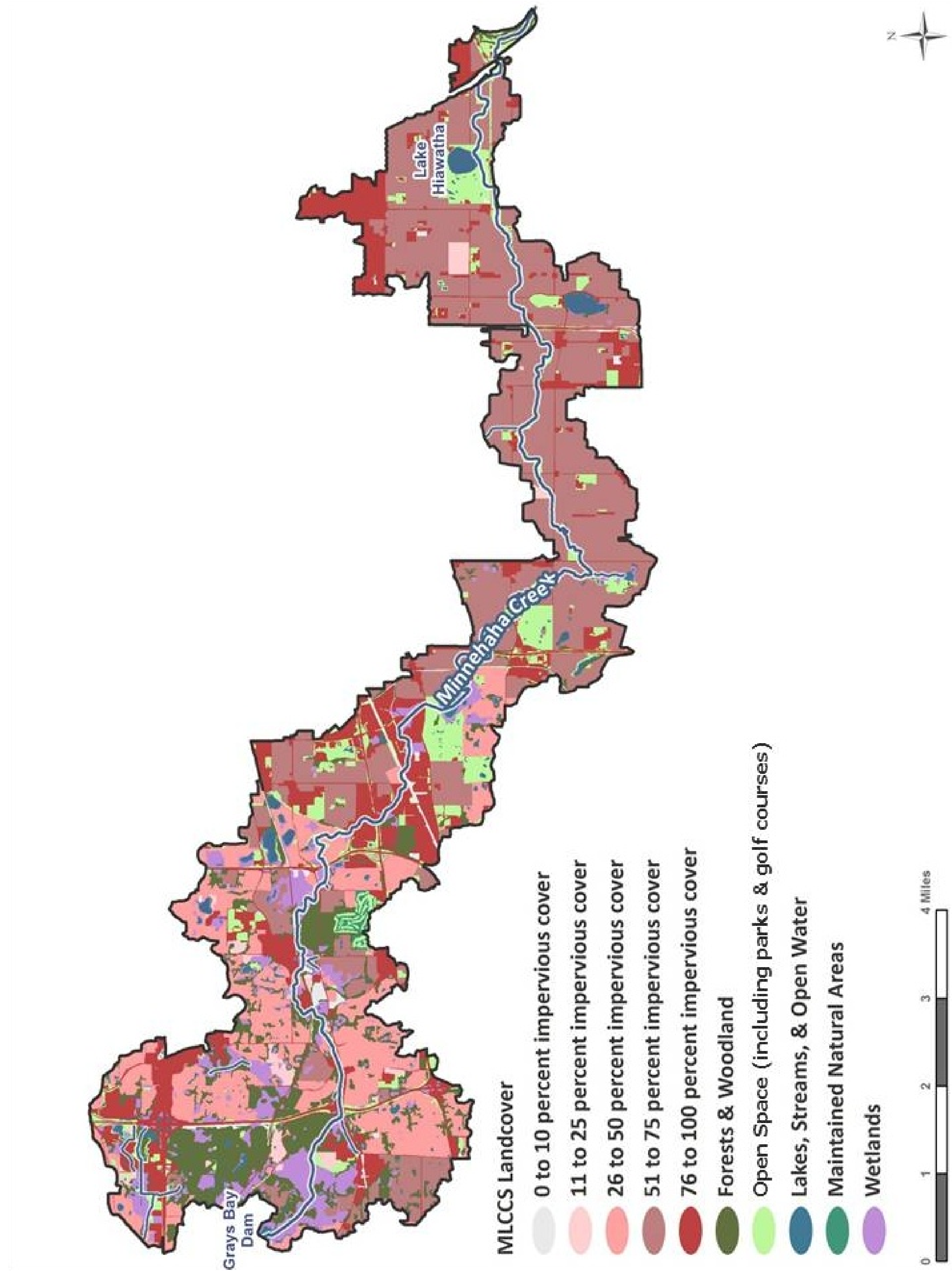


Figure 2-3. Minnehaha Creek / Lake Hiawatha TMDL study area land use.

2.4 Soils

Data from the Natural Resources Conservation Service (NRCS) were used to characterize soils in the Minnehaha Creek / Lake Hiawatha TMDL study area. General soils data and map unit delineations are available through the Soil Survey Geographic (SSURGO) Database. GIS coverages provide locations for soil map units at a scale of 1:250,000 (USDA 2002). A map unit is composed of several soil series having similar properties. Identification fields in the GIS coverages can be linked to a database that provides information on chemical and physical soil characteristics.

The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged moist conditions. Typically, clay soils that are poorly drained have lower infiltration rates, while sandy soils that are well drained have the greatest infiltration rates. NRCS has defined four hydrologic groups for soils (Table 2-5). The corresponding spatial distribution of hydrologic soil groups in the Minnehaha Creek / Lake Hiawatha TMDL study area is illustrated in Figure 2-4.

Much of the Minnehaha Creek / Lake Hiawatha TMDL study area soil map units did not have corresponding hydrologic soil group classifications available in SSURGO. These areas were impervious disturbed urban soils, water, or gravel pits and have been labeled in Figure 2-4 to verify those locations. The majority of soils that were classified in the Minnehaha Creek / Lake Hiawatha TMDL study area are classified as B soils. B soils are typically moderately deep and well drained soils. D soils were also prominent in the low-lying areas; these soils are generally hydric. Group A soils are scattered in the TMDL study area and have high to moderate infiltration potential (MCWD 2007).

Table 2-5. Hydrologic Soil Group characteristics.

Soil Group	Characteristics	Minimum Infiltration Capacity *(inches/hour)*
A	Sandy, deep, well drained soils; deep loess; aggregated silty soils	0.30 to 0.45
B	Sandy loams, shallow loess, moderately deep and moderately well drained soils	0.15 to 0.30
C	Clay loam soils, shallow sandy loams with a low permeability horizon impeding drainage (soils with a high clay content), soils low in organic content	0.05 to 0.15
D	Heavy clay soils with swelling potential (heavy plastic clays), water-logged soils, certain saline soils, or shallow soils over an impermeable layer	0.00 to 0.05
Source: NRCS, 1972		

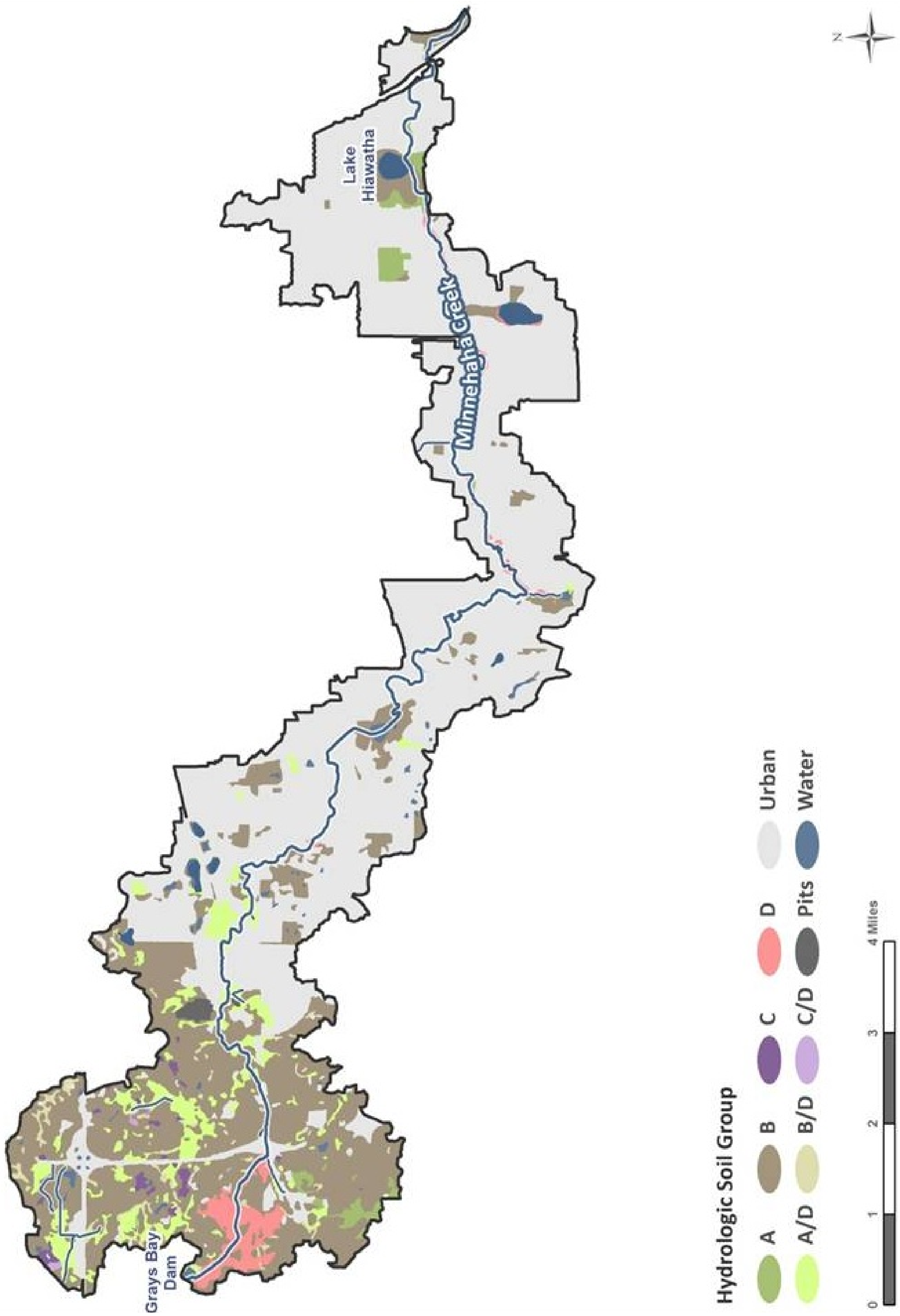


Figure 2-4. Minnehaha Creek / Lake Hiawatha TMDL study area Hydrologic Soil Groups.

2.5 Climate

Rainfall and temperature data are available for several gages near the Minnehaha Creek / Lake Hiawatha TMDL study area. An examination of precipitation patterns is a key part of watershed characterization. An analysis of rainfall intensity and timing is needed to evaluate watershed response to precipitation as part of TMDL development, particularly in the source assessment phase. Describing the frequency and magnitude of rain events in conjunction with an analysis of associated runoff are key considerations.

An example analysis is shown in Figure 2-5 using precipitation data from the Minneapolis - St. Paul Airport gage. The Minneapolis - St Paul Airport gage is just south of Lake Hiawatha and southeast of the Minnehaha Creek / Lake Hiawatha TMDL study area. The majority of rainfall events in the watershed are low intensity with less than 0.2 inches of rain (65%). Figure 2-6 shows the annual precipitation at the Minneapolis - St. Paul Airport gage.

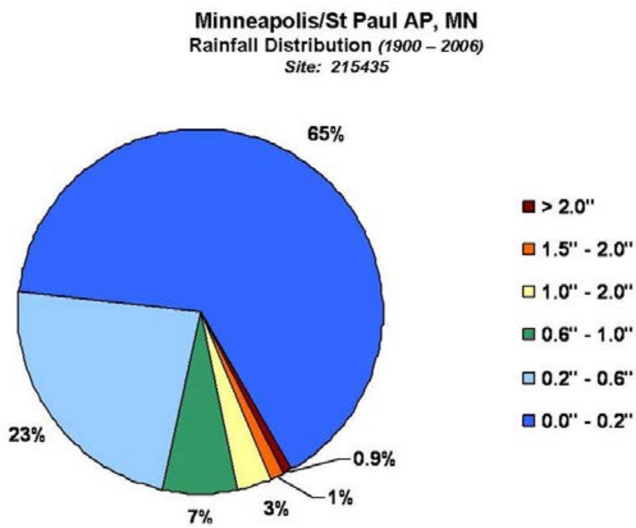


Figure 2-5. Rainfall distribution at Minneapolis airport.

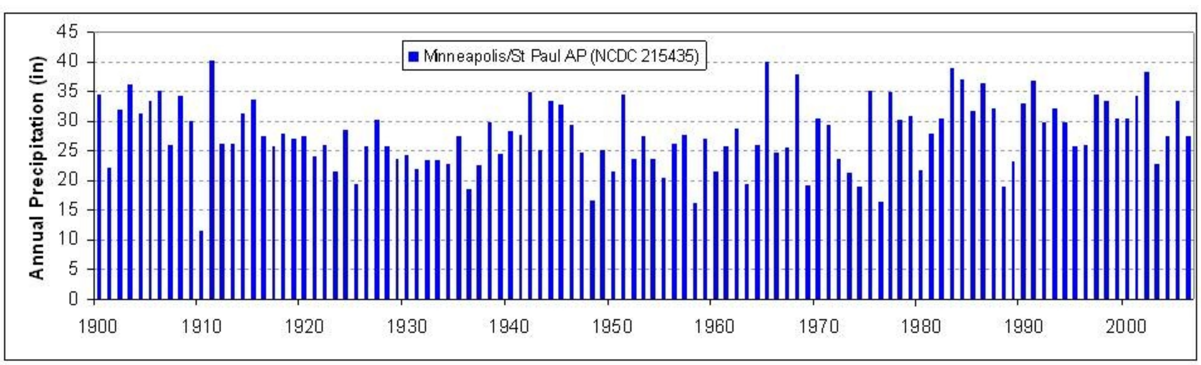


Figure 2-6. Annual precipitation at Minneapolis airport.

2.6 Geology

The *Minnehaha Creek Subwatershed Plan* (MCWD, 2007) and the *Hydrologic, Hydraulic and Pollutant Loading Study* detail the geology within the Minnehaha Creek / Lake Hiawatha watershed. The watershed contains the full stratigraphic sequence of bedrock units found in the Twin Cities Basin. The depth to bedrock varies between 100-200 feet in the upper watershed and 0-100 feet near the Mississippi River. The prominent upper bedrock unit is the Platteville-Glenwood Limestone. There is a bedrock valley trending north-south beneath the chain of lakes that cuts through the St. Peter Sandstone to the Prairie du Chien Limestone.

Quaternary deposits in the upper watershed are primarily from Des Moines Lobe glaciation and till deposits from the Superior Lobe glaciation (only existing in east central Minnetonka). The deposits are generally high relief loamy till with pockets of peat and muck along the creek corridor. Outwash plains were deposited along Minnehaha Creek in the lower subwatershed as it drained a glacial lake occupying the present Lake Minnetonka location. As the creek changed course it deposited fanned outwash over a wider area, these outwash plain deposits are sand and gravelly sand and can be up to 300 feet thick. Much of the land in the eastern portion of the watershed is river terrace deposits from glacial rivers, composed of sand, gravelly sand, and loamy sand. Near Minnehaha Falls and the Mississippi River the glacial drift has eroded away, exposing bedrock (MCWD 2007; Emmons & Olivier Resources 2003).

2.7 Topography

The Minnehaha Creek / Lake Hiawatha TMDL study area lies in a low lying river basin of Minnesota. Topography in the watershed is relatively flat. Figure 2-7 presents the general topography within the watershed and indicates that elevation ranges from 687 feet above sea level at the most downstream point in the watershed to 1,122 feet in the headwaters (USGS 1999). Minnehaha Creek drops a total of approximately 240 feet from 930 feet at Grays Bay Dam to 695 feet above sea level at its confluence with the Mississippi River.

The watershed east of the city of Hopkins contains gently rolling terraces and bottom lands. This is primarily the Mississippi Valley Outwash region punctuated by glacial activity leaving small lakes. The upper portion of the watershed is within the Emmons-Faribault moraine region and is characterized by rolling to steep hills with lakes formed in deep “kettles” (irregular depressions) (MCWD 2007).

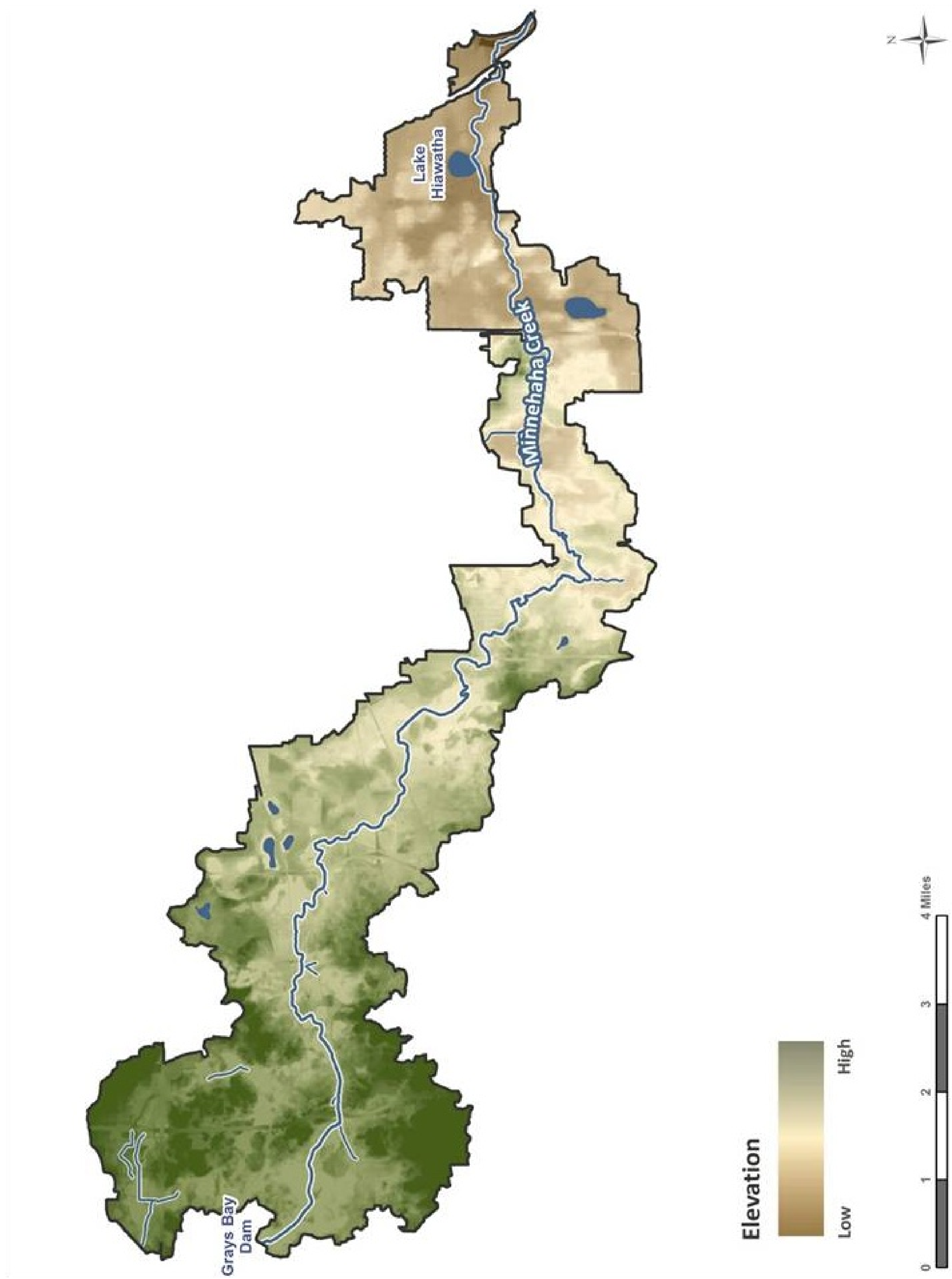


Figure 2-7. Minnehaha Creek / Lake Hiawatha TMDL study area topography.

3. Targets

3.1 Priority Ranking

The Minnehaha Creek / Lake Hiawatha TMDL study area was given a priority ranking for TMDL development for the following reasons:

- the adverse effect of the impairment on public health and aquatic life;
- the public value of the impaired water resource, the likelihood of completing the TMDL in an expedient manner;
- the inclusion of a strong base of existing data and the restorability of the waterbody;
- the technical capability and the willingness of local partners to assist with the TMDL; and
- the appropriate sequencing of TMDLs within a watershed or basin.

The Minnehaha Creek / Lake Hiawatha TMDL study area is a popular location for aquatic recreation, including boating, canoeing, swimming, fishing and other forms of aquatic recreation activities. Water quality degradation has led to efforts to improve the water quality within the Minnehaha Creek / Lake Hiawatha TMDL study area, and to the development of a TMDL to address water quality impairments.

3.2 Applicable Water Quality Criteria

Water quality standards (WQS) are the fundamental benchmarks by which the quality of surface waters is measured. Within the State of Minnesota, WQS are developed pursuant to the Minnesota Statutes (MS) Chapter 115, Sections 03 and 44. Authority to adopt rules, regulations, and standards as are necessary and feasible to protect the environment and health of the citizens of the State is vested with the Minnesota Pollution Control Agency (MPCA).

Through adoption of WQS into Minnesota's administrative rules (principally Chapters 7050 and 7052), MPCA has identified designated uses to be protected in each of its drainage basins and the criteria necessary to protect these uses. Both Lake Hiawatha and Minnehaha Creek are classified 2B, which are protected for aquatic life and recreation. The following sections describe the applicable portions of Minnesota's WQS, which relate to TMDL development that will address §303(d) impairments for both waters.

3.2.1 Minnehaha Creek

Water quality monitoring data indicate that recreational uses are not being attained in Minnehaha Creek, based on exceedances of numeric criteria for *E. coli*. The determination was based in part on the use of MCWD bacteria monitoring data, which was fecal coliform through 2004 and E. coli from 2005 through the present. MPCA's ratio of 200 to 126 was used to convert fecal coliform to *E. coli*. The conversion process and basis for this ratio are described in *"Bacteria TMDL Protocols and Submittal Requirements"* (MPCA 2007). The applicable criteria for *E. coli* is described in amendments to Minnesota's Rule 7050 *(Table 3-1)*, which serve as targets for the Minnehaha Creek TMDL. Wasteload and load allocations in the TMDL have been developed to achieve these values.

Table 3-1. Applicable criteria for Minnehaha Creek bacteria impairments.

Parameter	Units	Water Quality Standard
E. coli [1]	#/100 mL	1,260 in <10% of samples [2]
		Geometric mean < 126 [3]

[1] *E. coli* standards apply only between April 1 and October 31
[2] Standard shall not be exceeded by more than 10% of the samples taken within any calendar month
[3] Geometric mean based on minimum of 5 samples taken within any calendar month

3.2.2 Lake Hiawatha

Targets for lakes are based on Minnesota's Rule 7050, which identifies eutrophication standards for the various ecoregions of Minnesota *(Table 3-2)*. Lake Hiawatha is located in the North Central Hardwood Forests (NCHF) ecoregion. To be listed as impaired, the monitoring data must show that the standards for total phosphorus (TP) (the causal factor), as well as one of the response variables, either chlorophyll-*a* or Secchi depth, are violated. Minnesota's Rule 7050.0222, Subpart 2a describes how the criteria are applied: *"Eutrophication standards are compared to data averaged over the summer season (June through September)"*.

Because chlorophyll-*a* and Secchi depth are both response parameters, the TMDL for Lake Hiawatha is focused on TP; the causal parameter.

Table 3-2. Eutrophication standards for Lake Hiawatha.

Parameter	Units	NCHF Ecoregion Standard	Site-Specific Standard
Total Phosphorus	µg/L	TP < 40 µg/L	TP < 50 µg/L
Chlorophyll-a	µg/L	Chl < 14 µg/L	Chl < 14 µg/L
Secchi Depth	meters	SD > 1.4 m	SD > 1.4 m

Minnesota's Rule 7050.0222, Subpart 2a contains provisions for site-specific modifications to the eutrophication standards in order to account for characteristics unique to lakes and reservoirs that can affect trophic status. Unique characteristics include variations in hydraulic residence time. Because Lake Hiawatha is in-line to Minnehaha Creek, the residence time is relatively short (the 12-year average is 4.4 days).

Accordingly, the project team evaluated the available water quality data as well as other factors to establish an appropriate site-specific eutrophication standard for this lake (MPCA, 2013). This evaluation resulted in a total phosphorus standard of 50 µg/L and no change to the chlorophyll-*a* and Secchi depth values from the current eutrophication standard (14 µg/L and 1.4 m, respectively). The Lake Hiawatha TMDL was calculated to meet the site specific standard of 50 µg/L for TP, 14 µg/L for chlorophyll-a and a Secchi Depth of 1.4 m. The site specific standard was approved by EPA on July 24, 2013.

3.3 Spatial Distribution of Pollutants

The MCWD has an extensive hydrologic data program through which it collects and analyzes water quality information for Minnehaha Creek *(Figure 3-1)*. The MCWD hydrologic data monitoring program began in 1968 and program data is published annually in the Annual Hydrological Monitoring Report (posted on-line: http://www.minnehahacreek.org/data-center/monitoring-reports). Similarly, the Minneapolis Park & Recreation Board (MPRB) monitors water quality in Lake Hiawatha. Information from both programs can be used to provide a better description of the impairments relative to key locations and timing of the problems.

The monitoring data shows that water quality varies across the watershed due to its complex hydrology and diverse land use, both spatially and temporally. For this reason, key points along Minnehaha Creek are used to describe the spatial distribution of pollutant loads. Focus areas have been identified based on locations where either beneficial uses are most sensitive or where water quality criteria exceedances are most pronounced under critical conditions. These represent points where TMDL reduction targets are calculated.

The longitudinal profile for bacteria along Minnehaha Creek *(Figure 3-2)* shows where the exceedance of these parameters is greatest. In the case of bacteria (*E. coli*), the focus area is the reach of Minnehaha Creek just above Lake Hiawatha (Chicago Avenue). Monitoring data shows that water quality criteria exceedances are most pronounced at this location.

With respect to nutrients, Lake Hiawatha is the logical focal point used to identify reduction needs. The response to phosphorus loads in the watershed is most evident in Lake Hiawatha. The increase in chlorophyll-a concentrations and reduced Secchi depths is a reflection of the adverse effect that excess phosphorus has on recreational uses *(Figure 3-3 and Figure 3-4)*.

The dominant inputs of phosphorus to Lake Hiawatha are transported through Minnehaha Creek. A longitudinal profile of total phosphorus in Minnehaha Creek provides a better picture from a TMDL study area perspective *(Figure 3-5)*. Median phosphorus concentrations exceed 50 µg/L in Minnehaha Creek downstream of West 34^{th} Street (this is simply to provide a frame of reference; 50 µg/L is the Lake Hiawatha target and not an in-stream Minnehaha Creek target). The most pronounced increases in TP occur between West 34^{th} Street and Excelsior Boulevard.

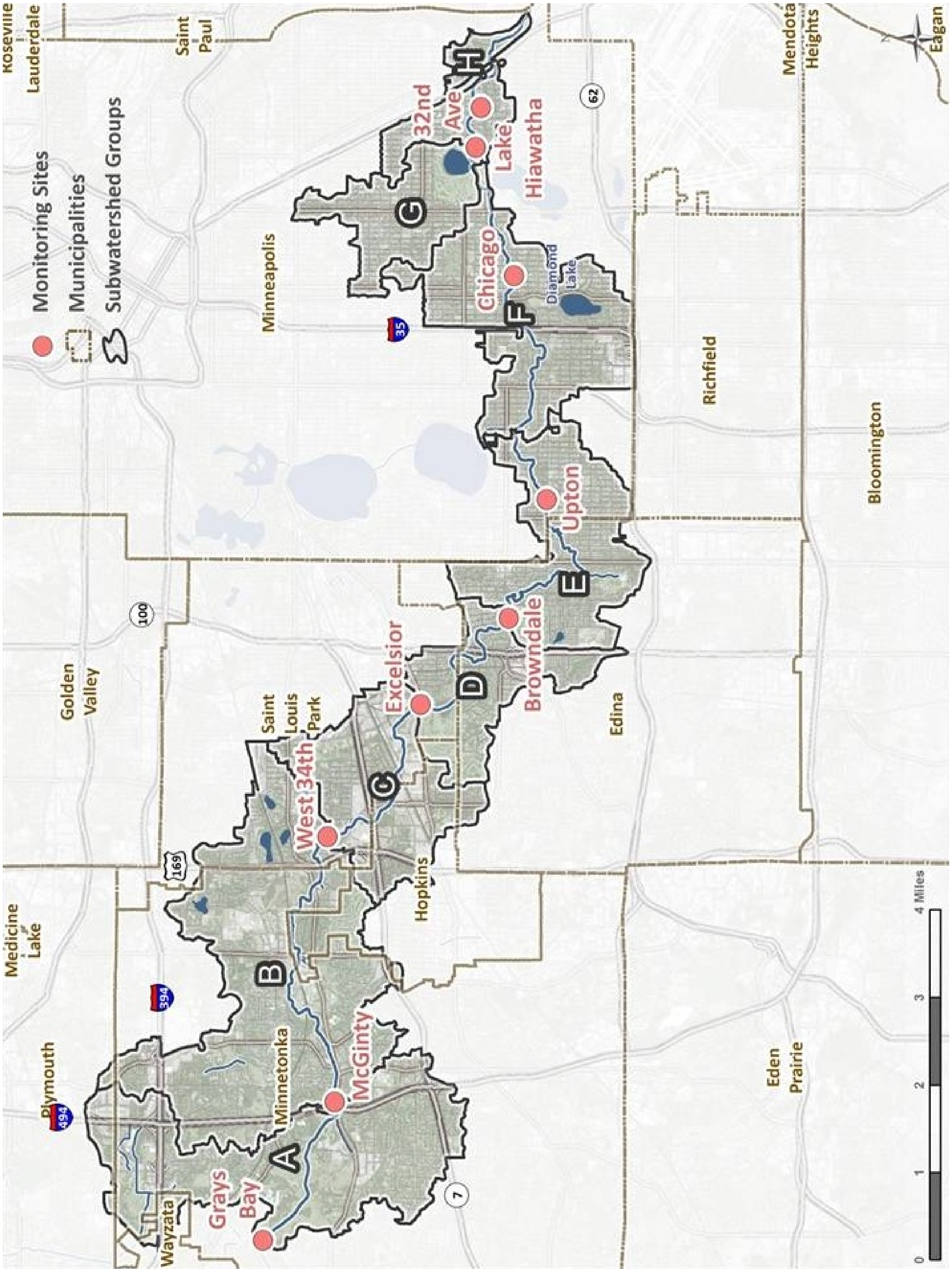


Figure 3-1. Minnehaha Creek / Lake Hiawatha TMDL study area subwatersheds and monitoring sites.

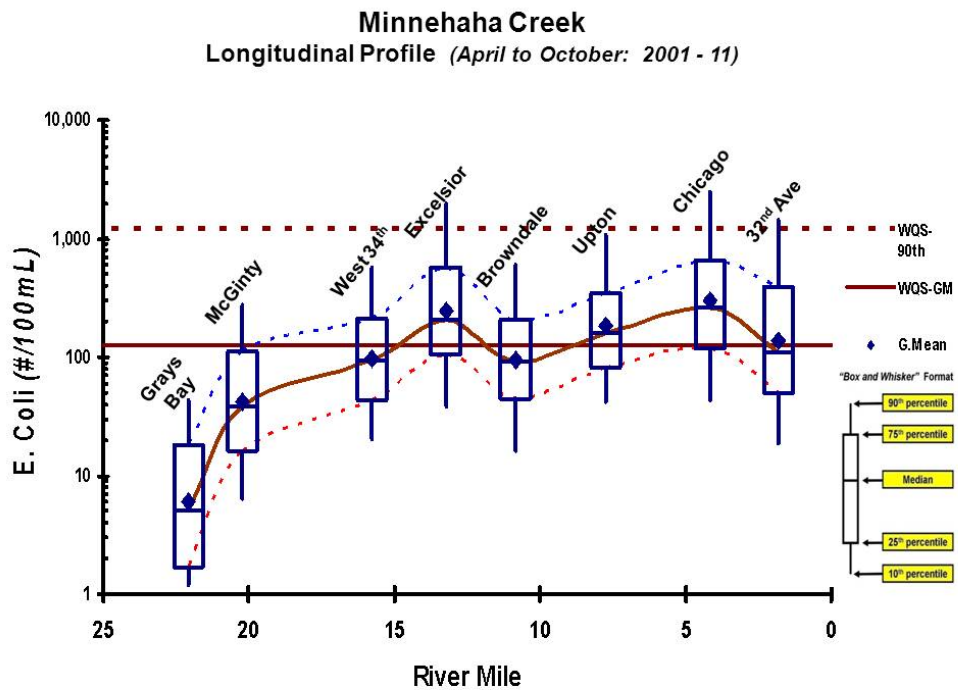


Figure 3-2. Longitudinal profile for *E. coli* along Minnehaha Creek.

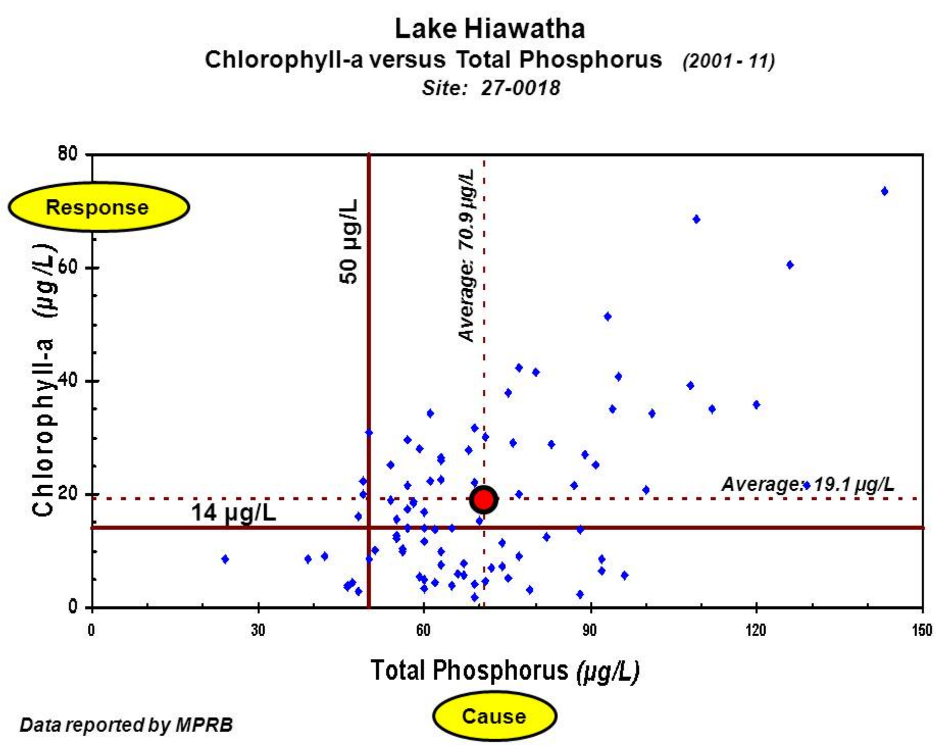


Figure 3-3. Lake Hiawatha chlorophyll-*a* versus total phosphorus.

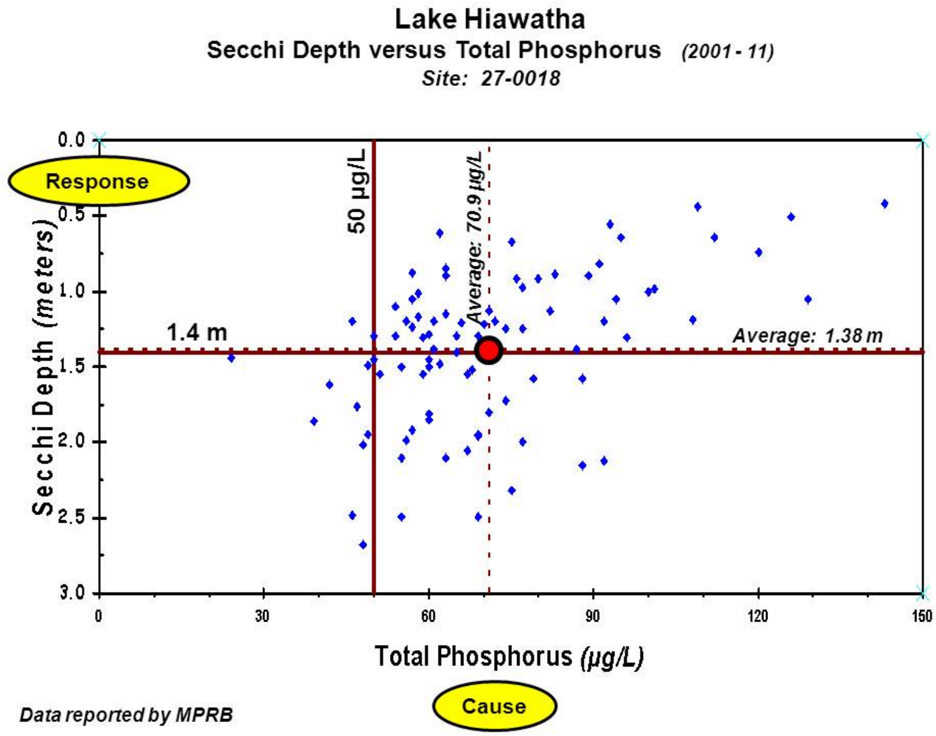


Figure 3-4. Lake Hiawatha Secchi depth versus total phosphorus.

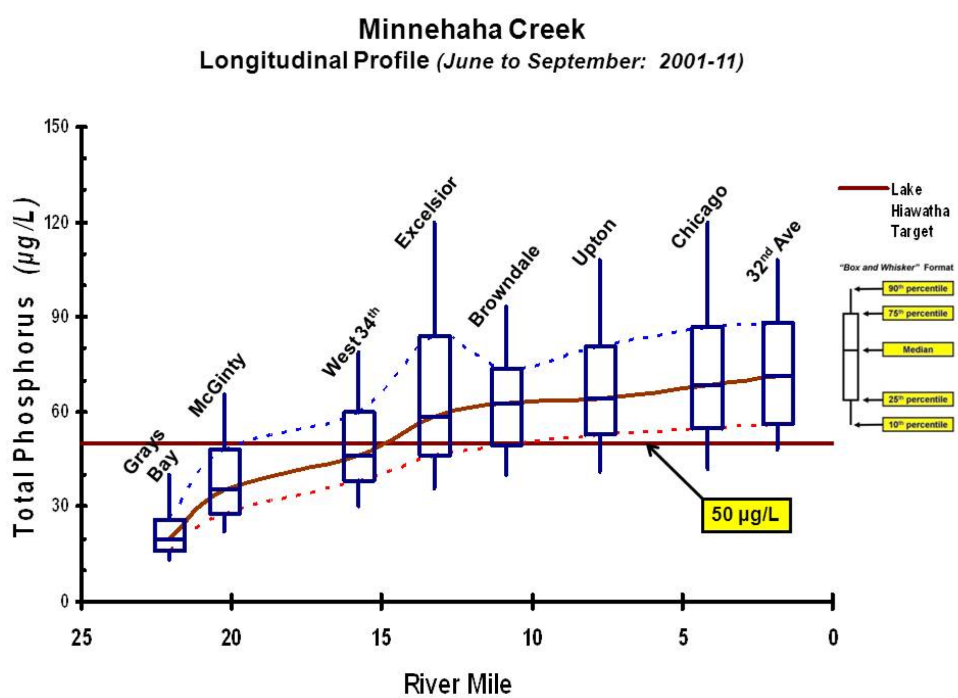


Figure 3-5. Longitudinal profile for total phosphorus along Minnehaha Creek.

3.4 Critical Conditions

The critical condition for lakes is the summer growing season, which in Minnesota is when phosphorus concentrations peak and clarity is at its worst. Lake goals focus on summer-mean total phosphorus, Secchi transparency and chlorophyll-a concentrations. Consequently, the lake response models have focused on the summer growing season (June through September) as the critical condition. Likewise, the load reductions in this TMDL are designed so that the lake will meet the water quality standards over the course of the growing season.

An important part of the TMDL analysis is an assessment of critical conditions. Depending on the beneficial use or parameter, critical conditions may be a function of seasonal variation (e.g., the effect of flow conditions) or inter-annual variation (e.g., the influence of drought years).

3.4.1 Seasonal Variation

Seasonal variation is accounted for through the use of annual loads in the technical analysis and developing targets for the summer period, when the frequency and severity of nuisance algal growth will be the greatest. Although the critical period is the summer, lakes are not sensitive to short term changes in water quality; rather lakes respond to long-term changes such as changes in the annual load. Therefore, the seasonal variation is accounted for in annual loads. The nutrient standards set by the MPCA – which are a growing season concentration average, rather than an individual sample (i.e., daily) concentration value – were set with this concept in mind. Additionally, by setting the TMDL to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during all other seasons.

Seasonal variation often plays a major role in defining critical conditions. For example, seasonal variation in flow is a key part of TMDL development (seasonal loads are directly proportional to seasonal flows). Figure 3-6 illustrates the seasonal variation in flow between 2001 and 2011 for the gage located on Minnehaha Creek. This station is operated by the Metropolitan Council. Flows in June are generally consistent, reflecting the effect of releases from Lake Minnetonka evidenced by the relatively small *"box"* (i.e., half the monthly average values are within the *"box"*). As summer progresses, this variability increases as indicated by the increasing size of the *"box"*.

Continuing the focus on the impaired parameters, seasonal patterns for bacteria are examined. Critical periods are seasons and flow conditions when *E. coli* concentrations are greatest. Based on MCWD monitoring data, the monthly geometric mean (or chronic criteria) is exceeded between June and October *(Figure 3-7)*.

3.4.2 Inter-annual Variation

In the case of Lake Hiawatha and nutrients, it is useful to examine patterns during those years when the response parameters exceed criteria, e.g., chlorophyll-a levels are highest and Secchi depth measurements are lowest *(Figure 3-8 to Figure 3-9)*. These years also correspond with low flows in Minnehaha Creek associated with restricted or no release of water from Grays Bay Dam *(Figure 3-10)*. Minnesota's *"Lake Nutrient TMDL Protocols and Submittal Requirements"* indicate that it is instructive to assess a range of conditions including the summer (122 day) one-in-ten year low flow (MPCA, 2007). This value (the 122-Q_{10}) is 37 cfs at the MPRB / Met Council gage, also shown in Figure 3-10. Inter-annual patterns for total phosphorus are shown in Figure 3-11, for comparison to the variation in flow conditions.

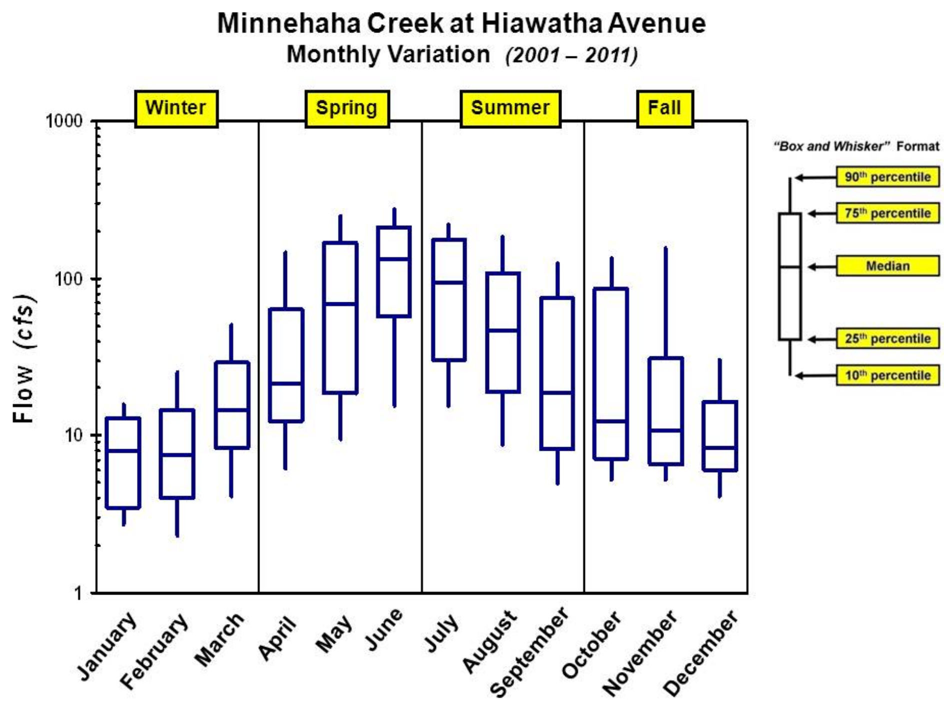


Figure 3-6. Seasonal variation in flow for Minnehaha Creek.

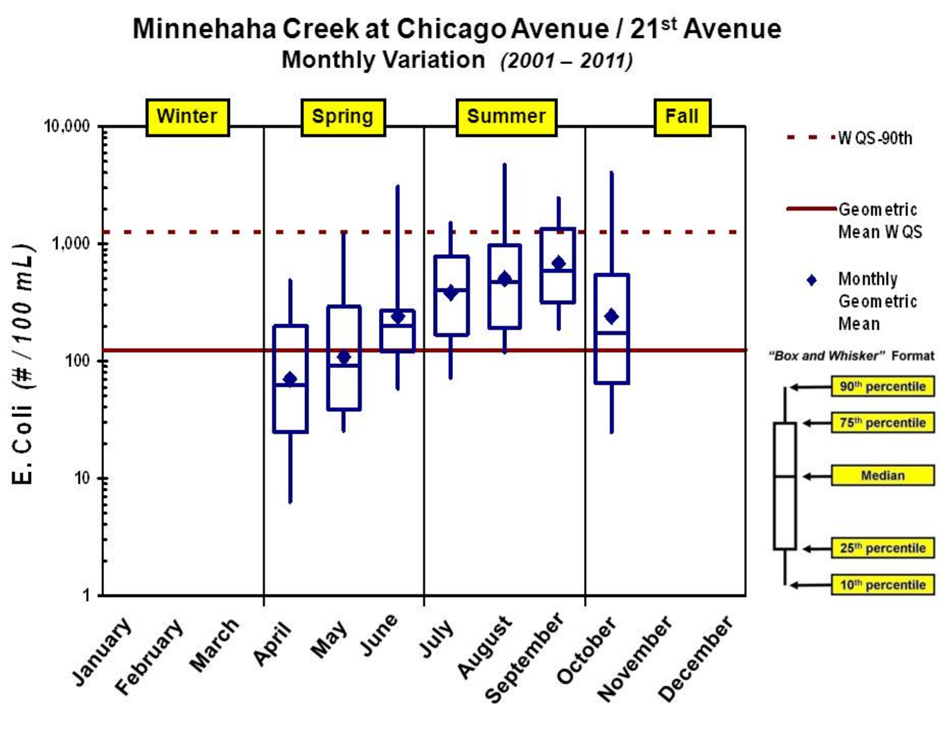


Figure 3-7. Seasonal variation in bacteria for Minnehaha Creek.

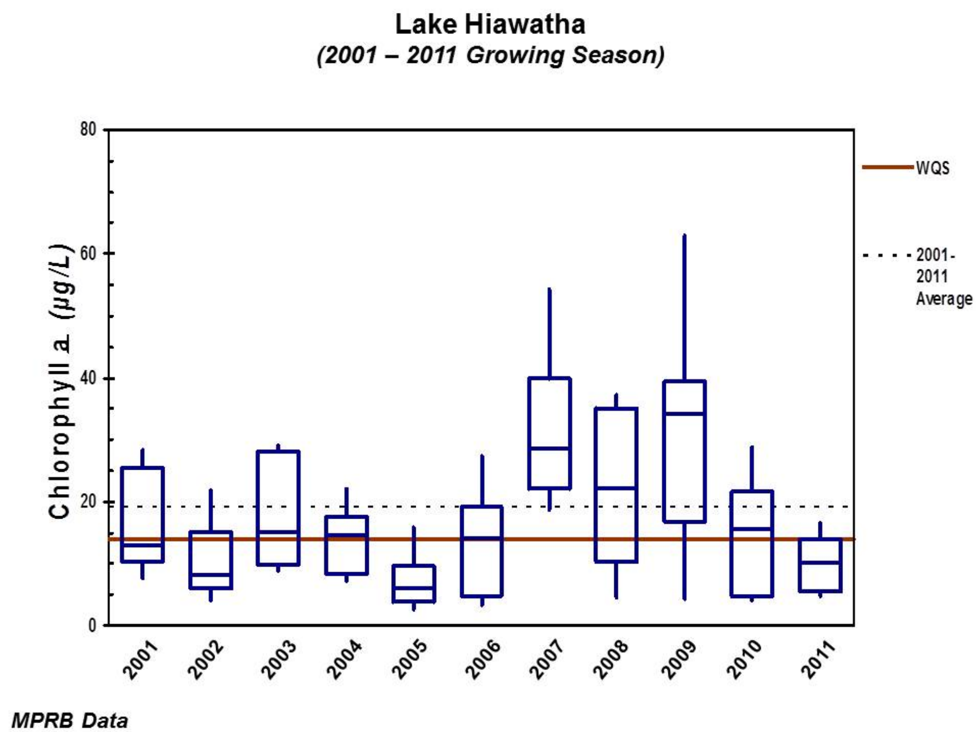


Figure 3-8. Lake Hiawatha interannual chlorophyll-a patterns *(2001 – 2011)*.

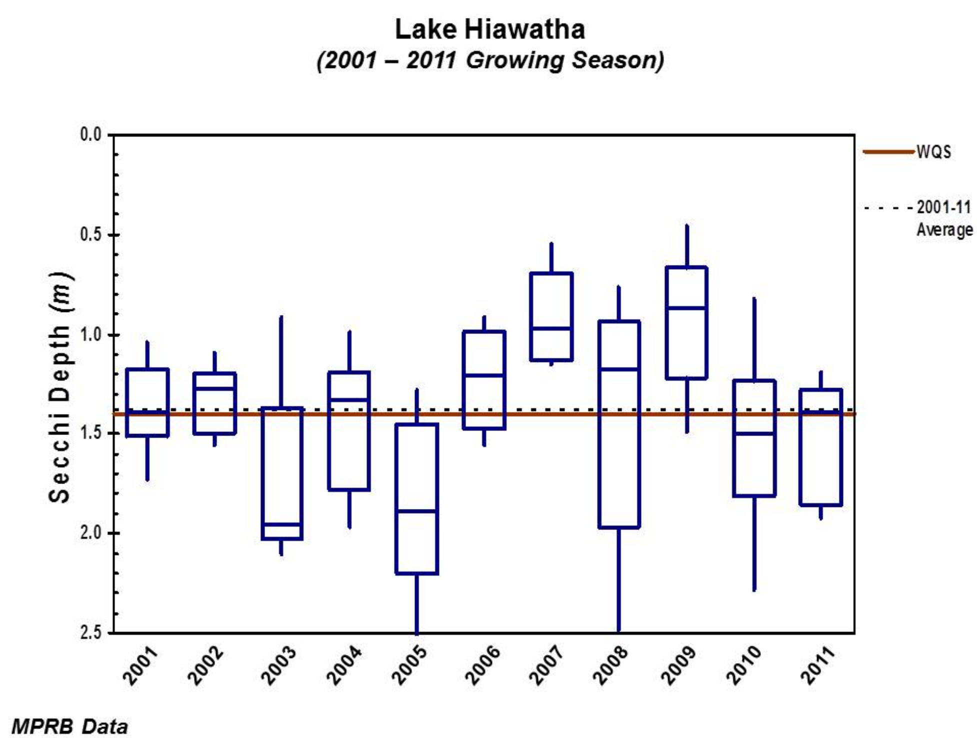


Figure 3-9. Lake Hiawatha interannual Secchi depth patterns *(2001 – 2011)*.

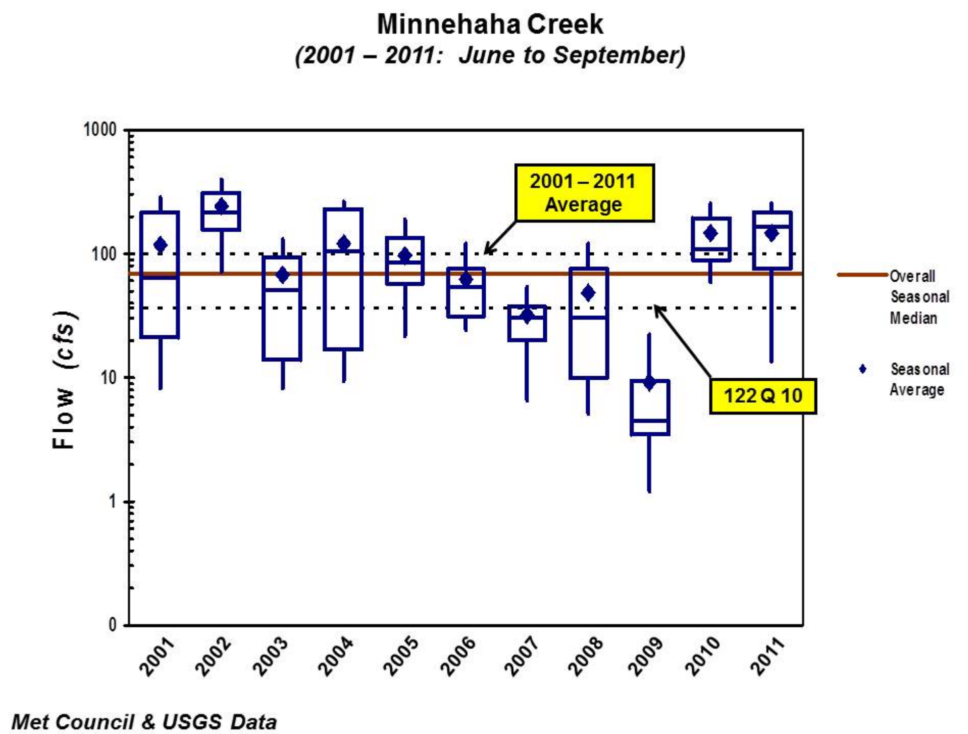


Figure 3-10. Minnehaha Creek interannual flow patterns *(2001 – 2011)*.

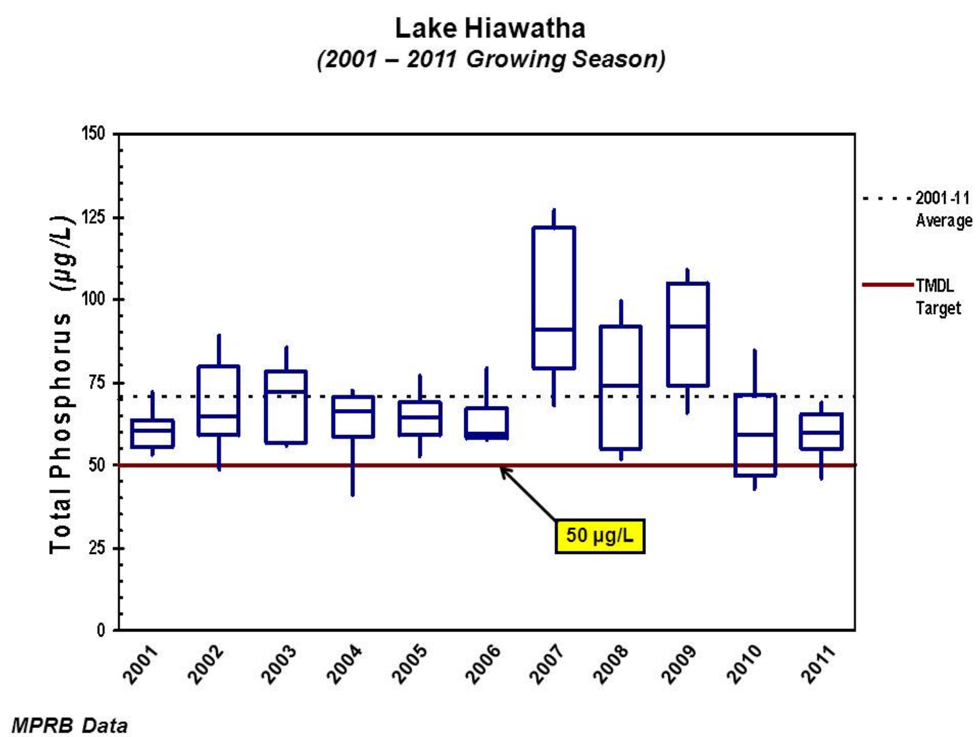


Figure 3-11. Lake Hiawatha interannual total phosphorus patterns *(2001 – 2011)*.

3.5 TMDL Reduction Needs

The analysis of both MCWD and MPRB monitoring data provides the information used to determine needed pollutant reductions *(Table 3-3)*. These reductions are based on the identified focal points and critical conditions.

The reduction needs for Lake Hiawatha are based on in-lake measurements. However, the major source of nutrients to the lake is Minnehaha Creek. For that reason, the Lake Hiawatha TMDL for total phosphorus must also include load reduction targets for Minnehaha Creek. An important part for identifying load reduction needs is information on flow at key points in the creek. The linkage analysis (Section 5) describes the process used to develop these flow estimates.

Table 3-3. TMDL reduction needs.

Parameter	2001-2011 Average	Target	TMDL Reduction Needed
E. coli (#/100mL)	301 [1]	126	58.1%
Total Phosphorus *(µg/L)*	70.9 [2]	50	29.5%

Notes: [1] Average value reflects April-Oct. geometric mean, consistent with water quality standards.

[2] Value reflects growing season average (June-Sept), consistent with site-specific criteria.

4. Source Assessment

Source assessments evaluate the type, magnitude, timing, and location of pollutant loading to a waterbody (USEPA, 1999). Source assessment methods vary widely with respect to their applicability, ease of use, and acceptability. The dominant sources of bacteria and nutrients to Minnehaha Creek are associated with stormwater. The high percentage of impervious surface in this urbanized watershed has resulted in a network of constructed drainage systems. Stormwater is efficiently conveyed to Minnehaha Creek through numerous stormwater outfalls. The increased stormwater volumes also deliver nutrients, bacteria, chloride, sediment, and other pollutants to the stream.

4.1 Point Sources

4.1.1 Bacteria

Point sources of bacteria in the Minnehaha Creek / Lake Hiawatha TMDL study area consist of regulated stormwater runoff. Bacteria loads in urban stormwater are directly conveyed to Minnehaha Creek and Lake Hiawatha via impervious surfaces, storm drains, and storm sewer networks.

Regulated Stormwater Runoff

Stormwater runoff is generated in the watershed during precipitation and snowmelt events. The sources of bacteria in stormwater include domestic pet waste, waterfowl, and waste from wild animals deposited in storm sewer systems (e.g., rats, raccoons). Unknown, illicit septic systems are a possible source. Seepage from sanitary sewers is a possible source, although sanitary sewers are almost always deeper than storm drains and deeper than the creek bed. Certain types of stormwater runoff are covered under National Pollutant Discharge Elimination System / State Disposal System (NPDES/SDS) permits based on where the stormwater originates.

Municipal Separate Storm Sewer Systems (MS4s). MS4s are defined by the MPCA as conveyance systems owned or operated by an entity such as a state, city, town, county, district, or other public body having jurisdiction over disposal of stormwater or other wastes. Stormwater runoff that falls under these permits is regulated as a point source and therefore must be included in the WLA portion of a TMDL (EPA, 2002; see 40 C.F.R. § 130.2(h)). EPA recommends that WLAs be broken down as much as possible in the TMDL, as information allows. This facilitates implementation planning and load reduction goals for the MS4 entities.

Phase I of the NPDES Stormwater Program identified Minneapolis as a large MS4 community, and assigned Minneapolis an individual NPDES/SDS permit. Under Phase II of the NPDES stormwater program, MS4 communities outside of urbanized areas, with populations greater than 10,000 (or greater than 5,000 if they discharge to or have the potential to discharge to an outstanding value resource, trout lake or trout stream or impaired water), and MS4 communities within urbanized areas are regulated MS4s. Hennepin County and the Minnesota Department of Transportation (Mn/DOT) also are NPDES/SDS permit holders in the Minnehaha Creek / Lake Hiawatha TMDL study area.

MS4 communities within urbanized areas are classified as mandatory MS4s. Under the NPDES stormwater program, the MS4 entities are required to obtain a permit, then develop and implement an MS4 Stormwater Pollution Prevention Program (SWPPP), or in the case of a Phase I permit holder, a Stormwater Management Program (SWMP), which outlines a plan to reduce pollutant discharge, protect water quality, and satisfy water quality requirements in the Clean Water Act. An annual report is submitted to the MPCA each year by the permittee documenting progress on implementation of the SWPPP. The municipal stormwater permit holds permittees responsible for stormwater discharging from the conveyance system they own and / or operate. The conveyance system includes ditches, roads, storm sewers, stormwater ponds, etc.

NPDES/SDS permits for MS4 communities have been issued to cities in the watershed as well as Hennepin County and Mn/DOT. The City of Minneapolis has an individual NPDES/SDS permit. The MS4 permit for the City of Minneapolis applies to stormwater owned or operated by the City of Minneapolis or the Minneapolis Park and Recreation Board (MPRB). The other cities, Hennepin County and Mn/DOT Metro District, are covered under the Phase II General NPDES/SDS Municipal Stormwater Permit. The unique identification numbers assigned to these cities, Hennepin County, and Mn/DOT Metro District are identified in Table 4-1.

Table 4-1. Stormwater NPDES permits in the Minnehaha Creek TMDL study area watershed.

NPDES Permit and / or Preferred ID	Name
MN0061018	City of Minneapolis
MS400138	Hennepin County MS4
MS400016	Edina City MS4
MS400024	Hopkins City MS4
MS400035	Minnetonka City MS4
MS400053	St Louis Park City MS4
MS400058	Wayzata City MS4
MS400112	Plymouth City MS4
MS400170	Mn/DOT Metro District MS4

Combined Sewer Overflows (CSOs). There are no known CSOs which could possibly contribute bacteria to Minnehaha Creek in the Minnehaha Creek watershed.

Sanitary Sewer Overflows (SSOs). There are no known SSOs which could possibly contribute bacteria to Minnehaha Creek in the Minnehaha Creek watershed.

Confined Animal Feeding Operations (CAFOs). There are no known CAFOs which could possibly contribute bacteria to Minnehaha Creek in the Minnehaha Creek watershed.

4.1.2 Total Phosphorus

Point sources of total phosphorus in the Minnehaha Creek / Lake Hiawatha TMDL study area consist of the following different types:

- Regulated stormwater runoff
- Wastewater discharges

Both point source types require NPDES permits.

Regulated Stormwater Runoff

Stormwater runoff, which delivers and transports phosphorus to Minnehaha Creek and Lake Hiawatha during the growing season, is generated in the watershed during precipitation events. The sources of phosphorus in stormwater are many including: decaying vegetation (leaves, grass clippings, etc.), domestic and wild animal waste, soil and deposited particulates from the air, oil and grease from vehicles, and phosphorus-containing fertilizer.

MS4 conveyance systems have already been discussed in the source assessment discussion for the bacteria TMDL for Minnehaha Creek (Section 4.1.1). Stormwater conveyed from these systems is a regulated point source and therefore must be included in the WLA portion of the TMDL.

Construction. Construction sites can contribute substantial amounts of sediment to stormwater runoff. Construction site owners must obtain coverage under the Construction Stormwater General Permit, which binds those parties to comply with conditions set in the permit. MPCA's NPDES stormwater program requires that all construction activity disturbing areas equal to or greater than one acre of land or that are part of a common plan of development or sale obtain a permit and create a SWPPP that outlines how runoff pollution from the construction site will be minimized during and after construction. Construction stormwater permits cover construction sites throughout the duration of the construction activities, and the level of on-going construction activity varies.

The MPCA reissued a revised statewide Construction Stormwater General Permit (MN R100001) in August 2013 in order to update the MPCA's construction stormwater general permit to be consistent with current federal guidelines. Federal rules have changed since the last construction stormwater general permit was issued in 2008. The construction stormwater general permit is designed to protect water resources from contaminants in stormwater runoff from construction sites. This general permit requires sediment and erosion controls for construction stormwater runoff.

Industrial. Minnesota's industrial stormwater program applies to facilities in ten categories of industrial activity with significant materials and activities exposed to stormwater. Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and are carried offsite. MPCA's industrial stormwater program requires that the facility obtain a permit and create a SWPPP for the site outlining the structural and/or nonstructural BMPs used to manage stormwater and the site's Spill Prevention Control and Countermeasure Plan. 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) or individual NPDES/SDS Permit if applicable. An annual report is generated documenting the implementation of the SWPPP.

Wastewater Discharges

Municipal and Commercial Facilities. Although stormwater is the dominant source of concern to Minnehaha Creek, other potential NPDES/SDS permitted sources have been identified and are considered in the TMDL development process *(Table 4-2)*. These facilities were identified using GIS data provided by MPCA. The location of NPDES permitted discharges in the Minnehaha Creek watershed is shown in Figure 4-1. Table 4-2 references the subwatershed group *(see Section 4.4)* where each facility is located.

Table 4-2 includes information from Discharge Monitoring Reports (DMRs) that summarizes average flow, effluent concentration data for each facility, and estimated growing season average phosphorus load.

Table 4-2. NPDES wastewater facility permits in the Minnehaha Creek TMDL study area.

Group	NPDES ID	Facility	Effluent Limit or Target Concentration *(µg/L)*	Average Flow *(mgd)*	Growing Season Average TP Load *(pounds)*
C	MN0045489	St. Louis Park GWP Reilly Tar Site: #001	30	0.1640	6.3 [1]
		St. Louis Park GWP Reilly Tar Site: #002	30	0.8640	26.4
D	MNG640084	St. Louis Park WTP	74	0.0117	1.1 [1]
G	MN0062723	Kwong Tung Foods	273	0.0131	4.6 [1]

Notes: [1] Includes a 25% increase to account for uncertainty in seasonal load estimates.

Combined Sewer Overflows (CSOs). There are no known CSOs which could contribute phosphorus to Minnehaha Creek or Lake Hiawatha in the Minnehaha Creek watershed.

Sanitary Sewer Overflows (SSOs). There are no known SSOs which could contribute phosphorus to Minnehaha Creek or Lake Hiawatha in the Minnehaha Creek watershed.

Confined Animal Feeding Operations (CAFOs). There are no known CAFOs which could contribute phosphorus to Minnehaha Creek or Lake Hiawatha in the Minnehaha Creek watershed.

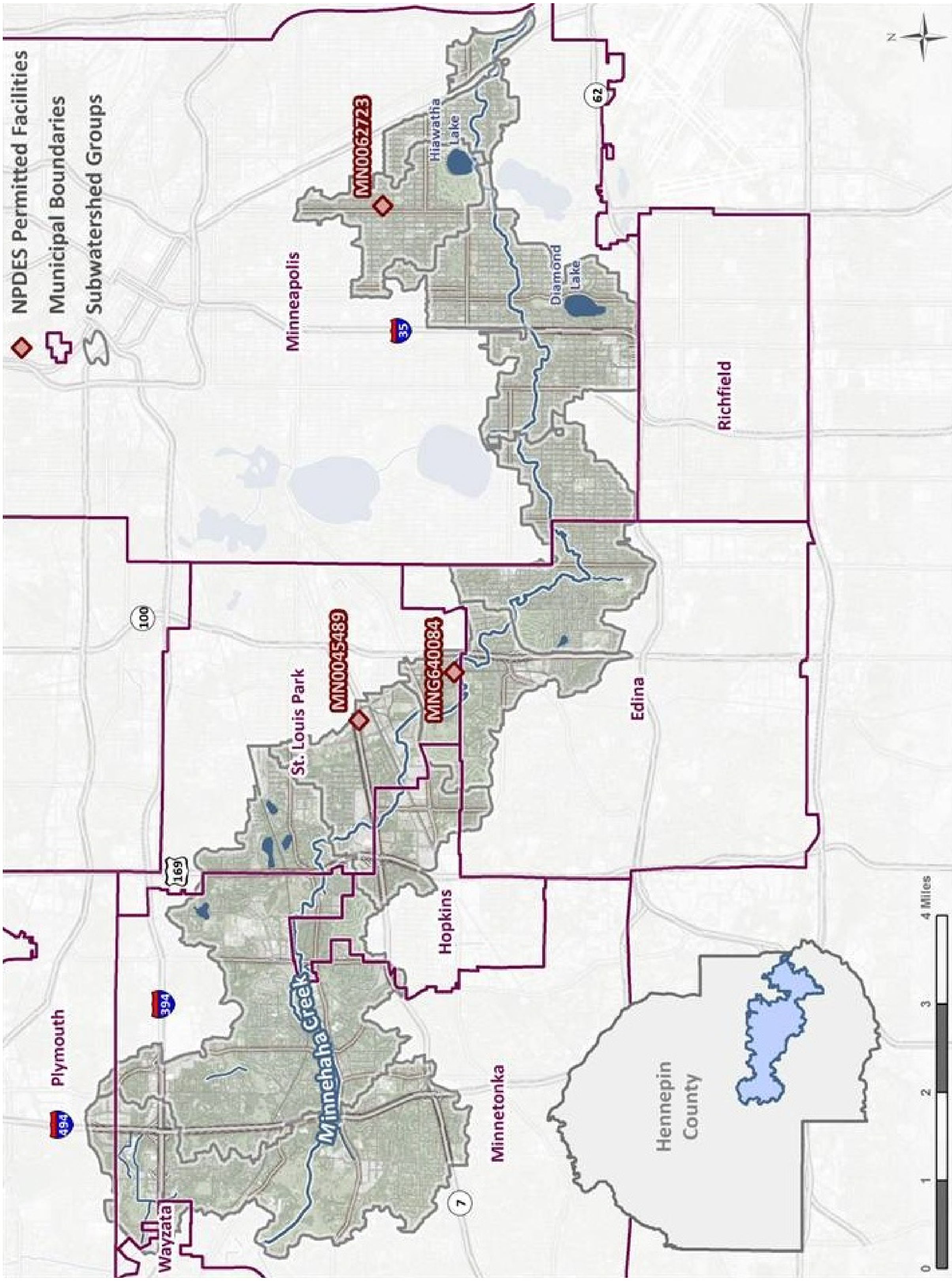


Figure 4-1. Minnehaha Creek / Lake Hiawatha TMDL study area NPDES wastewater facility locations.

4.2 Nonpoint Sources

4.2.1 Bacteria

Non-regulated stormwater runoff from non-MS4 regulated areas. Pet wastes in urban areas that do not go directly to an MS4 conveyance system can be nonpoint sources of *E. coli*. It also includes runoff from backyards adjacent to the stream. Other nonpoint sources of bacteria include waterfowl and waste from wild animals (e.g., deer, rats, raccoons), as well as sediment accumulations in wetlands and streambeds.

Wildlife. Wildlife is a known source of *E. coli* and nutrients in waterbodies. Many animals spend time in or around waterbodies. Deer, geese, ducks, raccoons, and other animals all create potential sources of *E. coli*. Wildlife contributes to the potential impact of contaminated runoff from animal habitats, such as urban park areas, forest, and rural areas.

4.2.2 Total Phosphorus

Nonpoint sources of total phosphorus in the Minnehaha Creek / Lake Hiawatha watershed consist of the following different types:

- Non-regulated stormwater runoff
- In-channel / streambank erosion
- Internal loading
- Atmospheric deposition
- Groundwater discharge
- Wildlife

Non-regulated stormwater runoff from non-MS4 regulated areas and the Lake Hiawatha direct watershed. Non-regulated stormwater runoff includes watershed runoff that does not flow into an MS4 conveyance system. It includes runoff from backyards adjacent to the stream, as well as land uses such as wetlands, forested, and woodland areas within the Minnehaha Creek / Lake Hiawatha TMDL study area.

In-Channel / Streambank Erosion. Erosion in or near the creek due to various causes will contribute some load of phosphorus which is ultimately delivered to Lake Hiawatha. The amount of loading from this source is very difficult to quantify and no load estimate has been made for this study.

Internal Loading. Phosphorus internal loading is the phosphorus that is released from the lake bottom sediments into the water column. Each year, phosphorus settles out of the water column and adsorbs onto particulate matter in the lake sediments and accumulates. This phosphorus may be re-released into the water column, and can occur through various mechanisms; anoxic conditions, physical disturbance by bottom-feeding fish, physical disturbance due to wind mixing and phosphorus release from decaying curly-leaf pondweed.

For the purposes of the Lake Hiawatha TMDL internal load is acknowledged as a potential nonpoint source contributor of nutrients to Lake Hiawatha. However, given the flow conditions of Minnehaha Creek and Lake Hiawatha, an internal load is not assigned to this potential nonpoint source. The average growing season residence time is relatively short, estimated to be 4.4 days *(see Section 5.2.2)*. In addition, an analysis based on FLUX32 estimates using MCWD data shows that phosphorus loads actually decrease through Lake Hiawatha. The 2001 – 2011 seasonal average loss is nearly 300 pounds total phosphorus using the MCWD monitoring sites upstream and downstream of Lake Hiawatha.

The loss of total phosphorus as Minnehaha Creek flows through Lake Hiawatha shows that it generally function as a *"sink"* on a typical June to September seasonal average basis. This indicates that, relative to other sources in the Minnehaha Creek watershed, internal loading of phosphorus in Lake Hiawatha is not a major contributor; likely due to the relatively short residence time. There may be periods when low flows and longer residence times create situations where there may be some episodic internal loading. However, from a water quality management perspective, the data points to higher priority source areas that should be addressed in implementation planning efforts.

Atmospheric Deposition. Atmospheric deposition represents the phosphorus that is bound to particulates in the atmosphere and is deposited directly to the lake surface as the particulates settle out of the atmosphere. Atmospheric deposition is usually a minimal source of phosphorus to a lake; however; if a lake has a very low watershed to lake area ratio, atmospheric deposition can represent a substantial portion of the total phosphorus load to a lake.

Atmospheric deposition for the Lake Hiawatha nutrient TMDL is calculated utilizing an average rate of 26.1 kilograms per square kilometer per year (kg/km^2/yr) (Barr, 2004). This is equivalent to 0.233 pounds per acre per year (lbs/ac/yr). These values are adjusted based on the summer season of June through September, which results in 4.1 pounds per growing season average TP to Lake Hiawatha from atmospheric deposition. Although atmospheric inputs must be accounted for in development of a nutrient budget, direct inputs to the lake surface are impossible to control.

Groundwater Discharge. Phosphorus may enter a lake through groundwater discharge to a lake. The concentration of phosphorus in groundwater is usually below the lake's water quality standard, and usually does not play a significant role in the eutrophication of a lake. However, in a lake with a lot of groundwater interaction, the phosphorus from groundwater can play a role in the phosphorus budget. Site-specific data are needed to estimate the role of groundwater in a lake's phosphorus budget; phosphorus loads due to groundwater were not estimated as part of this project.

Wildlife. Wildlife is a known source of nutrients in waterbodies. Many animals spend time in or around waterbodies. Deer, geese, ducks, raccoons, and other animals all create potential sources of nutrients. Wildlife contributes to the potential impact of contaminated runoff from animal habitats, such as urban park areas, forest, and rural areas.

4.3 Upstream Boundary Load (upstream load from Lake Minnetonka)

The upstream total phosphorus load from Lake Minnetonka is considered by MPCA as an upstream boundary load. This is a mix of nonpoint and point contributions from all of the sources that drain to Lake Minnetonka above the Minnehaha Creek / Lake Hiawatha TMDL boundary point. In the case of the Minnehaha Creek and Lake Hiawatha TMDL, the upstream boundary load's downstream discharge point is Grays Bay Dam. Releases from Grays Bay Dam to Minnehaha Creek are considered as upstream load contributions from this source. This upstream load is estimated to be a growing season average of 1,279 pounds, which is derived from water quality monitoring data collected by MCWD. The load is based on a FLUX32 estimate using MCWD data. This upstream load is accounted for in the Lake Hiawatha nutrient TMDL.

4.4 Subwatershed Approach

A subwatershed approach is used to determine the spatial distribution of source loads based on MCWD ambient water quality monitoring data. Because estimates of streamflow are needed to calculate the watershed load, details are described in the Linkage Analysis *(Section 5)*. Following a discussion of the technical rationale behind watershed calculations, all existing source and watershed loads are summarized in Table 5-9. [Note: An in-depth subwatershed source assessment analysis was done as an early phase of this project and results are captured in a report titled '*Watershed Source Assessment Report for the Minnehaha Creek – Lake Hiawatha Watershed'* (Tetra Tech, March 2010). This report provides more detail and is available as a resource for implementation planning purposes.]

The subwatershed approach capitalizes on work from previous watershed characterization and stream assessment studies conducted on Minnehaha Creek. In developing their *Water Resources Management Plan*, the MCWD used information from the HHPLS. This report was completed to better inform the MCWD of pollutant loading within the Minnehaha Creek watershed. The HHPLS subdivided the Minnehaha Creek subwatershed into 184 subwatershed units (MCWD, 2007). These subwatershed units provide a framework for constructing an inventory of stormwater source areas within the Minnehaha Creek watershed. The subwatershed unit boundaries were strategically developed to coincide with the stormwater drainage network.

Minnehaha Creek's physical and hydrologic regime is complex as it meanders from Grays Bay Dam to the Mississippi River. It is advantageous to develop a framework that groups subwatershed units where notable changes occur in the stream. Clustering subwatershed units enables a meaningful evaluation of major factors that affect water quality, particularly flows and source loads. The use of subwatershed groups creates an opportunity to connect source information to water quality monitoring results. Grouping subwatershed units together that are tributary to specific stream reaches not only enhances the source assessment; it sets the stage for the TMDL linkage analysis.

Subwatershed groups connect potential cause information to documented effects. The ability to summarize information at different spatial scales strengthens the overall TMDL development process, as well as enables more effective targeting of implementation efforts. Subwatershed groups used for the source assessment are identified in Table 4-3 and Figure 4-2.

Table 4-3. Minnehaha Creek / Lake Hiawatha TMDL source assessment subwatershed groups.

Group ID	Name	Drainage Area *(acres)*	Drainage Area *(sq. mi.)*	# of Subwatershed Units
A	Upper Minnehaha *(McGinty)*	3,494	5.46	16
B	West 34th Street	5,103	7.97	37
C	Excelsior Blvd.	1,998	3.12	16
D	Browndale Dam	1,427	2.23	12
E	Browndale Dam to Chain of Lakes outlet	2,172	3.39	18
F	Chain of Lakes outlet to Lake Hiawatha	2,504	3.91	32
G	Lake Hiawatha *(direct drainage)*	1,195	1.87	3
	TOTAL	17,893	28.0	134

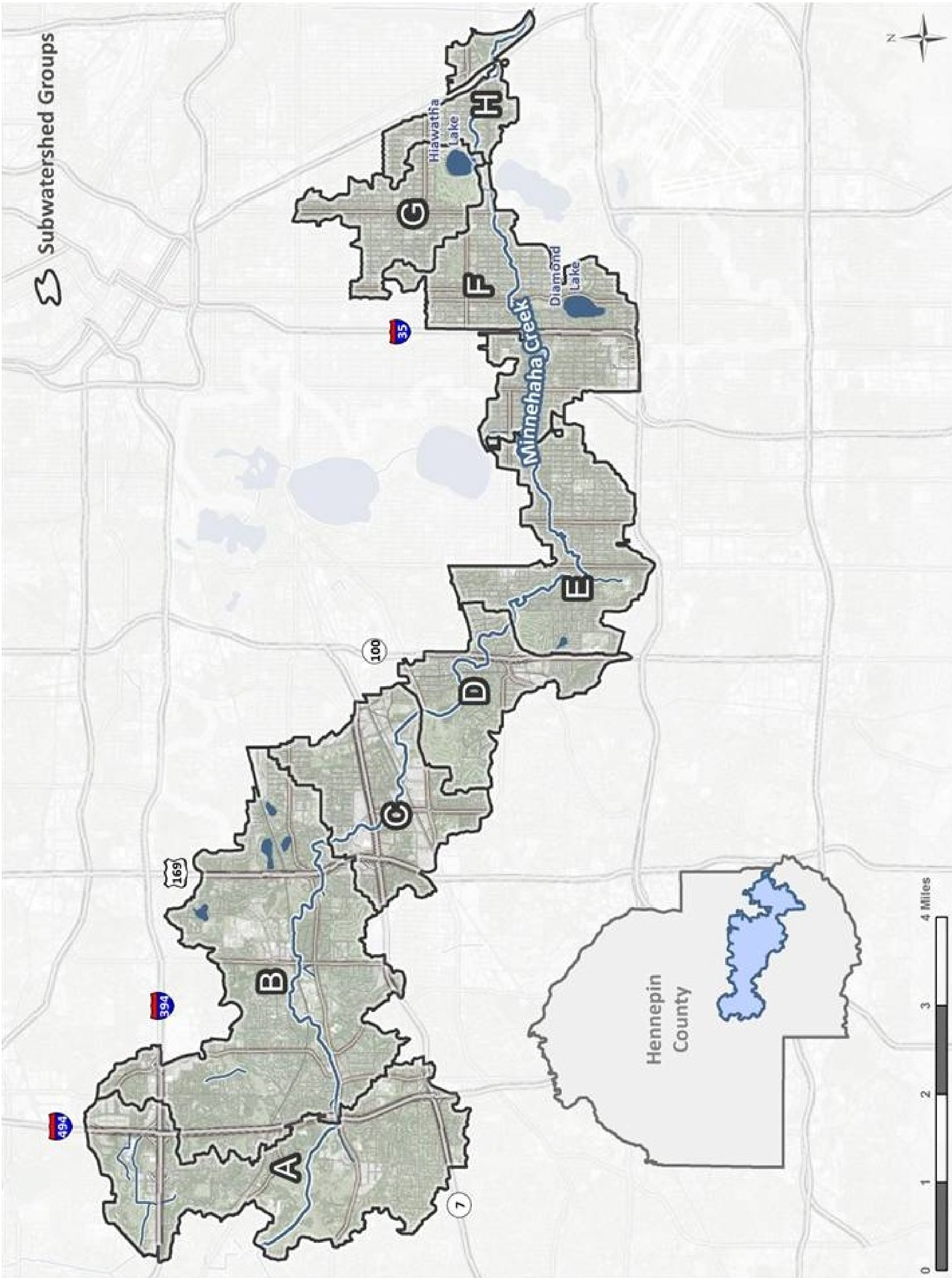


Figure 4-2. Minnehaha Creek / Lake Hiawatha TMDL study area subwatershed groups.

5. Linkage Analysis

Developing TMDLs requires a combination of technical analysis, practical understanding of important watershed processes, and interpretation of watershed loadings and receiving water responses to those loadings. An essential component of TMDL development is establishing a relationship between numeric indicators intended to measure attainment of beneficial uses and source loads. The linkage analysis examines connections between water quality targets, available data, and potential sources. The focus of this section is to evaluate the relationship between water quality data and potential source areas, as well as interpret watershed loadings and receiving water responses to those loadings.

5.1 Flow

The analysis of critical conditions highlights the importance of flow relative to water quality in Minnehaha Creek and Lake Hiawatha. Hydrology plays a major role in water quality. Streamflow is an important factor in determining the ability of a waterbody to assimilate pollutants. Flow information is needed to evaluate existing watershed loads and identify a total phosphorus loading capacity for Lake Hiawatha. In addition, a duration curve framework is used to identify TMDL loading capacities for bacteria. The duration curve approach allows for characterizing water quality under different flow regimes. Using the duration curve framework, the frequency and magnitude of water quality standard exceedances, allowable loadings, and size of load reductions are easily presented and can be better understood (USEPA, 2007).

The purpose of this section is to describe the approach used to estimate flows at key points along Minnehaha Creek. The values summarized in Table 3-3 provide an overall context for general pollutant reductions needed in the Minnehaha Creek watershed. However, a goal of the TMDL process is to develop a technical framework that can guide implementation efforts. This is best accomplished through an enhanced description of problems and concerns. Connecting water quality data to flow information enables a closer look at source areas and delivery mechanisms relative to conditions of greatest concern.

Assessment of flow information must recognize the complexity of Minnehaha Creek's physical and hydrologic regime. For instance, the reach from Grays Bay Dam to McGinty Road is surrounded by wetlands. Below McGinty Road, the stream is characterized by a mix of relatively straight channels combined with several sections surrounded by wetlands. After Excelsior Boulevard, the creek enters Meadowbrook Lake followed by a short straight channel, then into the section impounded by Browndale Dam. From Browndale Dam to Lake Hiawatha, Minnehaha Creek follows a fairly confined channel. Nearly seventy percent of all storm sewer outfalls entering Minnehaha Creek are below Browndale Dam.

Releases from Lake Minnetonka have a major effect on the underlying flow characteristics of Minnehaha Creek (e.g., the base flow). Stormwater runoff and the lack of infiltration from impervious surfaces have also influenced the physical habitat and water quality of the creek. For this reason, a method is needed to estimate the general proportion of water originating from Lake Minnetonka relative to water that is the result of rainfall or snowmelt. By examining both components (base and storm), daily average flows can be estimated at each water quality monitoring site. This information is then used to develop flow duration curves and calculate pollutant loads at key points in Minnehaha Creek.

5.1.1 Hydrograph Separation

Surface runoff following rain events can be one of the most significant transport mechanisms of sediment, nutrients, bacteria, and other pollutants. Precipitation is the primary driving mechanism responsible for storm flows and associated surface runoff. Rainfall / runoff models, such as HSPF, SWAT, or SWMM, are generally used to provide detailed estimates of the timing and magnitude of storm flows. However, these often involve very time-consuming and resource intensive efforts.

The use of basic hydrology and duration curves provides another method to examine general watershed response patterns regarding stormwater. Streamflow hydrographs can be separated into base flow and surface runoff components *(Sloto and Crouse, 1996)*. The base-flow component is traditionally associated with groundwater or controlled discharges (e.g., releases from Lake Minnetonka). The surface-runoff component is associated with precipitation that enters the stream as overland flow. Figure 5-1 illustrates the concept of hydrograph separation applied to Minnehaha Creek using the sliding interval method. Information from hydrograph separation can be used to develop a flow duration curve with either the base flow or surface runoff components.

A duration curve is simply a cumulative frequency distribution. It provides a framework that enables the analysis of patterns under different flow conditions. In the case of Minnehaha Creek, patterns of particular interest include the degree of influence that releases from Lake Minnetonka may exert on water quality. Similar to the use of duration curves to describe flow conditions (e.g., high, moist, mid, dry, low), zones can be defined that reflect the potential influence of Lake Minnetonka.

Base flows determined through hydrograph separation with Minnehaha Creek data are used to develop a flow duration curve, shown in Figure 5-2. The curve has been divided into five zones (A, B, C, D, E) consistent with the same intervals used to assess water quality data (USEPA, 2007). These zones are also depicted in Figure 5-1, along with precipitation data. In addition, dates when MCWD sampling occurred are noted on this graph.

5.1.2 Base Flow Conditions and Conductivity

A challenge in the overall analysis is estimating flows at water quality sampling points along the stream. One option is modeling that, as mentioned earlier, can be both time consuming and resource intensive. Another approach is to utilize the water quality monitoring data itself to develop these estimates. For example, conductivity can be a particularly useful parameter when examining flow information.

Figure 5-3 depicts a conductivity longitudinal profile for Minnehaha Creek. This graph was developed using all data to illustrate general spatial variability. The potential magnitude of tributary inflow volumes can be examined on a reach-by-reach basis using conductivity patterns. A starting point evaluates base flow conditions. This focus reduces variability associated with pollutant loads from storm events. Using a mass balance type approach, conductivity measurements are converted to *"load equivalents"* (e.g., a conductivity value of one µmhos/cm is treated as one mg/L for purposes of the load calculation). The resultant load units are expressed as C-tons per day. Figure 5-4 shows the relationship between conductivity load and flow for the Chicago Avenue site under base flow conditions. The base flow condition zone is labeled at the bottom to provide a frame of reference.

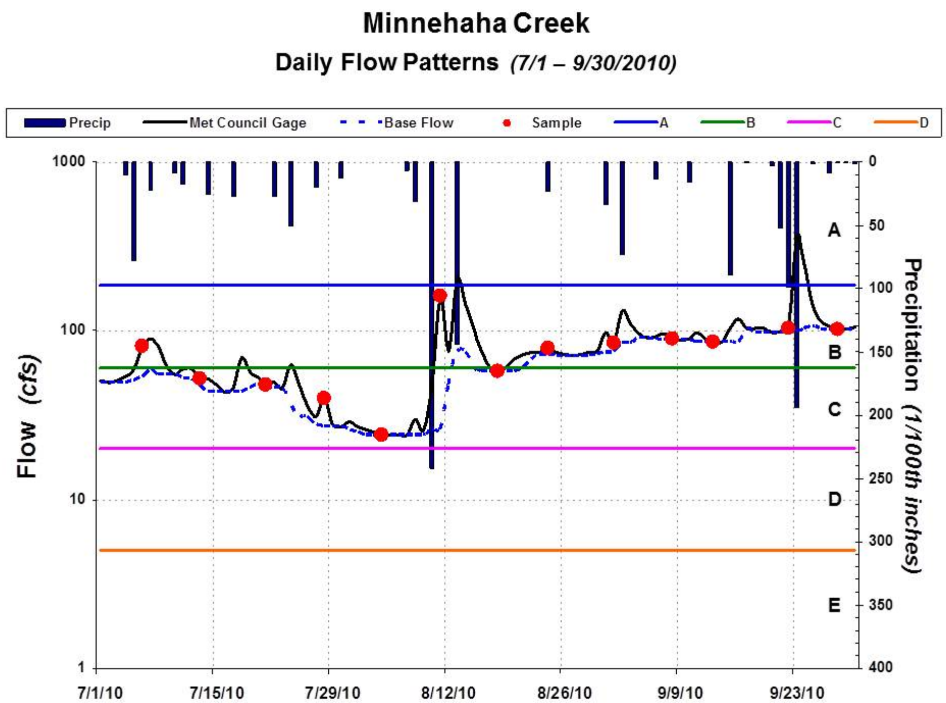


Figure 5-1. Hydrograph separation using Minnehaha Creek flow data.

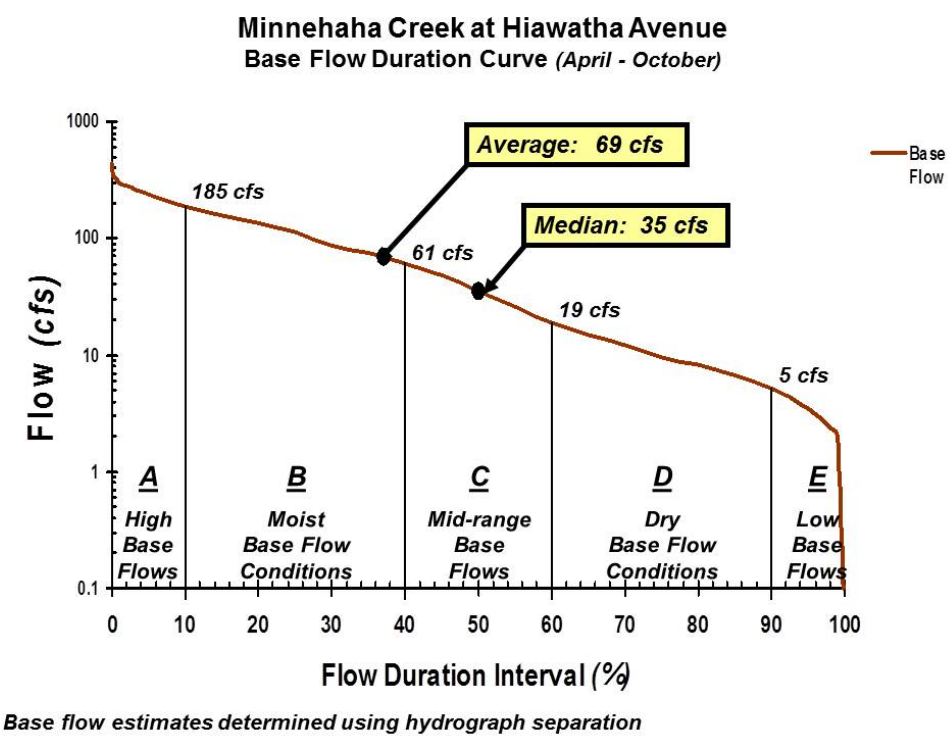


Figure 5-2. Base flow duration curve -- Minnehaha Creek *(April – October)*.

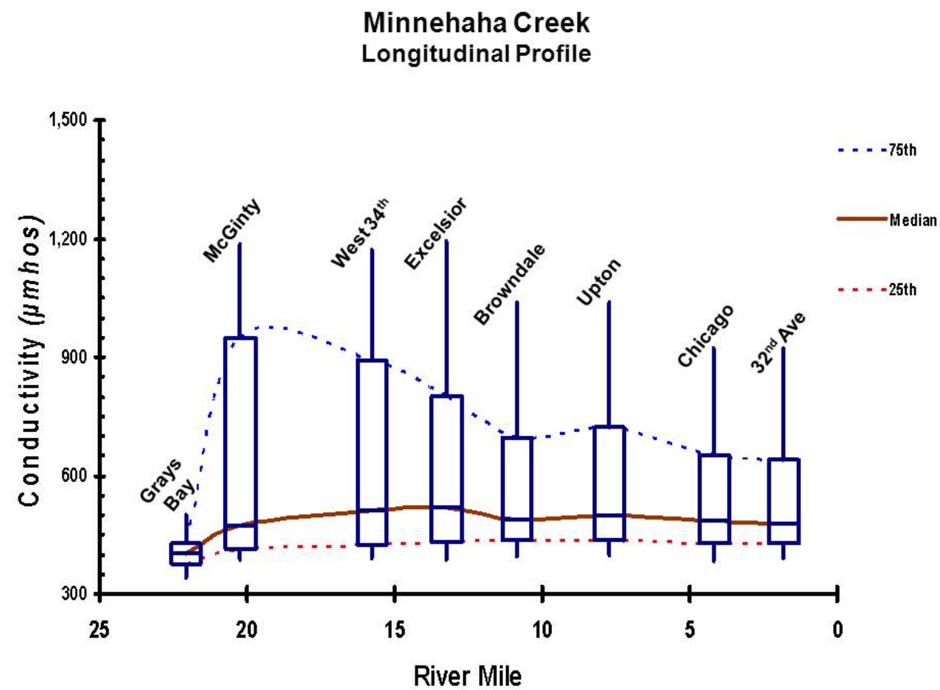


Figure 5-3. Longitudinal profile for conductivity along Minnehaha Creek.

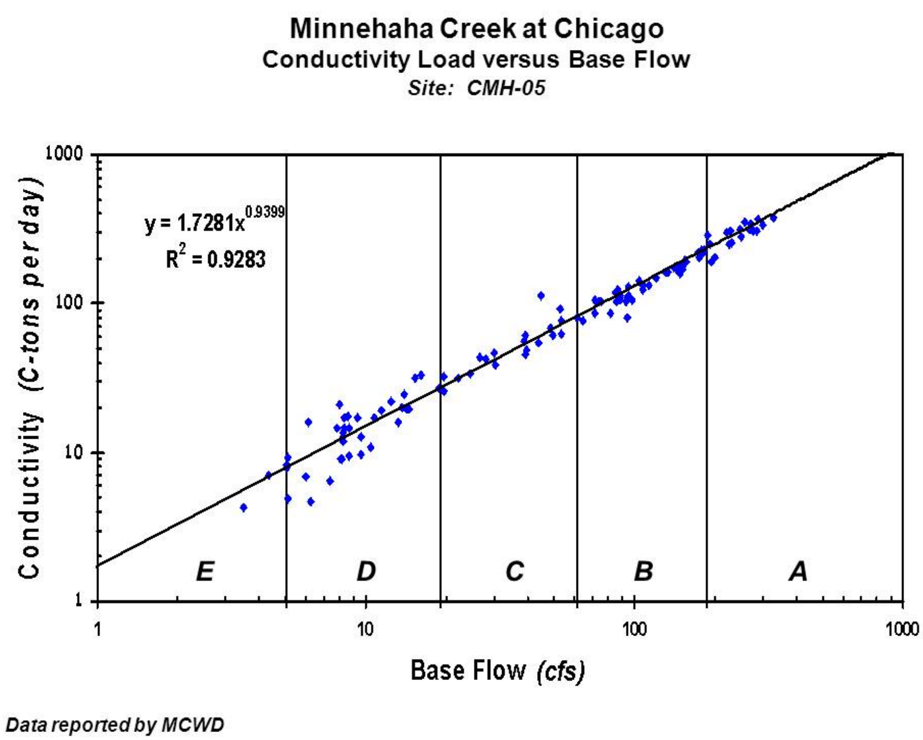


Figure 5-4. Relationship between conductivity load and flow *(CMH-05)*.

Figure 5-5 shows the longitudinal conductivity load profile when the base flow is greater than 185 cfs. The overall intent of this analysis is to determine at what point base flows in Minnehaha Creek may be influenced by factors other than releases from Grays Bay Dam. For that reason, conductivity measurements used in the evaluation are limited to those taken when the base flow to total flow ratio is at least 90 percent. This minimizes the effect of storm-related inflows (which will be examined separately). Also, only samples taken between May and October are used in this particular analysis. This minimizes the residual effect of winter de-icing activities.

Figure 5-5 indicates that conductivity loads remain fairly constant, confirming the dominant effect of Lake Minnetonka at high base flow conditions. Figure 5-6 through Figure 5-9 depict the conductivity loading analysis for other base flow conditions. Several points are worth noting. First, there is a slight increase in the Zone C median load between Gray Bay Dam and McGinty Road (though the 25th and 75th percentiles remain relatively constant). That increase becomes more pronounced in Zone D. This suggests a potential effect that the wetlands may exert on Minnehaha Creek water quality as flows drop towards the 10 to 20 cfs range. In addition, there is a slight drop in the Zone D conductivity load from Excelsior Boulevard to Browndale Dam.

Finally, the greatest variability is observed in Zone E. This is not surprising as it represents the lowest ten percent of base flow values. Under these conditions, Minnehaha Creek is essentially a sequence of pools and ponded water. Local factors at each monitoring site exert a greater influence on water quality than releases from Grays Bay Dam.

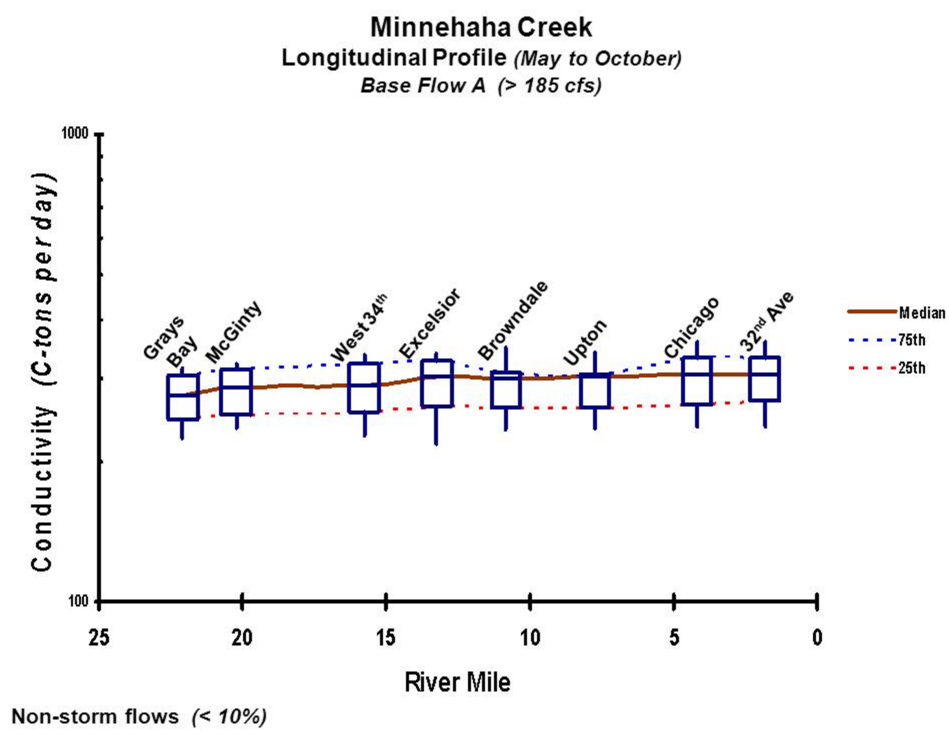


Figure 5-5. Minnehaha Creek conductivity load longitudinal profile *(base flow condition A)*.

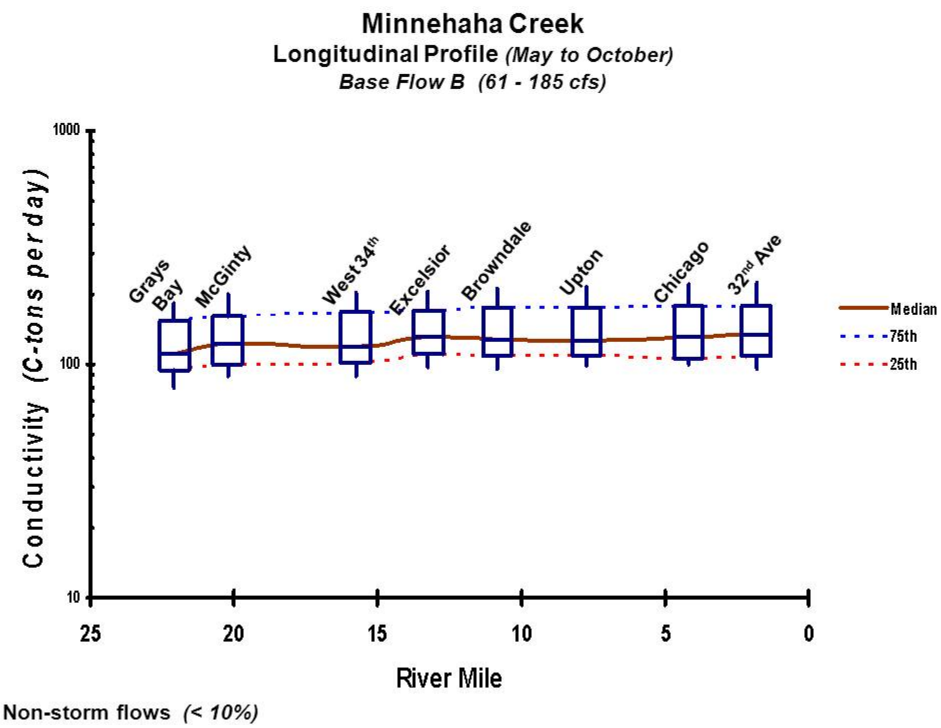


Figure 5-6. Minnehaha Creek conductivity load longitudinal profile *(base flow condition B)*.

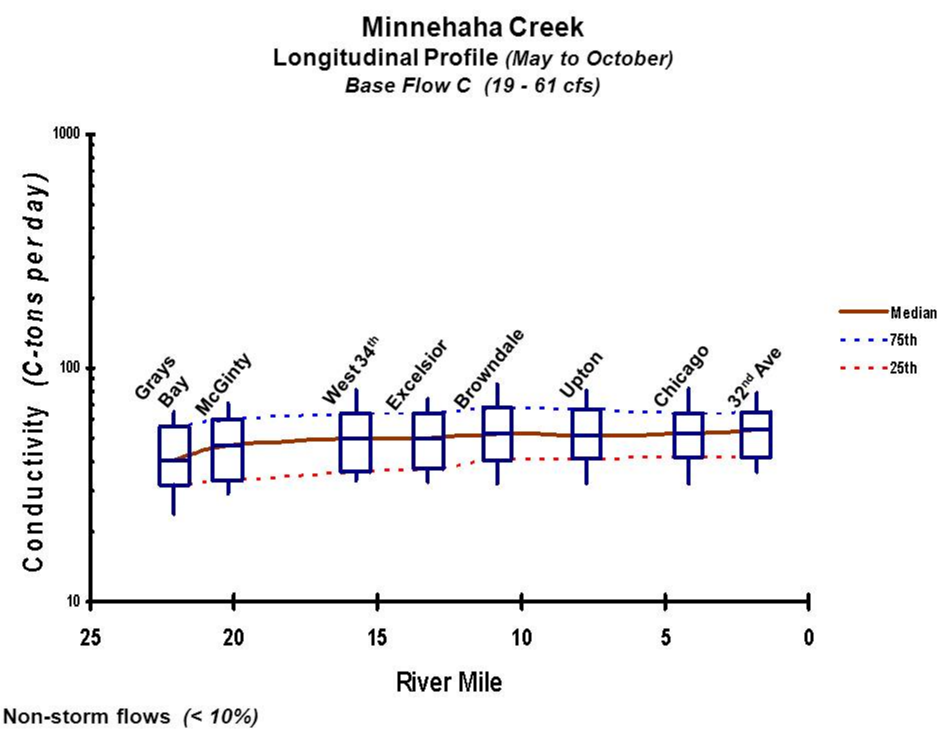


Figure 5-7. Minnehaha Creek conductivity load longitudinal profile *(base flow condition C)*.

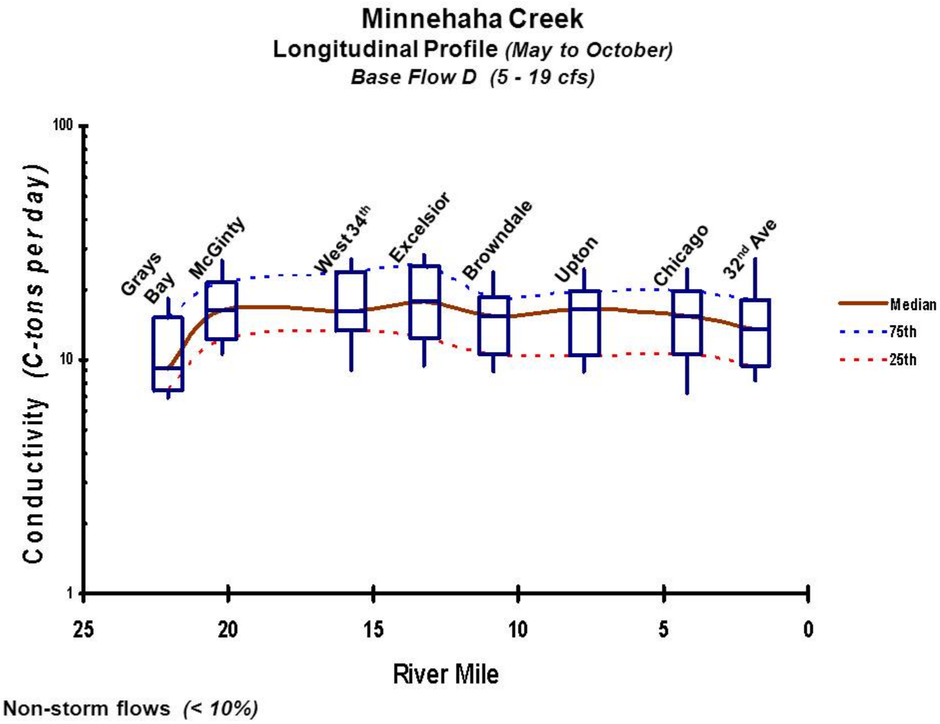


Figure 5-8. Minnehaha Creek conductivity load longitudinal profile *(base flow condition D)*.

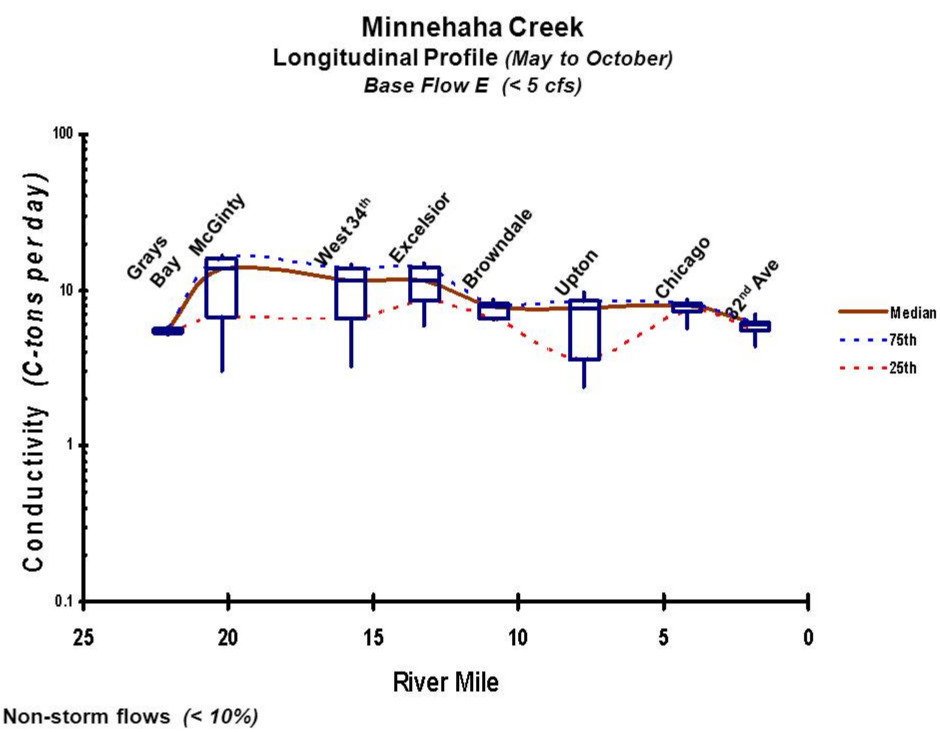


Figure 5-9. Minnehaha Creek conductivity load longitudinal profile *(base flow condition E)*.

5.1.3 Stormwater

An important part of the hydrologic analysis is to develop estimates of stormwater inputs to Minnehaha Creek, both amounts (e.g., volume) and location. These estimates are needed so that MCWD water quality monitoring data can be used to assess pollutant loads in Minnehaha Creek. As discussed earlier, stream discharge consists of two major components: base flow and surface runoff. In Minnehaha Creek, the base flow component generally represents Grays Bay Dam releases from Lake Minnetonka (except under very low flow conditions). For this reason, base flow estimates apply consistently throughout the length of the creek, as water flows from Lake Minnetonka to the Hiawatha Avenue gage. This assumption ensures continuity in developing a water balance.

The surface runoff component at each monitoring site is a function of land use, particularly impervious cover (IC). Flow volume (Qv), as a function of IC, can be calculated using the following equation, adapted from *"Urban Runoff Quality Management"* (ASCE / WEF, 1998):

$$Qv = C * P * (A/12)$$

where:

C = runoff coefficient
$= 0.858*i^3 - 0.78*i^2 + 0.774*i + 0.04$
i = watershed imperviousness ratio *(percentage divided by 100)*
P = amount of precipitation occurring in a 24-hour period *(inches)*
A = drainage area *(acres)*

This relationship can be used to estimate stormwater volumes at each site. Again, the Minnehaha Creek Hiawatha Avenue surface runoff component can be apportioned across the watershed through an area weighting process. Weighting is determined by the area of each subwatershed group and the runoff coefficient (C) of each group to account for the effect of impervious surfaces. This coefficient is based on subwatershed land use information and IC assumptions for each developed land use category.

Table 5-1. Minnehaha Creek stormwater runoff volume estimate factors.

Subwatershed Group	Name	Cumulative		Unit Runoff Coeff. *(C)*	Cumulative Stormwater Volume Factor *(%)*
		Surface Runoff Contributing Area** *(acres)*	IC *(%)*		
A	McGinty	1,017	7%	0.255	7%
B	West 34th	2,063	14%	0.271	15%
C	Excelsior	2,949	25%	0.451	25%
D	Browndale	3,753	30%	0.276	31%
E	Browndale to Chain of Lakes	5,919	53%	0.383	53%
F	Chain of Lakes to Lake Hiawatha	8,436	80%	0.394	80%
G	Lake Hiawatha	9,614	92%	0.403	93%
H	Lake Hiawatha to Mouth	10,389	100%	0.361	100%

Note: ** Subwatersheds either adjacent or directly connected through storm sewer system to Minnehaha Creek.

5.2 Lake Hiawatha

The purpose of this section is to evaluate the eutrophication response that results from phosphorus loading to Lake Hiawatha (as measured through chlorophyll-a and Secchi depth). Key physical characteristics for the lake are summarized in Table 5-2. Lake Hiawatha is in-line to Minnehaha Creek. As a result, flow and pollutant loads from the creek strongly influence water quality conditions in the lake. The water level in Lake Hiawatha fluctuates widely because of its direct connection to Minnehaha Creek. Thermal stratification in the lake during the summer months is typically destabilized by flow from the creek, as well as from runoff delivered directly through storm sewer connections (MPRB 2009a).

During normal flow periods, the lake's connection to the creek results in a relatively short residence time compared to most lakes in the Minneapolis area. These conditions tend to yield a low level of algae compared to the amount of total phosphorus present in the system. Excessive algae growth does occur in the lake during seasons with lower creek flow and longer residence time. Increased sediment coming from Minnehaha Creek flow also affects the water clarity in Lake Hiawatha. Sediment deltas have been observed in the lake (MPRB 2009a).

Table 5-2. Lake Hiawatha physical characteristics.

Characteristic	Units	
Surface area	*(acres)*	53.0
Average depth	*(feet)*	16.4
Maximum depth	*(feet)*	28.0
Littoral Area	*(acres)*	31.9
	(%)	60%
Volume	*(acre - feet)*	869
	(million – cubic feet)	37.9

5.2.1 Data Summary

Water Quality. In-lake observed concentration data are available for TP, chlorophyll-*a*, and Secchi depth from 1992 through 2011. These data were collected during the growing season, which extends from June 1 to September 30. Typically, 4 to 9 samples are collected per year. Figure 3-8, Figure 3-9, and Figure 3-11 displayed the trends in growing season mean (GSM) for these parameters. Across normal flow years, water quality remains stable due to short residence times and the dominant effect of Minnehaha Creek. Drought conditions cause increased TP and chlorophyll-*a* concentrations, as well as decreased Secchi depth. This pattern is particularly apparent in years 2007 and 2009. The water quality trends are also consistent with a milder drought that occurred in the summer of 2008.

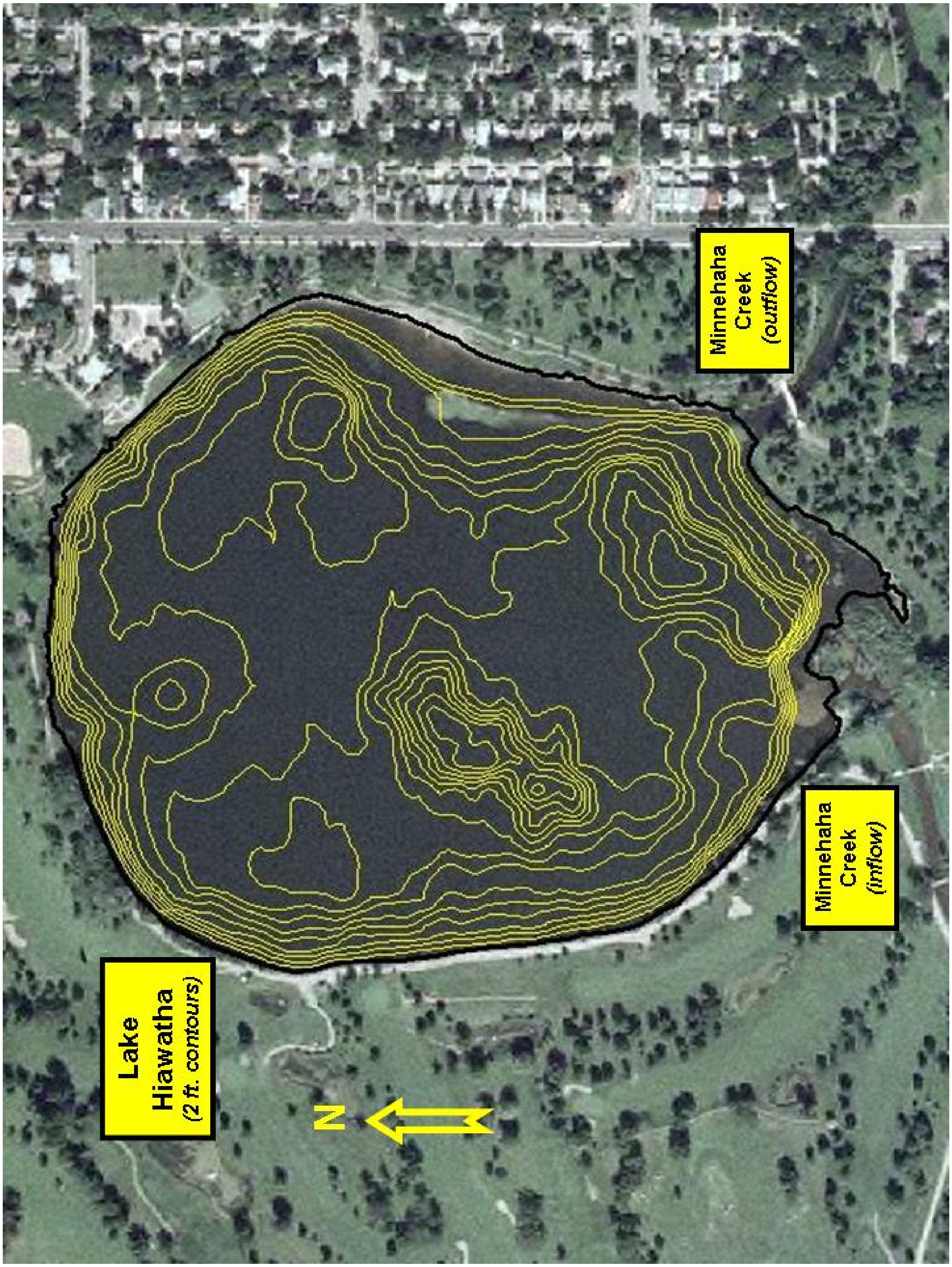


Figure 5-10. Lake Hiawatha.

Trophic Status. Carlson's Trophic State Index (TSI) provides a measure of lake eutrophication based on total phosphorus, chlorophyll-*a*, and Secchi disk depth. Indices can be calculated separately for each parameter for subsequent comparison. Annual averages from the 1992 through 2011 lake monitoring data were used to calculate annual TSI. The TSI scores for Secchi disk depth and chlorophyll-*a* are eutrophic. The scores for total phosphorus are eutrophic tending toward hypereutrophic.

The years 2007 and 2009 yielded the highest TSI scores. As noted earlier, these two years were drought years and Minnehaha Creek ran dry for portions of each summer (MPRB, 2009b). For most of the 20 years, the TSI score for chlorophyll-*a* in Lake Hiawatha was greater than the score for Secchi disk depth. This is indicative of larger particulates dominating water quality in the lake (Carlson, 1981). When the TSI scores for chlorophyll-*a* and Secchi disk depth are similar and less than the score for TP, then "algae dominate light attenuation".

Biological Communities. The distribution of phytoplankton and zooplankton are sampled annually in Lake Hiawatha by MPRB. During normal years, distribution of these communities is expected to change rapidly due to the influence of Minnehaha Creek. The distribution of these organisms reflects trends in lake hydrology and chemistry.

Based on a 2001 fish survey, the fish community in Lake Hiawatha is dominated by black bullhead, followed by black crappie, bluegill, and yellow perch. Compared to lakes with similar physical and chemical characteristics, black bullhead and yellow perch were relatively more abundant than typical populations. Northern pike and pumpkinseed sunfish were also found in the lake during the 2001 survey (Emmons and Olivier Resources, Inc., 2005).

5.2.2 Residence Time Analysis

The effect of flow volumes on residence time plays a major role in determining Lake Hiawatha's response to TP inputs from Minnehaha Creek. Flow monitoring data downstream of the Lake Hiawatha outlet is used to develop an analysis of residence times. Both the USGS and Met Council operate gaging stations that collect this information near Hiawatha Avenue. Recent bathymetry data indicates that the lake volume is 37.9 million cubic feet. This information can be used to summarize average residence times for Lake Hiawatha *(Table 5-3)*. Based on records from 2001 through 2011, the annual average June to September volume that passed through this location was 1,053 million cubic feet (or 100 cfs). At this flow rate, the average residence time for Lake Hiawatha is 4.4 days.

The average proportion of water volume that originates from Lake Minnetonka through Grays Bay Dam releases is also of interest. Hydrograph separation was described as a method to estimate the relative influence of releases from Lake Minnetonka on Minnehaha Creek. The same technique can be used to develop estimates of the relative average volume of Lake Minnetonka water in Lake Hiawatha in any given year (or over a 10-year period). The results of this analysis are also shown in Table 5-3.

Seasonal variation in flow has a strong influence on TP loads to Lake Hiawatha. MCWD monitors water quality at key points in Minnehaha Creek at weekly intervals. The closest site upstream to the inlet of Lake Hiawatha is the Golf Course footbridge (CMH-24), which has been monitored since 2007. Prior to 2007, the closest site above Lake Hiawatha was at Chicago Avenue (CMH-05). Data from these two locations can be used in conjunction with FLUX32 to estimate the total phosphorus load from Minnehaha Creek into Lake Hiawatha. FLUX32 is a computer program designed to estimate loads past a sampling station over a given period of time

(Walker, 1999). MPCA has used this program in formulating nutrient balances for other lake TMDLs in Minnesota. Figure 5-11 shows how seasonal phosphorus loads vary with seasonal flow based on FLUX32 estimates. Each dot represents the seasonal average flow and corresponding TP load for each year between 2001 and 2011.

Table 5-3. Lake Hiawatha inflow volume summary.

Year	Inflow Volume		Residence Time (days)	Approximate Source of Inflow **			
				(million ft^3)		(%)	
	(cfs)	(million ft^3)		Baseflow	Stormflow	Baseflow	Stormflow
2001	118.8	1,252	3.7	1,048	203	*84%*	*16%*
2002	243.5	2,567	1.8	2,001	566	*78%*	*22%*
2003	68.2	719	6.4	570	149	*79%*	*21%*
2004	122.8	1,294	3.6	1,128	166	*87%*	*13%*
2005	98.0	1,033	4.5	855	177	*83%*	*17%*
2006	61.6	649	7.1	493	156	*76%*	*24%*
2007	32.4	341	13.5	225	116	*66%*	*34%*
2008	48.6	512	9.0	408	104	*80%*	*20%*
2009	9.3	98	47.4	47	50	*49%*	*51%*
2010	146.2	1,541	3.0	1,258	282	*82%*	*18%*
2011	149.4	1,575	2.9	1,343	232	*85%*	*15%*
11-yr Avg	99.9	1,053	4.4	853	200	*77%*	*23%*
Note: ** Approximate source of inflow based on hydrograph separation analysis							

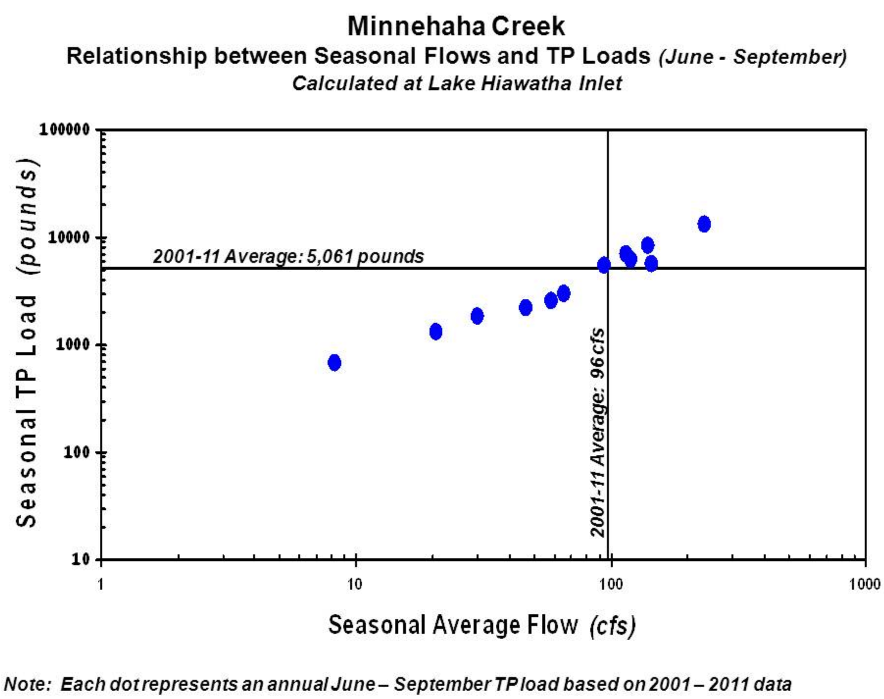


Figure 5-11. Lake Hiawatha seasonal TP loads as a function of seasonal inflow.

5.3 Watershed Loading and Response

An important part of the linkage analysis is to develop estimates of pollutant contributions at key points along Minnehaha Creek. A starting point is a loading assessment based on monitoring data collected by MCWD. The following sections discuss this information for each pollutant.

5.3.1 Bacteria

Flow duration curves (FDC) are an important component of the overall water quality analysis. Duration curves provide a quantitative summary that describes the full range of flow conditions, both magnitude and frequency of occurrence. Figure 5-12 depicts an April through October (i.e., the season of applicability for MPCA's *E. coli* WQS) flow duration curve for Minnehaha Creek using the Metropolitan Council / MPRB and USGS gages. FDC graphs have flow duration interval (percentage of time flow exceeded) on the x-axis and discharge (flow per unit time) on the y-axis. FDC plots are typically subdivided into five flow regimes: high flows (those exceeded 0–10% of the time), moist conditions (flows exceeded 10–40% of the time), mid-range flows (exceeded 40–60% of the time), dry conditions (flows exceeded 60–90% of the time), and low flows (exceeded 90–100% of the time).

The FDC is transformed into a load duration curve (LDC) by multiplying individual flow values by the WQS (126 organisms / 100 mL), and then by a conversion factor. The resulting points create the LDC graph *(Figure 5-13)*. The LDC graph has flow duration intervals (percentage of time flow exceeded) on the x-axis and *E. coli* loads (number of bacteria per unit time) on the y-axis. This LDC expresses *E. coli* loads as billions of bacteria per day. The curved line on the LDC graph represents the loading capacity (or TMDL) for that monitoring site, which reflects the WQS and flow conditions at that location.

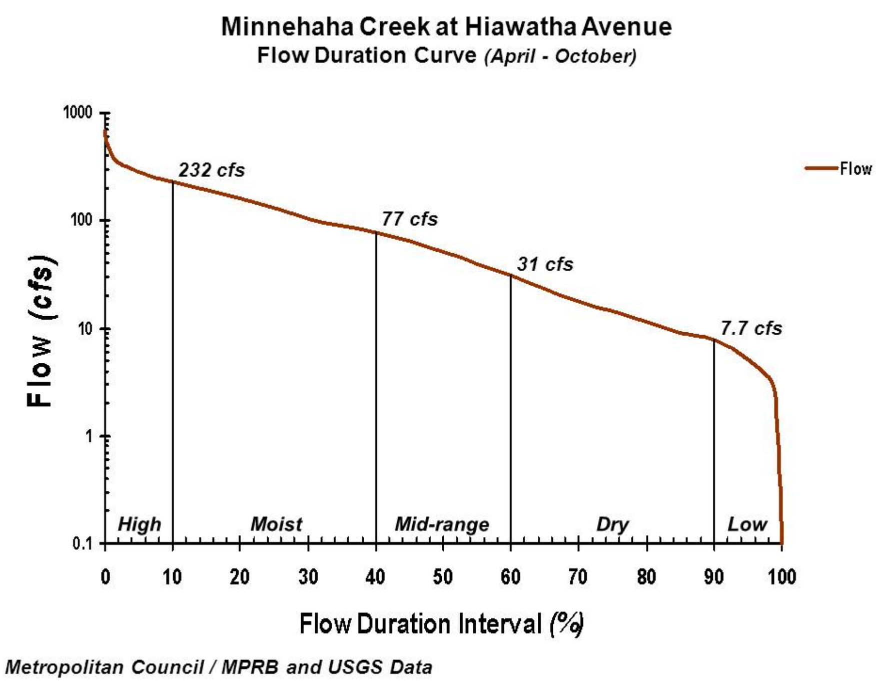


Figure 5-12. Flow duration curve -- Minnehaha Creek *(April – October)*.

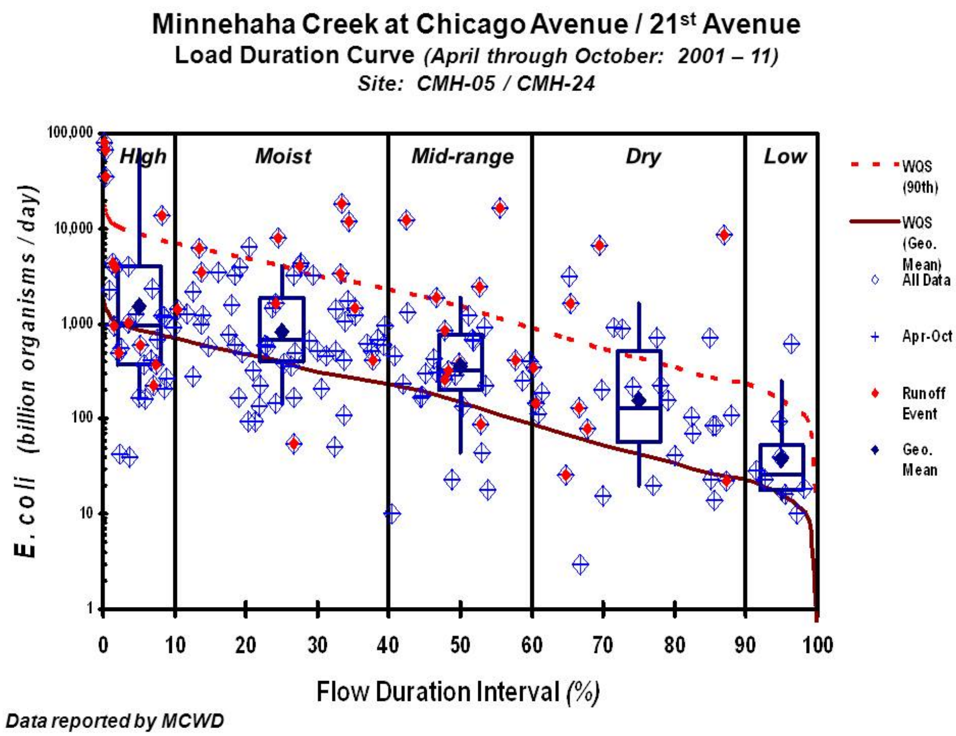


Figure 5-13. Load duration curve for *E. coli* in Minnehaha Creek at Chicago Avenue.

As indicated in Section 3.3, MCWD conducts water quality monitoring in the Minnehaha Creek. Data collection includes measurements of fecal coliform and *E. coli* concentrations at specific sampling points within the watershed. A longitudinal profile of April through October *E. coli* concentrations along Minnehaha Creek was presented in Figure 3-2. The geometric mean water quality standard is exceeded at several points including Excelsior Boulevard, Upton Avenue, Chicago Avenue, and 32nd Avenue. Fecal coliform and *E. coli* values from MCWD's monitoring program are converted to individual sampling loads by multiplying the sample concentration by the estimated flow for the date of sample collection. Individual sampling loads are displayed on Figure 5-13 with the LDC for the Chicago Avenue / 21st Avenue sites, where the greatest reductions are needed and directly above where Minnehaha Creek enters Lake Hiawatha.

LDC graphs similar to Figure 5-13 are organized to display individual sampling loads and the calculated LDC. Watershed managers can use these graphs (individual sampling points plotted with the LDC) to understand the relationship between flow conditions and water quality exceedances within the watershed. Individual sampling loads which plot above the LDC represent violations of the WQS, and the allowable load under those flow conditions at those locations. The difference between individual sampling loads plotting above the LDC and the LDC, measured at the same flow is the amount of reduction necessary to meet WQS.

Duration curves can be used to examine flow conditions associated with *E. coli* WQS exceedances. The primary benefit of duration curves is to provide insight regarding patterns between water quality concerns and hydrology. Bacteria reduction needs at key assessment points along Minnehaha Creek can be determined by examining the geometric mean for *E. coli* in each duration curve zone *(Table 5-4)*. These reductions are summarized in Table 5-5. The use of duration curves in water quality assessment creates a framework that enables data to be characterized by flow conditions, as illustrated in Figure 5-13. Also, critical conditions and seasonal variation are considered in the creation of the FDC by using flows measured during the recreation season.

Table 5-4. Minnehaha Creek April – October *E. coli* geometric mean values by duration curve zone.

Subwatershed Group	Name or Location	Duration Curve Zone (# / 100 mL)				
		High	***Moist***	***Mid***	***Dry***	***Low***
--	Grays Bay Dam	5.3	4.7	7.7	7.8	30.6
A	McGinty	17.3	38.7	45.5	67.7	124.8
B	West 34th	71.3	78.4	106.4	169.1	131.3
C	Excelsior	143.7	194.8	281.6	526.8	230.1
D	Browndale	85.5	104.4	122.0	67.7	56.7
E	Browndale to Chain of Lakes	156.0	185.7	149.7	232.3	237.2
F	Chain of Lakes to Lake Hiawatha	208.8	275.5	302.2	473.7	395.0
H	Lake Hiawatha to Mouth	180.0	143.8	99.9	148.6	133.5

Table 5-5. Minnehaha Creek *E. coli* reduction needs by duration curve zone.

Subwatershed Group	Name or Location	Duration Curve Zone (percent reduction)				
		High	***Moist***	***Mid***	***Dry***	***Low***
--	Grays Bay Dam	---	---	---	---	---
A	McGinty	---	---	---	---	---
B	West 34th	---	---	---	25%	4%
C	Excelsior	12%	35%	55%	76%	45%
D	Browndale	---	---	---	---	---
E	Browndale to Chain of Lakes	19%	32%	16%	46%	47%
F	Chain of Lakes to Lake Hiawatha	40%	54%	58%	73%	68%
H	Lake Hiawatha to Mouth	30%	12%	---	15%	6%

*** Highlighted cells denote critical reaches and flow conditions for Minnehaha Creek bacteria TMDL where reductions are needed.

5.3.2 Total Phosphorus

A longitudinal profile of the average growing season phosphorus cumulative loads along Minnehaha Creek can be derived from water quality monitoring data collected by MCWD. These loads, shown in Figure 5-14, are based on FLUX32 estimates at each key location in Minnehaha Creek using MCWD data. The load at Grays Bay Dam represents contributions from upstream inputs (i.e., drainage from Lake Minnetonka).

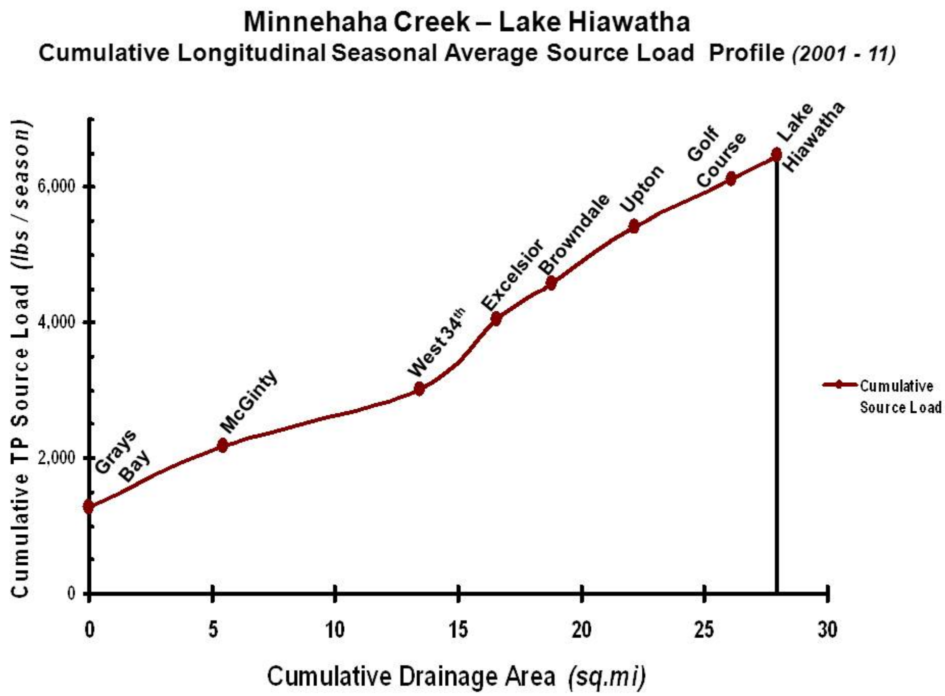


Figure 5-14. Minnehaha Creek total phosphorus cumulative load longitudinal profile.

The total phosphorus load at Browndale Dam is an aggregate value. It consists of both the group D load, as well as the loss of phosphorus as Minnehaha Creek flows through Meadowbrook Lake and the Browndale pool *(shown in Figure 3-5)*. The rationale used to determine this load is discussed in the following section that describes the watershed load determination.

Watershed Load. A close examination of incremental contributions along Minnehaha Creek provides information that can guide implementation planning and help evaluate allocation options. Contributions of particular interest include total phosphorus unit area loads for each subwatershed group. Unit area loads provide a way to compare source contributions from watersheds of different size.

Unit area loads for each subwatershed group are determined by dividing the total phosphorus increase for each group (pounds per growing season) by the group area (acres). The resultant value, expressed as pounds per acre per growing season, reflects the watershed load for each group. It accounts for differences in watershed size, land use, and management practices. Table 5-6 summarizes this information.

Table 5-6. Seasonal total phosphorus loads along Minnehaha Creek.

Group	Name (downstream location of group)	Area (acres)	2001 – 2011 Seasonal Average Total Phosphorus Load (June – September)		
			Subwatershed Group Load		Cumulative Watershed Load (pounds)
			Unit Area (lbs / acre)	Seasonal (pounds)	
--	Grays Bay Dam	---	---	1,279	1,279
A	McGinty	3,494	0.260	908	2,187
B	West 34th	5,103	0.162	827	3,014
C	Excelsior	1,998	0.500	1,033 [1]	4,047
D	Browndale	1,427	0.378 [2]	539	4,586
E	Browndale to Chain of Lakes	2,172	0.378	821	5,407
F	Chain of Lakes to Lake Hiawatha	2,504	0.283	709	6,116
G	Lake Hiawatha	1,195	0.283	347 [3]	6,463
	TOTAL	17,893	0.290 [4]	5,184 [4]	6,463

Notes:
[1] Accounts for point source contributions.
[2] Estimate based on group E unit area load.
[3] Estimate based on group F unit area load; accounts for point source and atmospheric loads.
[4] TMDL study area watershed load only; excludes upstream load from Grays Bay Dam

The unit area load for each group is reflected in Figure 5-14. This graph shows the cumulative total phosphorus load by drainage area. The slope of the line between monitoring points is the change in phosphorus load for each group as a function of area. The steepest slope is between West 34th and Excelsior (group C), corresponding to the highest group unit area load in Table 5-6. In addition to the watershed load, there are three point sources in this stream reach (group C) with a growing season average discharge of 33.8 pounds *(see Table 4-2)*.

In order to determine phosphorus reductions for group D, it is necessary to identify the watershed load to the reach between Excelsior Boulevard and Browndale Dam. An estimate of the watershed load to group D is derived from unit area loads to group E based on comparable land use between these two groups (i.e., single family residential). This results in an estimated watershed growing season total phosphorus load to group D of 539 pounds (using 0.378 pounds per acre). Similarly, it is necessary to identify a watershed load for direct drainage to Lake Hiawatha (group G). This is derived from the unit area load to group F based on comparable land use; both consist exclusively of land within Minneapolis. This results in an estimated watershed growing season total phosphorus load to group G of 347 pounds (using 0.283 pounds per acre, as well as adding in the point source load and atmospheric deposition).

Finally, Table 5-7 provides a summary of the MS4 jurisdiction composition for each subwatershed unit. This information is used to apportion subwatershed group loads to individual LGU loads. Road right-of way widths were provided by Mn/DOT and Hennepin County, which were used to calculate their land areas.

Table 5-7. Local government unit / MS4 area composition of subwatershed units.

Local Government Unit / MS4 Jurisdiction	**Subwatershed Group** *(values represent percent of LGU / MS4 jurisdiction in each subwatershed group)*						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Plymouth	*4.5%*	*0.5%*					
Wayzata	*2.8%*						
Minnetonka	*83.3%*	*71.8%*					
St. Louis Park		*15.4%*	*55.7%*	*24.0%*			
Hopkins		*7.0%*	*33.6%*	*6.6%*			
Edina			*4.8%*	*63.1%*	*61.8%*		
Minneapolis					*36.9%*	*95.7%*	*98.7%*
Hennepin County	*0.8%*	*1.5%*	*0.7%*	*0.9%*	*1.3%*	*1.9%*	*1.3%*
Mn Dept. of Transportation	*8.6%*	*3.8%*	*5.2%*	*5.4%*		*2.4%*	

A part of the linkage analysis is to examine the relationship between water quality data and potential source areas. Land use exerts a major influence on water quality in Minnehaha Creek. Table 5-8 provides a summary of land use information by subwatershed group. Included is the number of storm sewer outfalls in each group. A way to view the relationship between water quality data is through an analysis of unit area loads *(Table 5-6)*. These values reflect the range of land use diversity in the watershed, as well as the complex hydrology of Minnehaha Creek.

The upper portion of Minnehaha Creek (group A), for example, flows through a major wetland complex. Residential and commercial development is present in this portion of the drainage, which likely contributes some phosphorus to the creek. However, the wetlands could also be a source of phosphorus to the upper reaches of Minnehaha Creek. This would be the result of low dissolved oxygen in connected wetland areas releasing phosphorus from bottom sediments. In addition, historic agricultural land use in this same area could be responsible for higher levels of phosphorus in the wetland sediments.

The subwatersheds that drain the area between West 34th Street and Excelsior Boulevard (group C) represent the highest total phosphorus source area to Minnehaha Creek based on MCWD water quality monitoring data. This is evident in terms of the greatest absolute total phosphorus load increase, as well as on a unit area basis (Table 5-6). This subwatershed group is dominated by residential, commercial, industrial, and institutional land. Within group C, the highest level of development is where Minnehaha Creek flows through the general vicinity of Knollwood Mall, as well as the adjacent commercial / industrial areas between Blake Road and Louisiana Avenue.

The water quality data describes the relative magnitude of total phosphorus loads that other subwatersheds contribute to Minnehaha Creek, particularly groups B, E, and F. This information reinforces the need to consider the role of stormwater sources in developing implementation strategies that reduce phosphorus loads.

Table 5-8. Minnehaha Creek land use summary.

Land Use Type	Subwatershed Group Land Use							Watershed Total
	A	B	C	D	E	F	G	
Developed – *Pervious*	*21%*	*30%*	*23%*	*25%*	*30%*	*30%*	*22%*	***27%***
Developed – *Impervious*	*31%*	*32%*	*56%*	*40%*	*53%*	*55%*	*59%*	***42%***
Parks &Recreation, Undeveloped	*5%*	*5%*	*10%*	*20%*	*11%*	*9%*	*14%*	***9%***
Wetlands	*16%*	*12%*	*4%*	*6%*	*3%*	*1%*	*0%*	***8%***
Forest & Woodland	*24%*	*17%*	*5%*	*3%*	*1%*	*2%*	*0%*	***11%***
Other	*3%*	*4%*	*2%*	*6%*	*2%*	*3%*	*5%*	***3%***
Subwatershed Group Area								
(acres)	3,494	5,103	1,998	1,427	2,172	2,504	1,195	**17,893**
Stormwater Outfalls								
(number)	0	21	29	7	32	53	1	**143**

Summary. Table 5-9 summarizes existing seasonal total phosphorus loads by subwatershed group and contributing source within each group. Table 5-10 provides a summary of total phosphorus loads to Lake Hiawatha. This includes the upstream background load from Lake Minnetonka released to Minnehaha Creek at the Grays Bay Dam TMDL boundary point *(Section 4.3)*. It also accounts for loads from individual NPDES facilities *(Section 4.1.2)*, as well as atmospheric deposition loads *(Section 4.2.2)*.

The remaining watershed load is determined by unit area loads for each subwatershed group using MCWD monitoring data and FLUX32 *(Table 5-6)*. The non-MS4 stormwater portion is based on the amount of wetlands, forested, and woodland areas in each subwatershed group. Individual MS4 contributions comprise the remaining watershed load, and are apportioned to each MS4 based on the percentages shown in Table 5-7. Construction and industrial stormwater loads are included in the seasonal average TP MS4 watershed loads for 2001 – 2011, as noted in Table 5-10.

Table 5-9. Summary of existing seasonal total phosphorus loads by group.

	Subwatershed Group Load (pounds per growing season)						
	Upstream Boundary	A / B [1]	C	D	E	F	G [2]
Regulated Stormwater							
Plymouth		24.5					
Wayzata		13.0					
Minnetonka		872.7					
St. Louis Park		104.0	503.7	118.1			
Hopkins		47.3	304.1	32.4			
Edina			43.0	309.7	488.7		
Minneapolis					291.7	660.3	333.1
Hennepin County		13.7	6.6	4.2	10.6	13.3	4.5
Mn Dept. of Trans.		66.0	46.9	26.5	0.0	16.7	
NPDES Wastewater Facilities							
St. Louis Park WTP			1.1				
Reilly Tar Site: #001			6.3				
Reilly Tar Site: #002			26.4				
Kwong Tung Foods							4.6
Non-point Source & Background							
Non-MS4 stormwater		593.8	94.9	48.1	30.0	18.7	0.7
Atmospheric deposition							4.1
Internal TP release							0.0
Upstream Boundary Load							
Upstream of Grays Bay Dam	1,279.0						
TOTAL EXISTING LOAD	1,279	1,735	1,033	539	821	709	347

Notes: [1] Groups A and B combined recognizing that both are predominantly in Minnetonka.
[2] Subwatershed group G is direct drainage to Lake Hiawatha.

Table 5-10. Lake Hiawatha total phosphorus loading summary.

	2001 – 2011 Average Growing Season TP Load *(pounds)*
Regulated Stormwater	
Plymouth *(MS4)*	24.5
Wayzata *(MS4)*	13.0
Minnetonka *(MS4)*	872.7
St. Louis Park *(MS4)*	725.8
Hopkins *(MS4)*	383.8
Edina *(MS4)*	841.4
Minneapolis *(MS4)*	1,285.1
Hennepin County *(MS4)*	52.9
Mn Dept. of Transportation *(MS4)*	156.1
Industrial stormwater	*included in MS4 load estimates*
Construction stormwater	*included in MS4 load estimates*
NPDES Wastewater Facilities *(see Section 4.1.2)*	
St. Louis Park WTP	1.1
Reilly Tar Site: #001	6.3
Reilly Tar Site: #002	26.4
Kwong Tung Foods	4.6
Non-point Source & Background	
Non-MS4 stormwater	786.2
Atmospheric deposition *(see Section 4.2.2)*	4.1
Internal phosphorus release *(see Section 4.2.2)*	0.0
Upstream Boundary Load	
Upstream of Grays Bay Dam *(see Section 4.3)*	1,279.0
TOTAL	6,463.0

6. TMDL Development

Under the current regulatory framework for development of TMDLs, calculation of the loading capacity for impaired segments identified on the §303(d) list is an important first step. EPA's current regulation defines loading capacity as *"the greatest amount of loading that a water can receive without violating water quality standards"*. The loading capacity provides a reference, which helps guide pollutant reduction efforts needed to bring a water into compliance with standards.

The loading capacity for these TMDLs must consider Minnesota's water quality standards. In the case of bacteria, this is the monthly geometric mean of 126 organisms per 100 mL for *E. coli*. These criteria apply between April 1 and October 31.

As stated in Section 3.2.2, the total phosphorus TMDL target for Lake Hiawatha is a concentration of 50 µg/L average for June through September, which is the site-specific water quality standard.

The following sections describe the process used to determine TMDLs for each pollutant including loading capacity, allocations, and margin of safety.

6.1 Bacteria (Minnehaha Creek)

6.1.1 Loading Capacity

Typically loading capacities are expressed as a mass per time (e.g. pounds per day). However, for bacteria loading capacity calculations, mass is not always an appropriate measure because indicators such as *E. coli* are expressed in terms of organism counts. This approach is consistent with the EPA's regulations which define *"load"* as *"an amount of matter that is introduced into a receiving water"* (40 CFR §130.2). To establish the loading capacities for the Minnehaha Creek TMDL, MPCA uses the water quality standard for *E. coli*, specifically the monthly geometric mean between April 1 and October 31 (126 organisms / 100 mL).

The duration curve framework is used as the basis to identify the appropriate flow for the bacteria TMDL. Daily average flow estimates from April through October are used to derive the duration curves. A loading capacity is *"the greatest amount of loading that a water can receive without violating water quality standards"* (40 CFR §130.2). Therefore, a loading capacity set at the WQS will assure that the water does not violate WQS. If all sources meet the WQS at discharge, then the waterbody should meet the WQS and the designated use.

The *E. coli* TMDL for Minnehaha Creek is calculated at its outlet to the Mississippi River. The loading capacities are calculated by multiplying the duration curve flows based on the Met Council / MPRB gage upstream of the mouth of Minnehaha Creek times the monthly geometric mean *E. coli* criteria times the appropriate conversion factor (0.024463). The loading capacities for the midpoints of the duration curve flow zones are shown in Table 6-1.

Table 6-1. *E. coli* -- Minnehaha Creek loading capacity.

Duration Curve Zone *(billion - organisms per day)*				
High	***Moist***	***Mid***	***Dry***	***Low***
857	412	153	41.0	13.7

6.1.2 Allocations

The allocations for the Minnehaha Creek bacteria TMDL are developed for the full range of flows using the duration curve approach. Allocations fall into two major classes: WLAs for regulated point sources and LAs to address nonpoint source and background. As discussed in Section 4.1.1, the only regulated point sources of bacteria in the Minnehaha Creek watershed are loads delivered through MS4 systems (there are no wastewater treatment facilities, CSOs, SSOs, or CAFOs).

Because of the complexity associated with quantifying regulated bacteria stormwater loads in Minnehaha Creek, the MS4 WLA for this *E. coli* TMDL is categorical (with the exception of Mn/DOT, as it specifically requested a separate WLA). Challenges associated with quantifying MS4 stormwater *E. coli* loads include the dynamics and complexity of bacteria in urban streams. Factors such as die-off and re-growth contribute to general uncertainty that makes quantifying stormwater bacteria loads particularly difficult.

A categorical wasteload allocation means that the WLA is assigned to all MS4 jurisdictions in the watershed (Table 4-1). This approach is consistent with USEPA policy, which states: *"It may be reasonable to express allocations for NPDES-regulated stormwater discharges from multiple point sources as a single categorical WLA when data and information are insufficient to assign each source"* (USEPA, 2002).

The use of a categorical *E. coli* WLA for Minnehaha Creek is also consistent with two aspects of MPCA guidance and policy for incorporating MS4 stormwater programs into TMDLs. First, a categorical WLA is appropriate when each permittee can perform the same stormwater management activities to accomplish the requirements of the TMDL. This situation also occurs when the TMDL prescribes a set of Best Management Practices (BMPs) for more than one stormwater entity and those BMPs alone will achieve the WLA (MPCA, 2011).

Second, categorical WLAs may be appropriate when a single MS4 or other entity will track BMP implementation and associated load reductions. An example would be a watershed district (e.g., MCWD). MCWD has a long established monitoring program that documents conditions in Minnehaha Creek. MCWD also works with LGUs in the watershed to track progress towards achieving WQS.

The MS4 WLA for Mn/DOT is based on the *"Combination"* approach used to determine TP allocations *(see Section 6.2.2)*. This method combines the jurisdictional area data for each LGU *(Table 5-7)* with impervious cover information (which recognizes the challenges associated with implementing retro-fit controls on developed land).

The entire Lake Minnetonka watershed above Grays Bay Dam is considered a boundary condition in this TMDL study. This report does not calculate or assign allocations to point and non-point sources in the Lake Minnetonka watershed. As noted in Table 5-4, Minnehaha Creek immediately downstream of Grays Bay Dam currently meets MPCA's *E. coli* water quality criteria. The load allocation for the Lake Minnetonka / Grays Bay Dam boundary condition is based on continuing to meet existing loads determined from MCWD monitoring data.

The amount of the loading capacity apportioned to non-MS4 stormwater is based on the amount of wetlands, forested, and woodland areas in the Minnehaha Creek watershed (consistent with the approach for total phosphorus discussed in Section 5.3.2). Table 6-2 provides a complete summary of the Minnehaha Creek bacteria TMDL.

Table 6-2. Minnehaha Creek bacteria TMDL summary.

	Duration Curve Zone Allowable Load *(billion - organisms per day)*				
	High	***Moist***	***Mid***	***Dry***	***Low***
TOTAL LOADING CAPACITY	857	412	153	41.0	13.7
WLA -- TOTAL	610.0	295.7	107.8	28.77	8.23
Stormwater WLAs Categorical *(MS4)*	588.2	285.1	103.9	27.74	7.94
Mn/DOT *(MS4)*	21.8	10.6	3.9	1.03	0.29
LA -- TOTAL	161.3	75.1	29.9	8.13	4.10
Non-MS4 stormwater	129.3	62.7	22.9	6.10	1.74
Upstream Boundary Load *(above Grays Bay Dam)*	32.0	12.4	7.0	2.03	2.36
MOS *(explicit 10%)*	85.7	41.2	15.3	4.10	1.37

6.1.3 Margin of Safety

The margin of safety (MOS) accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload, monitored flows and in-stream water quality. The purpose of the MOS is to account for uncertainty so the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 10% of the total load was applied where 10% of the loading capacity for each flow regime was subtracted before allocations were made among wasteload and non-point sources. This explicit approach for determining the MOS is consistent with methods used in other Minnesota bacteria TMDLs.

6.2 Phosphorus (Lake Hiawatha)

6.2.1 Loading Capacity

Development of a loading capacity for Lake Hiawatha poses several challenges. The loading capacity for Lake Hiawatha is dependent on the flow conditions during the growing season of any particular year. As noted earlier, Lake Hiawatha is in-line to Minnehaha Creek. Flow and pollutant loads from the creek strongly influence water quality conditions in the lake. The water level in Lake Hiawatha fluctuates widely because of its direct connection to Minnehaha Creek. In addition to these day-to-day fluctuations, there is a high level of variability in year-to-year seasonal inflow volumes to Lake Hiawatha, as described in Table 5-3. This makes the task of developing specific load reductions very difficult.

From a technical perspective, the loading capacity is a function of the seasonal (June to September) inflow. The 11-year seasonal average residence time of flow through Lake Hiawatha is relatively short; 4.4 days *(Table 5-3)*. As a result, it is reasonable to assume that the general phosphorus reduction needs identified for Lake Hiawatha *(Table 3-3)* can be applied to the cumulative watershed load for Minnehaha Creek *(Table 5-6 and Table 5-10)*. This reduction is 29% based on the 50 µg/L target total phosphorus TMDL target.

As noted earlier, MCWD monitors water quality at key points in Minnehaha Creek at weekly intervals. Using FLUX32, the average growing season total phosphorus cumulative watershed load from Minnehaha Creek to Lake Hiawatha was 6,463 pounds based on 2001 to 2011 data. The loading capacity for Lake Hiawatha was determined by a comparison of the in-lake site-specific target to actual monitoring data collected over the past 11 years. This analysis identified the percent reduction from current levels needed to achieve the target. This percent reduction is then applied to Minnehaha Creek cumulative watershed total phosphorus loads based on MCWD water quality monitoring data collected over the same period of time. The total phosphorus loading capacity is summarized in Table 6-3.

Table 6-3. Total phosphorus -- Minnehaha Creek loading capacity development.

TP	Site Specific Criteria	2001-2011 Average	Reduction Needs		Loading Capacity
			Percent	TP	
Concentration *(µg/L)*	50	70.9	*29.5% =*	(70.9-50) / 70.9	
Load *(lbs/season)*		6,463		1,907	4,556

6.2.2 Allocations

The majority of the watershed is covered under MS4 National Pollutant Discharge Elimination System (NPDES) permits. Figure 5-14 presented a longitudinal profile of total phosphorus load along Minnehaha Creek, shown by cumulative drainage area. Unit area loads, expressed as pounds per acre per growing season, provide a way to compare source contributions at points along Minnehaha Creek. The resultant values *(Table 5-6)* reflect the load for each subwatershed group, which accounts for differences in watershed size, land use, and management practices.

The load at Grays Bay Dam represents contributions from upstream inputs (i.e., drainage from Lake Minnetonka). The current load at Grays Bay Dam (or the head of Minnehaha Creek) is estimated to be 1,279 pounds per growing season and is not subject to reduction since Gray's Bay is meeting its water quality standard. In developing the TMDL, the difference between the existing load at Grays Bay Dam and the loading capacity for Lake Hiawatha is the amount available for allocation to downstream sources.

The basic framework to develop WLAs in the Minnehaha Creek / Lake Hiawatha TMDL study area centers on achieving needed source load reductions to Lake Hiawatha. Ambient water quality monitoring data collected by MCWD provided information used to estimate unit area loads *(Table 5-6)*. This table includes cumulative source load contributions along Minnehaha Creek at the downstream point of each subwatershed group, also shown in Figure 6-1. This graph reflects all cumulative loads to Lake Hiawatha including the upstream background load, atmospheric deposition, loads from individual NPDES facilities, and individual subwatershed group loads.

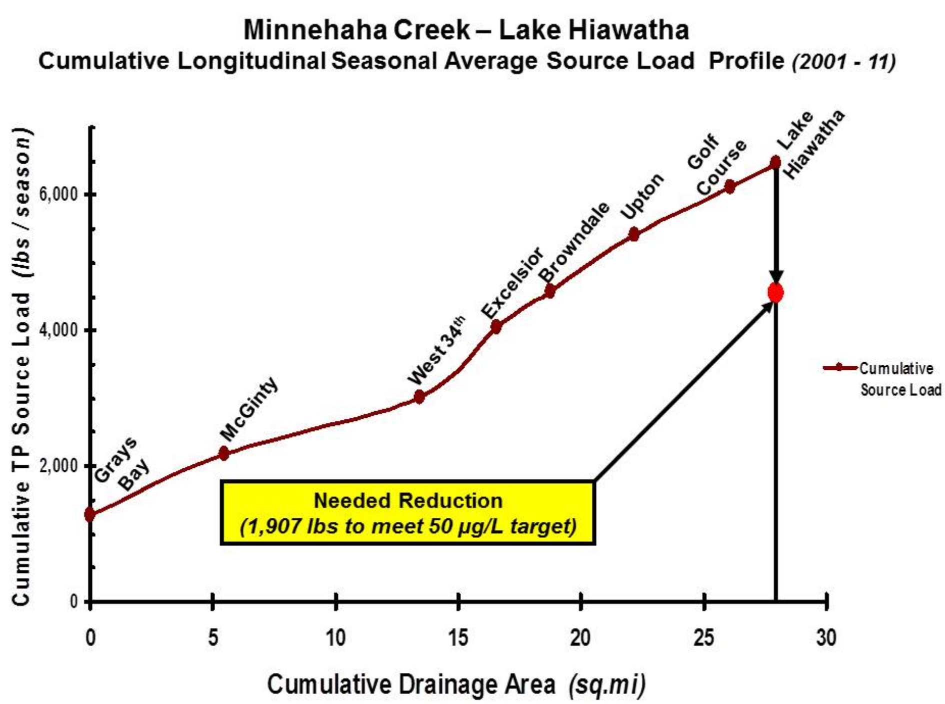


Figure 6-1. Minnehaha Creek cumulative total phosphorus source load.

The main focus of the allocation process is to ensure that source load reductions meet the loading capacity target for Lake Hiawatha. For MS4 and non-MS4 stormwater, four allocation methods were considered, which include:

- Equal percent reduction
- Area export coefficient
- Percent impervious cover
- Combination approach *(area export & impervious cover)*

Each allocation method was evaluated in the context of achieving needed source load reductions (1,907 pounds to meet the 50 µg/L growing season average total phosphorus TMDL target). Reductions will be measured from a baseline year of 2006 (the mid-point of the loading assessment period). Reductions due to activities implemented after 2006 will be credited towards achieving allocation targets.

Reduction needs are summarized for each allocation option by subwatershed group based on the 50 µg/L total phosphorus Lake Hiawatha target *(Table 6-4)*. Groups A and B are both located predominantly in the City of Minnetonka. For this reason, allocations are combined under each option and reductions calculated accordingly. Table 6-4 also includes reductions for group G (direct drainage to Lake Hiawatha). Load estimates for these subwatersheds are based on unit area load values calculated for group F. Similar to subwatershed group F, group G consists exclusively of land within Minneapolis.

Following feedback on the four allocation options, the *"Combination"* approach was selected as the preferred alternative. The *"Combination"* option averages the allocations determined through the *"Area Export Coefficient"* and the *"Impervious Cover"* methods. This method recognizes the importance of both subwatershed group size (represented by the *"Area Export Coefficient"* allocations) and the challenges associated with implementing retro-fit controls on developed land (as accounted for in the *"Impervious Cover"* allocations).

Table 6-4. Summary of subwatershed group reductions by allocation method.

Allocation Method	Subwatershed Group					
	A / B [1]	C	D	E	F	G [2]
Equal Percent Reduction	*36.8%*	*36.8%*	*36.8%*	*36.8%*	*36.8%*	*36.8%*
Area Export Coefficient	*9.3%*	*64.6%*	*51.6%*	*51.5%*	*35.3%*	*36.9%*
Impervious Cover	*31.1%*	*53.7%*	*55.3%*	*40.6%*	*17.3%*	*16.9%*
Combination Method	*20.2%*	*59.1%*	*53.4%*	*46.1%*	*26.3%*	*26.9%*

Notes: [1] Groups A and B combined recognizing that both are predominantly in Minnetonka.
[2] Subwatershed group G is direct drainage to Lake Hiawatha.

The summary information presented for each allocation option focused on total seasonal phosphorus loading by individual subwatershed group. However, information is also needed for each jurisdiction to identify individual MS4 wasteload allocations and to estimate reductions that guide implementation efforts. This provides a logical perspective in terms of overall watershed management to meet water quality objectives for Lake Hiawatha. Table 5-7 provided a summary of the local government unit (LGU) / MS4 jurisdiction composition for each subwatershed unit. This information is used to connect subwatershed group loads and allocations to individual MS4 loads and WLAs.

The four individual NPDES wastewater facilities are included in existing load estimates and also need WLAs. Table 4-2 summarized the subwatershed group in which the facility is located; the NPDES permit number, facility name, effluent limit or target concentration, WLA flow, and growing season average TP load. Their WLAs are set at the growing season average total phosphorus loads provided in Table 4-2. This is reasonable given that these loads represent a very small fraction of the overall allowable load.

Allocations developed using the *"Combination"* approach are summarized in Table 6-5. Similar to calculation of existing load estimates, individual jurisdiction allocations are included in Table 6-5 along with WLAs for other NPDES permittees. The allocation for non-MS4 stormwater is approximated based on the land areas under the land uses classified as wetlands, forested, and woodland areas. For this TMDL this load allocation category also includes in-channel / streambank erosion. As indicated previously the amount of loading from this source is very difficult to quantify and no load estimate has been made for this study. Also, no effort has been made in this TMDL to associate existing streambank contributions with subwatershed groups. However, loading reductions have occurred from stream restoration projects led by the MCWD, which will likely continue to occur with future projects.

The WLA for stormwater discharges from sites where there is construction activities reflects the number of construction sites $\geq$ 1 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 be met.

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 coverage under the appropriate NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local stormwater management requirements must also be met.

WLAs for construction and industrial stormwater are derived from area estimates, per MPCA policy and guidance (MPCA, 2011). Based on MPCA 2008-12 data for Hennepin County, an average of 1,374 acres were under permit annually (or 0.374 percent of the area). Applying this percentage to the loading capacity translates to a growing season average of 17.5 pounds TP. This same percentage is applied to determine the industrial stormwater WLA. Because the entire watershed is covered by MS4 permits, construction and industrial stormwater WLAs are included in the MS4 WLA. The fraction of each MS4 WLA allocated to construction and industrial stormwater is 1.3 percent (17.5 pounds for construction stormwater plus 17.5 pounds for industrial stormwater divided by 2,668.8 pounds for the total MS4 stormwater allocation).

Table 6-5. Summary of seasonal total phosphorus allocations by group.

	Subwatershed Group Load *(pounds per growing season)*						
	Upstream Boundary	**A / B [1]**	**C**	**D**	**E**	**F**	**G [2]**
Regulated Stormwater							
Plymouth		19.6					
Wayzata		10.4					
Minnetonka		696.7					
St. Louis Park		82.9	194.9	55.0			
Hopkins		37.8	117.6	15.1			
Edina			16.6	144.4	263.4		
Minneapolis					157.3	486.5	241.0
Hennepin County		10.9	2.6	2.0	5.7	9.7	3.3
Mn Dept. of Trans.		52.7	18.0	12.4		12.3	
NPDES Wastewater Facilities							
St. Louis Park WTP			1.1				
Reilly Tar Site: #001			6.3				
Reilly Tar Site: #002			26.4				
Kwong Tung Foods							4.6
Non-point Source & Background							
Non-MS4 stormwater		474.0	38.8	22.4	16.2	13.8	0.5
Atmospheric deposition							4.1
Internal TP release							0.0
Upstream Boundary Load							
Upstream of Grays Bay Dam	1,279.0						
TOTAL ALLOCATION	1,279	1,385.0	422.2	251.3	442.6	522.3	253.5

Notes: [1] Groups A and B combined recognizing that both are predominantly in Minnetonka.
[2] Subwatershed group G is direct drainage to Lake Hiawatha.

A summary of seasonal total phosphorus reductions by subwatershed groups is provided in Table 6-6. Table 6-7 summarizes the existing load and allocation information by individual MS4 jurisdiction including an estimate of needed reductions. Table 6-8 provides a complete summary of the Lake Hiawatha total phosphorus TMDL that includes both seasonal average and daily allocations.

Table 6-6. Summary of seasonal total phosphorus TMDL reductions by group.

	Subwatershed Group Load *(pounds per growing season)*					
	A / B [1]	**C**	**D**	**E**	**F**	**G [2]**
Regulated MS4 Stormwater						
Existing Load	1,141.2	904.3	490.9	791.0	690.3	337.6
Allocation	911.0	349.6	228.9	426.4	508.5	244.3
Needed Reduction	***20%***	***60%***	***53%***	***46%***	***26%***	***28%***
Non-MS4 Stormwater						
Existing Load	593.8	94.9	48.1	30.0	18.7	0.7
Allocation	474.0	38.8	22.4	16.2	13.8	0.5
Needed Reduction	***20%***	***60%***	***53%***	***46%***	***26%***	***28%***

Notes: [1] Groups A and B combined recognizing that both are predominantly in Minnetonka.
[2] Subwatershed group G is direct drainage to Lake Hiawatha.

Table 6-7. Individual MS4 wasteload allocation summary.

	Total Phosphorus Load *(pounds per growing season)*			**Reduction** *(percent)*
	Existing Load	**Allocation**	**Needed Reduction**	
Plymouth	24.5	19.6	4.9	20%
Wayzata	13.0	10.4	2.6	20%
Minnetonka	872.7	696.7	176.0	20%
St. Louis Park	725.8	332.8	393.0	54%
Hopkins	383.8	170.5	213.3	56%
Edina	841.4	424.4	416.9	50%
Minneapolis	1,285.1	884.8	400.4	31%
Hennepin County	52.9	34.2	18.7	35%
Mn Dept. of Transportation	156.1	95.4	60.6	39%

Table 6-8. Lake Hiawatha total phosphorus TMDL summary.

	Allowable Load (pounds)	
	Seasonal	**Daily**
TOTAL LOADING CAPACITY	4,556.0	37.344
WLA -- TOTAL	2,707.2	22.190
Stormwater WLAs		
Plymouth *(MS4)*	19.6	0.161
Wayzata *(MS4)*	10.4	0.085
Minnetonka *(MS4)*	696.7	5.710
St. Louis Park *(MS4)*	332.8	2.728
Hopkins *(MS4)*	170.5	1.398
Edina *(MS4)*	424.4	3.479
Minneapolis *(MS4)*	884.8	7.252
Hennepin County *(MS4)*	34.2	0.280
Mn Dept. of Transportation	95.4	0.782
Industrial stormwater	*Included in MS4 WLA*	*Included in MS4 WLA*
Construction stormwater	*Included in MS4 WLA*	*Included in MS4 WLA*
NPDES Facility WLAs		
St. Louis Park WTP	1.1	0.009
Reilly Tar Site: #001	6.3	0.052
Reilly Tar Site: #002	26.4	0.216
Kwong Tung Foods	4.6	0.038
LA -- TOTAL	1,848.8	15.154
Non-MS4 stormwater	565.7	4.636
Atmospheric deposition	4.1	0.034
Internal phosphorus release	0.0	0.000
Upstream Boundary Load *(above Grays Bay Dam)*	1,279.0	10.484
MOS	Implicit	Implicit

6.2.3 Margin of Safety

A margin of safety has been incorporated into this TMDL by using conservative assumptions. These were utilized to account for an inherently imperfect understanding of the watershed and lake system. One conservative assumption regards total phosphorus losses that occur in Meadowbrook Lake / Browndale pool reach of Minnehaha Creek. Another pertains to the site-specific standard for this lake. In the justification for this site-specific standard (MPCA, 2013) it was shown that based on the period of water quality data (2000 to 2011) that 50 µg/L total phosphorus is a conservative in-lake water quality endpoint.

7. Reasonable Assurance and Implementation Strategies

Reasonable assurance (RA) activities are programs that are in place to assist in attaining the Minnehaha Creek and Lake Hiawatha TMDL allocations and applicable water quality standards. The RA evaluation provides documentation that the TMDL's WLA and LA are properly calibrated and the TMDL loads will ultimately meet the applicable water quality targets. Without such calibration, a TMDL's ability to serve as an effective guidepost of water quality improvement is significantly diminished. The development of a rigorous RA demonstration should include:

- Reduction strategies and a monitoring program to measure the progress of pollutant reduction activities within the TMDL study area;
- Explanation of the implementation schedule, milestones, and tracking systems; and
- A list of potential follow-up actions.

There are two separate but complimentary frameworks in place to ensure progress toward achieving the water quality targets identified in this TMDL. The first is between the MPCA and regulated MS4s through the MPCA's Stormwater Program. The second is between the Minnehaha Creek Watershed District (MCWD) and local government units (LGUs) in the TMDL study area through the MCWD's Water Resources Management Plan and the LGUs' local water management plans. Both of these frameworks are described in detail below.

7.1 MPCA Stormwater Program

The MPCA is responsible for applying federal and state regulations to protect and enhance water quality within the Minnehaha Creek / Lake Hiawatha TMDL study area. The MPCA oversees all regulated MS4 entities (ex. cities of Plymouth, Wayzata etc., Mn/DOT, Hennepin County, and the MCWD) in stormwater management accounting activities. Within the Minnehaha Creek / Lake Hiawatha TMDL study area there are Phase I and Phase II MS4 permittees. The City of Minneapolis is a regulated Phase I MS4 community. All other regulated MS4s in the Minnehaha Creek / Lake Hiawatha TMDL study area fall under the category of Phase II. MS4 NPDES/SDS permits require regulated municipalities to implement BMPs to reduce pollutants in stormwater runoff to the Maximum Extent Practicable (MEP).

All owners or operators of regulated MS4s (also referred to as "permittees") are required to satisfy the requirements of the MS4 general permit; Minneapolis is issued an individual permit, which is similar but contains additional requirements. The MS4 general permit requires the permittee to develop a Stormwater Pollution Prevention Program (SWPPP) that addresses all permit requirements, including the following six minimum control measures:

- Public education and outreach
- Public participation
- Illicit Discharge Detection and Elimination (IDDE) 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 U.S. EPA prior to the effective date of the general permit, and assigns a wasteload allocation to an MS4 permittee, that permittee must document the WLA in their application and provide an outline of the best management practices to be implemented in the current permit term to address any needed reduction in loading from the MS4.

MPCA requires applicants submit their application materials and SWPPP document to 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 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.

The TMDL assigns bacteria and nutrient loads for the Minnehaha Creek and Lake Hiawatha TMDLs to the regulated MS4s. The pollutant load allocations for each MS4 entity are outlined in the TMDL *(Table 6-2 and Table 6-7)*. The MS4 Phase II General permit requires permittees to develop compliance schedules for any U.S. EPA-approved TMDL wasteload allocations not being achieved at the time of permit application. This includes BMPs that will be implemented over five-year permit term, timelines for their implementation, and a long term strategy for continued progress toward ultimately achieving those WLAs. For any WLA that is being met at the time of application, at least the same level of treatment must be maintained into the future. Per federal rule, all MS4 permittees, regardless of TMDL status, are required to reduce loading from their storm sewer system to MEP.

Reasonable assurance that the WLAs calculated for the Minnehaha Creek and Lake Hiawatha TMDLs will be implemented is provided by regulatory actions. According to 40 CFR 122.44(d)(1)(vii)(B), NPDES permits must be consistent with assumptions and requirements of all WLAs in an approved TMDL. MPCA's stormwater program and its NPDES permit program are the state programs responsible for ensuring that implementation activities are initiated and maintained and are consistent with the WLAs calculated from the TMDLs. The NPDES program requires construction and industrial sites to create SWPPPs which summarize how stormwater will be minimized from construction and industrial sites.

7.2 MCWD Water Resources Management Plan

The Minnehaha Creek Watershed District (MCWD) was created under the Minnesota Watershed District Act of 1955, which charged watershed districts with integrating water management efforts among city, county and state agencies. The MCWD is the local unit of government responsible for managing and protecting the water resources of the Minnehaha Creek / Lake Hiawatha watershed. The overall goals of restoring impaired water resources and protecting water resources from further degradation require an active partnership between the MCWD and local government units (LGUs) which include all the cities and townships with the MCWD. MCWD has actively engaged in partnering efforts with LGUs whose jurisdiction areas are within the boundaries of the Minnehaha Creek / Lake Hiawatha TMDL study area. The MCWD's main effort at partnering with LGUs has been via implementation efforts devised from MCWD's *Comprehensive Water Resources Management Plan of 2007* (referred to as the '*2007 MCWD Plan*').

Prior to the development of the Minnehaha Creek and Lake Hiawatha TMDLs, the MCWD sought to improve water quality within the TMDL study area boundaries. These efforts included various watershed studies and the crafting of nutrient loading reduction strategies. The MCWD completed a *Hydrologic, Hydraulic and Pollutant Loading Study (HHPLS)* in 2003 to investigate water quantity and quality within the watershed. The HHPLS was intentionally designed to parallel the MPCA's TMDL program and incorporated an extensive public process to help identify water quality goals for all the major lakes and streams within the Minnehaha Creek watershed. Information from this effort was utilized as the foundation for MCWD developing initial nutrient load reduction targets.

The *2007 MCWD Plan* includes phosphorus load reduction plans that were developed for each lake that did not meet the water quality goals identified through the *HHPLS*. These phosphorus load reduction plans consist of three main components: the MCWD regulatory program, MCWD capital projects, and LGU requirements. The load reductions assigned to the LGUs were calculated based on existing land uses where a 15 percent reduction in loading was required from residential land use; 25 percent from agricultural land use; and 10 percent from other developed land use.

Under MN Statutes 103B.231, each LGU is required to prepare its own local water management plan, capital improvement program, and official controls as necessary to bring local water management into conformance with the watershed plan. These local water management plans are then reviewed and approved by the watershed district. Therefore, within the MCWD, the LGUs must identify in their local water management plans specific steps they will take to accomplish the phosphorus reductions that are assigned to them in the *2007 MCWD Plan*. The MCWD provides the LGUs with the flexibility to determine the most efficient and cost-effective means of achieving the reductions. The LGUs must annually report to the MCWD their progress toward accomplishing their load reductions.

This existing framework for identifying reduction strategies and tracking progress toward achieving water quality goals closely parallels the framework for tracking progress toward TMDL goals through the MPCA's Stormwater Program. With the completion of the Minnehaha Creek and Lake Hiawatha TMDLs, the MCWD will serve to coordinate implementation efforts among LGUs and help ensure progress toward the TMDL targets.

In addition to the reductions that were assigned to the LGUs and reductions that were anticipated through implementation of the MCWD's regulatory program, the *2007 MCWD Plan* identified capital improvement projects that the MCWD would undertake in order to achieve the remaining reductions that were needed to meet the water quality targets. Although the MCWD is a regulated MS4, its jurisdiction as a regulated MS4 entity is limited to the conveyances owned or operated by the District within the U.S. Census Bureau-defined urban area which is a fairly small area. Since the MCWD generally does not need the credit for the reductions it will achieve through its capital improvement program for the purposes of MS4 permit compliance, MCWD has adopted a policy that allows for the distribution of this credit among its member communities.

This policy ensures that credit for pollutant reductions achieved through MCWD projects is accounted for and is distributed in a fair and equitable way among its member communities in recognition that the funding for those projects comes from a watershed-wide *ad valorem* tax levy. The MCWD will track and report annually, by May 30th, to the MS4s and MPCA a summary of the reductions achieved through its projects in the previous calendar year and the breakdown of credit by MS4.

7.3 Funding

The MCWD is funded through local property taxes. This annual tax base comprises one of the main funding mechanisms for MCWD sponsored implementation activities within the watershed. The MCWD 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 which the MCWD and LGUs may apply for in the State of Minnesota such as; grants under the Clean Water Legacy Act and funding through the Clean Water Partnership program. MCWD may also explore the funding mechanisms provided through the federal Section 319 grant program which provides cost share dollars to implement voluntary activities in the watershed.

Clean Water Legacy Act

The CWLA is a statute passed in Minnesota in 2006 for the purposes of protecting, restoring, and preserving Minnesota water and providing significant funding to do so. The Act discusses how MPCA and the involved public agencies and private entities will coordinate 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 the Clean Water Fund for restoration and protection grants, and has developed a detailed grants policy explaining what is required to be eligible to receive Clean Water Fund money (FY '11 Clean Water Fund Competitive Grants Policy; Minnesota Board of Soil and Water Resources, 2011).

7.4 Implementation Activities

A review of planned implementation activities was conducted as part of the RA review for both of these TMDLs. The goal was to examine efforts already underway within the Minnehaha Creek / Lake Hiawatha TMDL study area and factor these activities into the analysis of needed reductions. Table 7-1 provides a summary of this information organized by subwatershed group. Implementation activities recommendations primarily address stormwater sources and streambank stabilization. The categories to address stormwater sources include:

- Prevention
- Maintenance
- Retrofitting urban areas with stormwater BMPs
- New BMP installation at the time of new or re-development.

Total phosphorus reductions achieved through streambank stabilization and riparian corridor restoration can work to address loads contributed from non-MS4 stormwater sources. MCWD has initiated projects in several areas along Minnehaha Creek, most notably the Reach 20 project *(Figure 7-1)*. The *2007 MCWD Plan* identifies additional future stream restoration projects for several other reaches *(noted in Table 7-1)*.

Retrofitting urban areas with stormwater BMPs, especially those practices that reduce the volume of runoff, can reduce TP loads from existing developed areas. Controlling runoff associated with development typically consists of end-of-pipe measures such as stormwater detention and retention, or on-site (decentralized) stormwater management, which increases infiltration and reduces runoff generation by decreasing imperviousness. Decentralized BMPs that promote infiltration and filtration, also referred to as green infrastructure (GI), include:

- Bioretention
- Bioswales
- Rain gardens
- Green roofs
- Infiltration basins and trenches, and
- Permeable pavement.

TMDL implementation planning will incorporate load reduction activities identified by the MCWD in their Capital Improvement Program (CIP) and by LGUs in their local water management plans and SWPPPs. When these activities are not enough to meet the loading reductions calculated by the Minnehaha Creek and Lake Hiawatha TMDLs, additional implementation activities will be identified and adaptive management strategies will be initiated.

Table 7-1. Summary of planned capital improvement projects by subwatershed group.

Group	Estimated TP Removal *(lbs/year)*	Proposed Year	MS4 *(Project Name)* Location / Description
A	Unknown	2012	**Wayzata** *(Holdridge Neighborhood)* SE of Hwy 12 and 101 *(subwatershed MC-4)* · Installing water main and reconstructing streets.
C	60 [1]	2012-13	**St. Louis Park / MCWD** *(Reach 20 Project)* Meadowbrook Road to Louisiana Avenue · Stream re-meander and stormwater treatment project.
C	140	2014	**MCWD/St. Louis Park** *(Knollwood Mall Area)* [2] Subwatersheds 54-57 · Stormwater treatment project.
C	17	2014	**Hopkins / MCWD** *(Cottageville Park)* NE of Blake Road & Lake Street, Subwatersheds 61-62 · Treatment of stormwater (likely ponds) that currently discharges directly to Minnehaha Creek.
C	122-379	2014-2016	**MCWD/Hopkins** *(325 Blake/Powell Rd/Lake St)* [2] Subwatersheds 60,61,64,65 · Stormwater treatment project.
E	45	2014-2015	**Edina/MCWD** *(54th St and Arden Park)* [2] Subwatersheds 85-87 · Stormwater treatment project.
E	NQ [3]	2013-16	**MCWD** *(Minnehaha Creek Streambank Improvements)* Reaches 12,14 · Streambank restoration projects – intended to address erosion, as well as improve vegetation and habitat.
E / F	159	2014	**MCWD/MPRB-Minneapolis** (*MPRB Infiltration Project)* [2] Subwatersheds 99,132,135,169 · Treatment of stormwater that currently discharges directly to Minnehaha Creek using infiltration basins.
F	NQ [3]	2013-16	**MCWD** *(Minnehaha Creek Streambank Improvements)* Reaches 6,7,9 · Streambank restoration projects – intended to address erosion, as well as improve vegetation and habitat.
G	185	2012	**Minneapolis** *(Blue Water Partnership Project)* Lake Hiawatha direct drainage · Rain garden and connection of residential land and right of way to ponds in Hiawatha Golf Course.
G	Unknown	2013	**MPRB** *(Hiawatha Golf Course Parking Lot)* Hiawatha Golf Course · Reconstruction of parking lot. At this time, not planning any BMPs beyond what is required, but there may be opportunities to do more.
G	30 [4]	2012	**Minneapolis** *(Flood Area 22)* Lake Hiawatha direct drainage

Notes:
1 In first phase; likely more in future phases.
2 These projects fall under a general heading of Minnehaha Creek Regional Volume and Load Reduction in the MCWD CIP with overall goal of reducing phosphorus loading by 626 lbs.
3 Not quantified in MCWD Plan.
4 No design yet; conservative place holder.

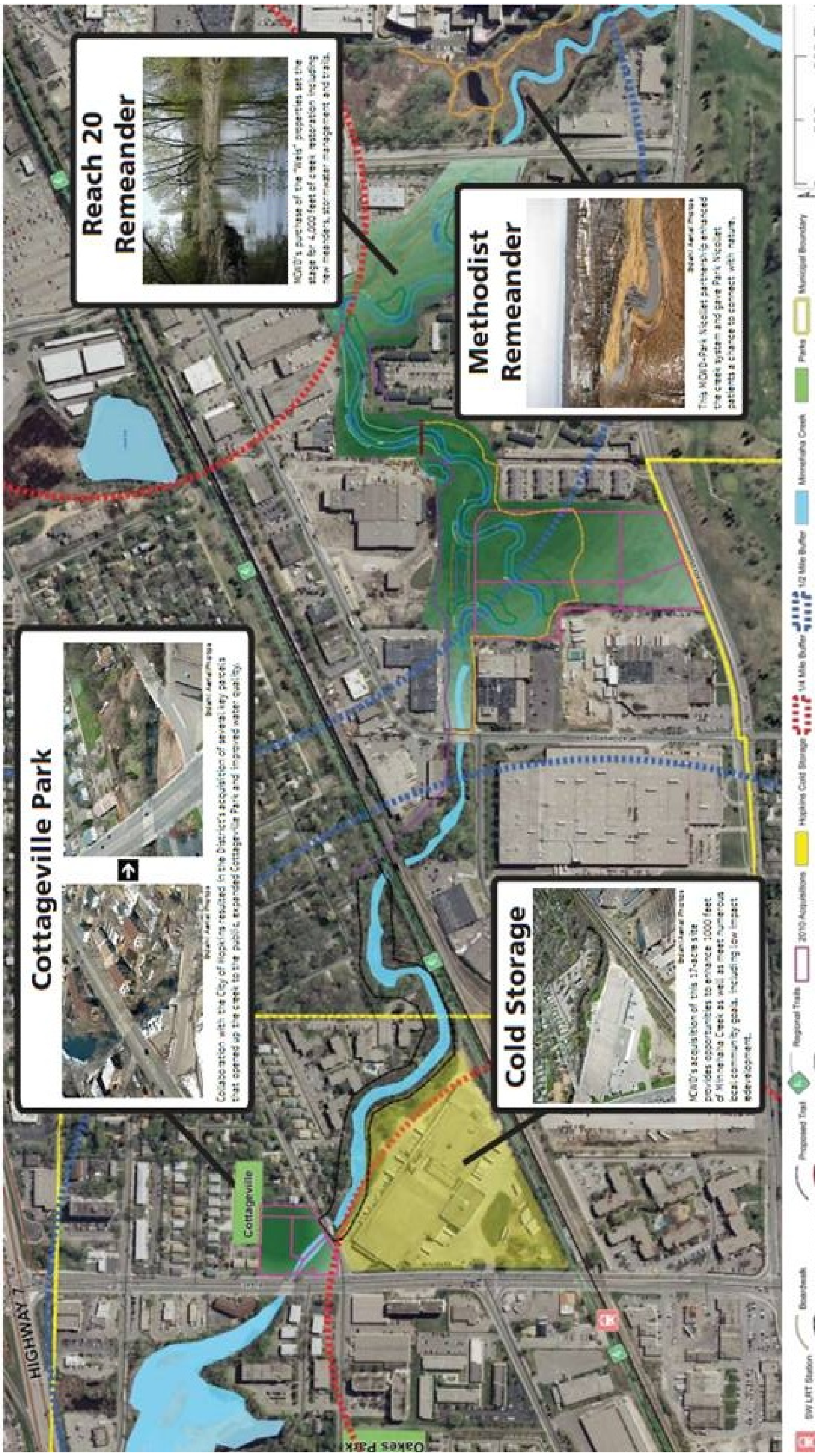


Figure 7-1. MCWD subwatershed group C stream restoration and stormwater treatment activities.

Bacteria -- Stormwater BMPs

As living organisms, bacteria are a unique pollutant. There are many challenges for quantifying them and estimating loads; likewise, there are challenges with respect to reducing excess loads. At this time with our current understanding the best approaches for addressing excess bacteria loads appear to fall into categories of source reduction or volume control practices. These practices include, but are not limited to:

- Pet waste management and disposal ordinances
  - Education
  - Disposal options
  - Enforcement
- Illicit discharge ordinances
  - Banning non-stormwater discharges from storm sewer systems
  - Enforcement
- Illicit discharge detection and elimination (IDDE) program enhancement
  - Incorporate into existing BMP inspection program
  - Municipal staff trained to recognize illicit discharges
  - Reporting system for staff and public
- Municipal operations
  - Street sweeping
  - Removal of solids from sumps, pipes and conveyance structures upstream of creek outfalls
  - Cleaning and rehabilitation of pipes, including lining (cured-in-place-pipe) to eliminate cracks and joints
- Volume control / infiltration BMPs
- Filtration BMPs

7.5 Schedule and Tracking

After the approval of the TMDL by EPA, the MCWD 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. The reduction targets assigned to LGUs through the *2007 MCWD Plan* were generally less stringent than those identified in the TMDL and can therefore serve as interim goals through the end of the current plan cycle in 2017. Progress toward the TMDL targets will be assessed as part of the decennial MCWD Plan revision and new targets will be set for that plan cycle.

7.6 Adaptive Management

Adaptive implementation is an iterative implementation process that makes progress toward achieving water quality goals while using any new data and information to reduce uncertainty and adjust implementation activities. This process involves the review of annual progress made toward key milestones and the potential revision of implementation activities to meet the TMDL target loads. By using the adaptive implementation approach, the MCWD and other MS4s can utilize the new information available from water quality monitoring activities following initial TMDL implementation efforts to appropriately target the next suite of implementation activities.

7.7 Monitoring Activities

Follow-up monitoring is integral to the adaptive implementation approach. Monitoring provides assurance that efforts are succeeding in attaining water quality standards following implementation of applicable BMPs and control measures. To assess progress toward meeting the phosphorus and bacteria TMDL targets, routine monitoring of Minnehaha Creek will continue to be a part of the MCWD annual Hydrologic Data program (http://www.minnehahacreek.org/data-center), particularly at key TMDL assessment points *(Figure 3-1)*. Also, critical to monitoring progress will be the continued work of the MPRB, which includes monitoring of Lake Hiawatha, operation and sampling of the Xerxes Avenue station and beach monitoring of bacteria.

MCWD is currently reviewing its ambient water quality monitoring program to ensure data gaps identified during TMDL development are filled. One example is improving estimates of flow released from Grays Bay Dam. In addition, follow-up monitoring should be considered to address challenges associated with meeting water quality criteria for bacteria. Source identification methods should be evaluated for potentially applicability in the Minnehaha Creek / Lake Hiawatha TMDL study area. Information from bacteria source tracking can be used to help guide implementation efforts. Source tracking methods under review as part of the Upper Mississippi River Basin bacteria TMDL effort include: identification of Bacteroides specific to humans, livestock, and wildlife; human-specific viruses; human pharmaceuticals, fluoride or caffeine.

The City of Minneapolis completes water quality monitoring to understand and improve stormwater management program effectiveness. Minneapolis is committed to water quality sampling within their city boundaries, which do extend into the Minnehaha Creek / Lake Hiawatha TMDL study area. Minneapolis has collected water quality samples for total phosphorus and bacteria. Total phosphorus sampling typically involves grab samples collected from precipitation events of 0.10 inch or greater over a range of seasons and events and flow-paced composite samples over non-ice time period (approx. March to November) and grab samples at least two times during typical winter thaw (approx. December to March). Bacteria samples are quarterly *E. coli* grab samples.

On an ongoing basis, illegal connections are sometimes discovered by Minneapolis sewer maintenance crews, followed by corrective action. In 2014 / 2015, Minneapolis will be performing a new dry weather field screening program, in accordance with the City's NPDES Phase I MS4 Permit and Code of Federal Regulations 40 CFR Part 122.26(d)(1)(iii)(D) Field Screening Protocol. The presence of dry weather flow could indicate illegal connections for materials that should be going to the sanitary sewer system, not the storm drain system. This will be similar to a dry weather field screening program the City conducted in 1991/1992 at 400+ sites, which included about 20 outfalls along Minnehaha Creek. (There are 100 or so outfalls along Minnehaha Creek, many of them for small areas such as parkland). A scope is being prepared by the City of Minneapolis for the field screening study; the site screenings to be carried out in 2014 and 2015. One consideration for locations will definitely be TMDL waters.

7.8 Future Implementation Activity Recommendations

The following discussion takes advantage of recent stormwater BMP targeting work conducted in the upper Midwest. A recommended approach to guide the next phase of stormwater BMP planning efforts starts with a multi-scale analysis framework constructed from available land use and stream inventory information; this in turn helps the targeting process. The multi-scale analysis points to priority areas where stormwater management practices under consideration can be evaluated through screening analyses using BMP performance and level of implementation curves.

This section presents information on the multi-scale analysis framework and BMP targeting in the context of implementation planning for the Minnehaha Creek / Lake Hiawatha TMDL study area. The highest group unit area TP load is the area between West 34th and Excelsior (group C). Because the greatest load reductions are expected from this area, this subwatershed group serves as an example to demonstrate how these tools can be used to connect TMDL targets to stormwater management program implementation *(Figure 7-2)*. Although material presented on urban BMPs may appear focused on volume reduction, the presumption is that decreased stormwater flows will also result in reduced TP loads.

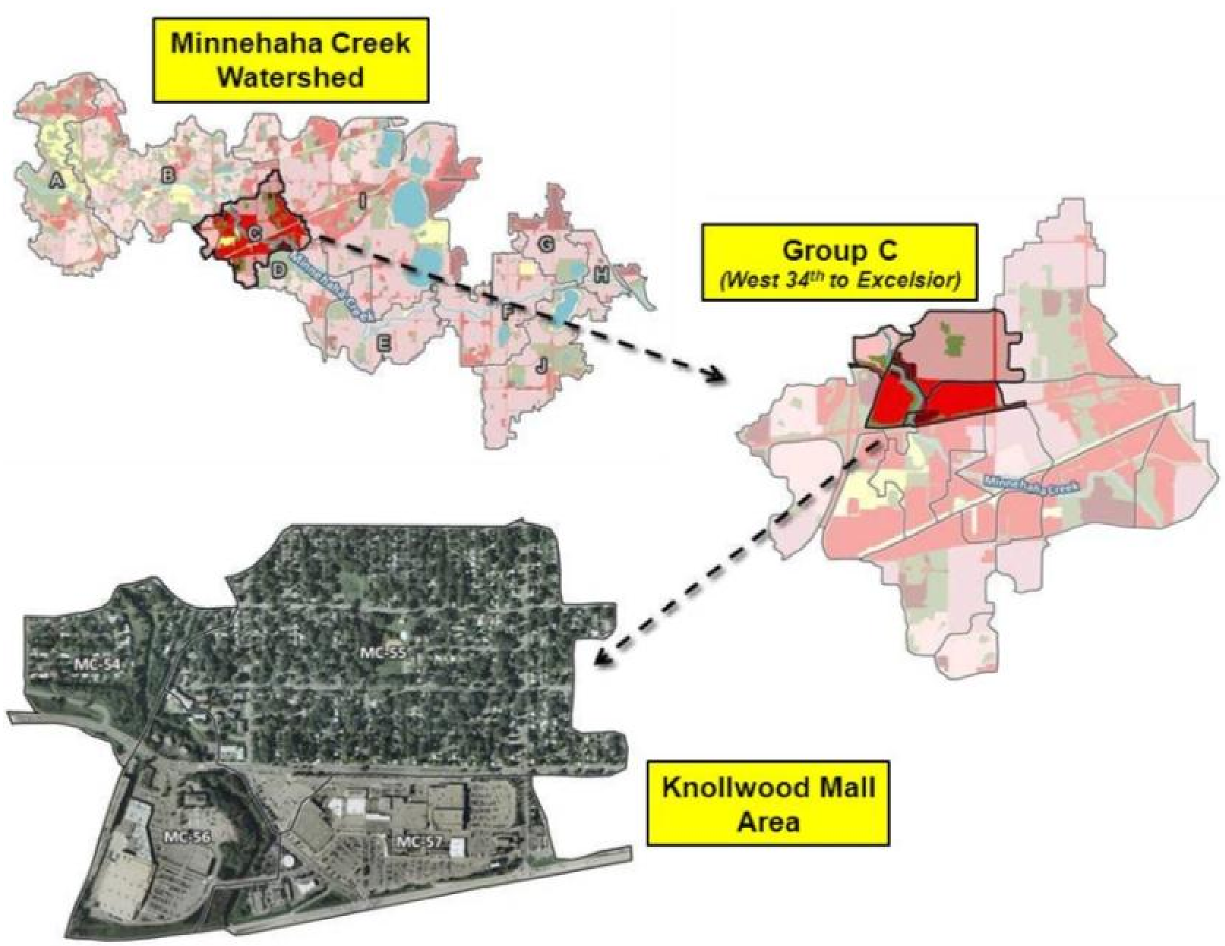


Figure 7-2. Minnehaha Creek multi-scale analysis framework.

7.8.1 Multi-scale Analysis

A multi-scale analysis based on GIS data can be used to identify high priority catchments for BMP implementation within each subwatershed group. These are critical areas that have a disproportionate effect on water quality. This approach is consistent with a focus advocated by USEPA and a number of states; one that recognizes BMPs placed in critical locations can help treat small areas that produce disproportionate amounts of pollution.

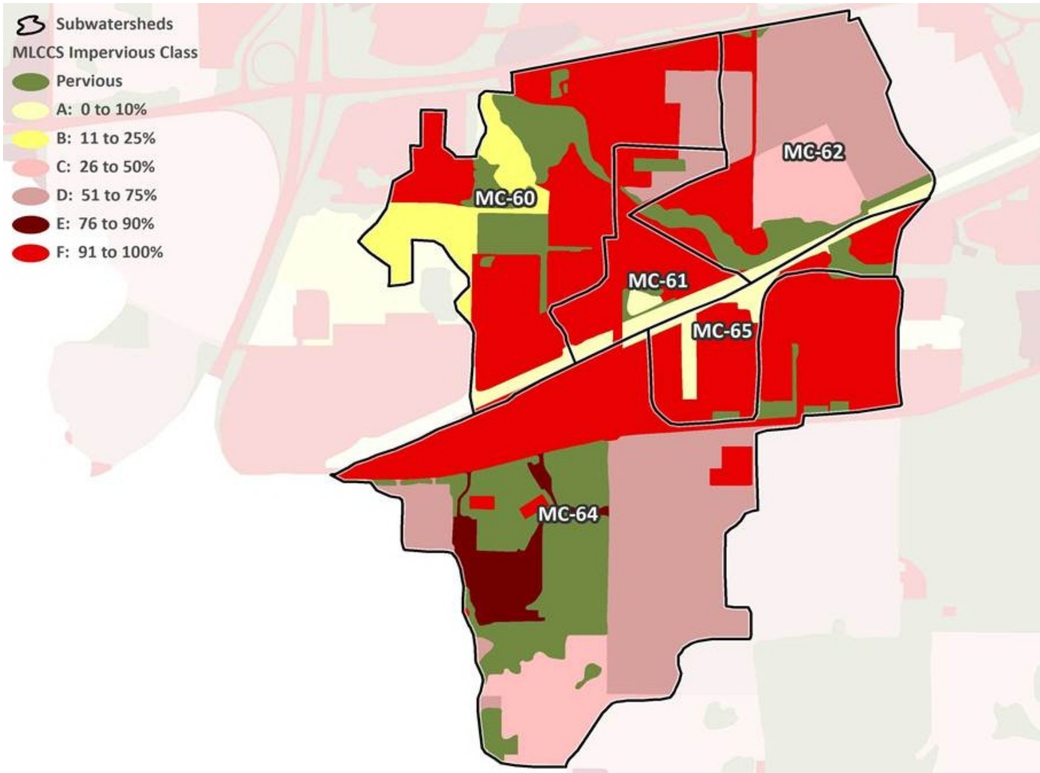
Critical locations in urbanized watersheds are typically those areas with high levels of impervious cover; these locations can be identified using GIS tools. In the Minnehaha Creek / Lake Hiawatha TMDL study area, GIS information from MLCCS includes impervious cover classes (e.g., 91% to 100% impervious cover, 76% to 90%, etc.). These classes can be divided into development intensity categories (e.g., high, medium, low, developed open space) that describe typical land uses (Table 7-2). Estimates of impervious cover by subwatershed group provide a method to identify priority locations that warrant an in-depth assessment of potential BMP implementation opportunities.

For instance, MCWD is evaluating the feasibility of constructing a regional stormwater treatment facility in subwatershed MC-61. This facility will include treatment of stormwater runoff diverted from portions of MC-60, MC-64, and MC-65 (noted in Table 7-1 and shown in Figure 7-3). Stormwater volume and load reduction estimates involve assumptions regarding key design parameters, such as capture depth (e.g., BMP sizing) or substrate properties (e.g., infiltration rate). The proposed Blake Road facility can illustrate the value of BMP performance curves for estimating volume and load reductions given uncertainty associated with design parameter assumptions.

Another priority area in group C is a cluster of subwatersheds (MC-54, MC-55, MC-56, MC-57) in the Knollwood Mall area (Figure 7-4). Several volume reduction practices are being considered that would reduce total phosphorus loads to the creek. A common question associated with this situation centers on the types and amount of BMP installation needed to meet load reduction targets. The Knollwood Mall area can illustrate the benefit derived from level of implementation curves for BMP planning.

Table 7-2. MLCCS impervious cover classes.

<table>
<tr><th colspan="2">MLCCS Impervious Cover Estimate (percent)</th><th rowspan="2">Development Category</th><th rowspan="2">Typical Land Uses</th></tr>
<tr><th>Range</th><th>Average</th></tr>
<tr><td>91-100%</td><td>(95)</td><td rowspan="2">High Intensity</td><td rowspan="2">Commercial (retail, office)
Institutional (school, hospital), Apartments</td></tr>
<tr><td>76-90%</td><td>(83)</td></tr>
<tr><td>51-75%</td><td>(63)</td><td rowspan="2">Medium Intensity</td><td rowspan="2">Residential</td></tr>
<tr><td>26-50%</td><td>(38)</td></tr>
<tr><td>11-25%</td><td>(18)</td><td>Low Intensity</td><td rowspan="2">Residential, Recreational</td></tr>
<tr><td>0-10%</td><td>(5)</td><td>Developed Open Space</td></tr>
</table>



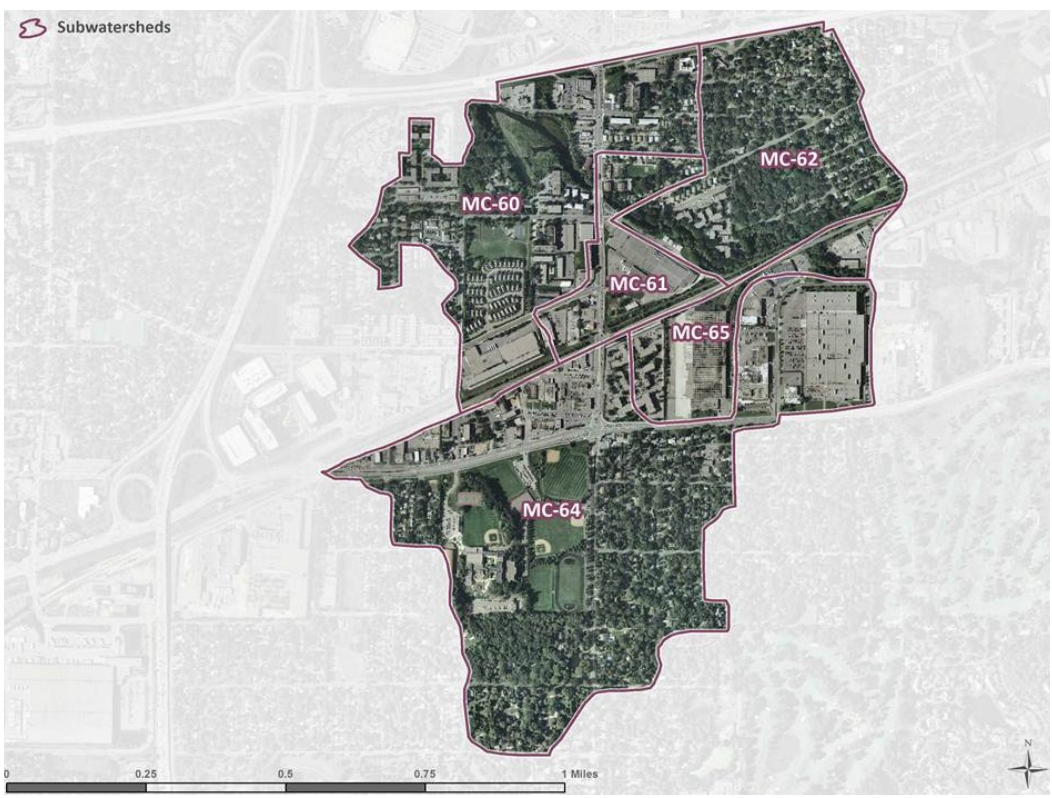


Figure 7-3. Land use and air photo of Blake Road area subwatersheds (group C).

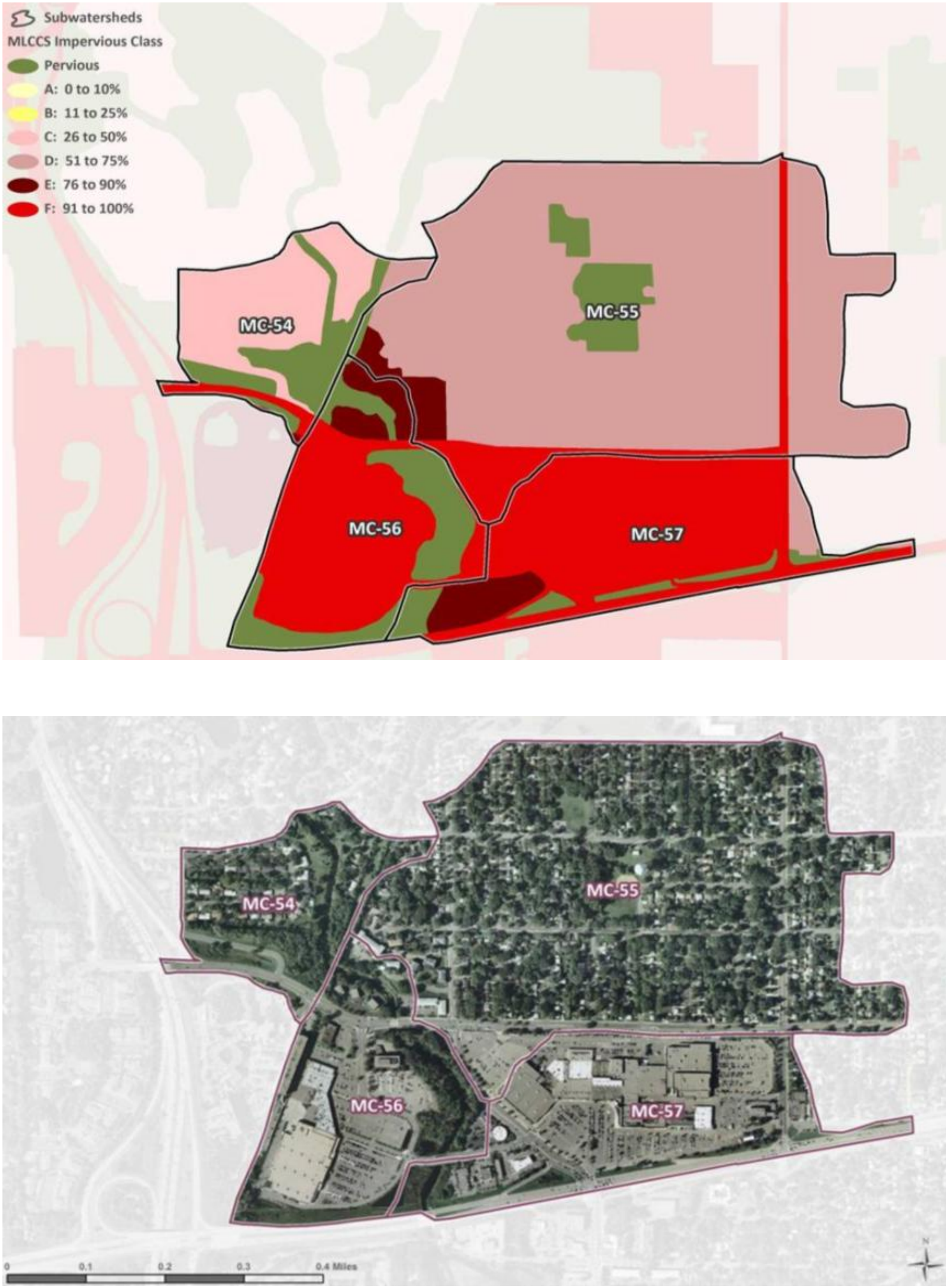


Figure 7-4. Land use and air photo of Knollwood Mall subwatersheds (group C).

7.8.2 BMP Performance Curves

The proposed regional facility for the Blake Road area is intended to treat stormwater runoff contributed from portions of MC-60, MC-61, MC-64, and MC-65. The estimated amount of impervious surface contributed by these areas is summarized in Table 7-3 using information from a preliminary feasibility study (Wenck, 2013). Based on these impervious cover characteristics and a simple rainfall – runoff analysis, the estimated 2001-2011 June to September stormwater volume from this area was approximately 210 acre-feet (or about 10 inches). To illustrate the utility of BMP performance curves, stormwater volume reduction estimates are developed for an infiltration basin.

Table 7-3. Subwatershed impervious cover summary for proposed Blake Road treatment facility.

Subwatershed	Total Area *(acres)*	Impervious Area		Drainage Area Description
		(percent)	*(acres)*	
MC-61	21.1	85%	17.9	Blake Road property
MC-60	29.6	85%	25.2	Lake Street Diversion
MC-64 / MC-65	208.9	75%	156.7	Powell Road Diversion
TOTAL	259.6	77%	199.8	

Urban stormwater BMPs in the Minnehaha Creek / Lake Hiawatha TMDL study area can be evaluated according to design specifications based on the general process type, such as storage / infiltration processes versus channelized processes *(Figure 7-5)*. A unit-process approach has many advantages over most other analytical tools, which simply assign a single percent effectiveness value to each type of practice (i.e., literature based BMP reduction estimates). In a treatment process approach, overall urban stormwater BMP performance is evaluated as a function of physical configuration, storm size, associated runoff intensity and volume, as well as moisture conditions.

A general estimate of BMP performance can be developed for each practice being considered based on the process type. One way to view this information is in terms of sizing. Sizing of BMPs is typically focused on capturing a certain depth of runoff (e.g., water quality volume). Using a process-based approach, curves can be developed that show the performance of a BMP over a long-term period (rather than as a single storm or design storm event). This is an important aspect of a BMP opportunity assessment. Inherently, assumptions must be made when transitioning from a location specific analysis (e.g., site-scale) to an evaluation of larger areas, such as the neighborhood or watershed scale *(Figure 7-6)*.

Key sizing parameters for many stormwater BMPs, including infiltration basins, are those that determine storage volume (namely surface area and depth). Major components include surface storage, substrate storage, and underdrain storage. Other key design parameters that affect BMP performance include infiltration rates and design drainage area (particularly the amount of effective impervious area being treated). Example design parameters that can be varied in urban storage / infiltration-type BMPs are shown in Table 7-4.

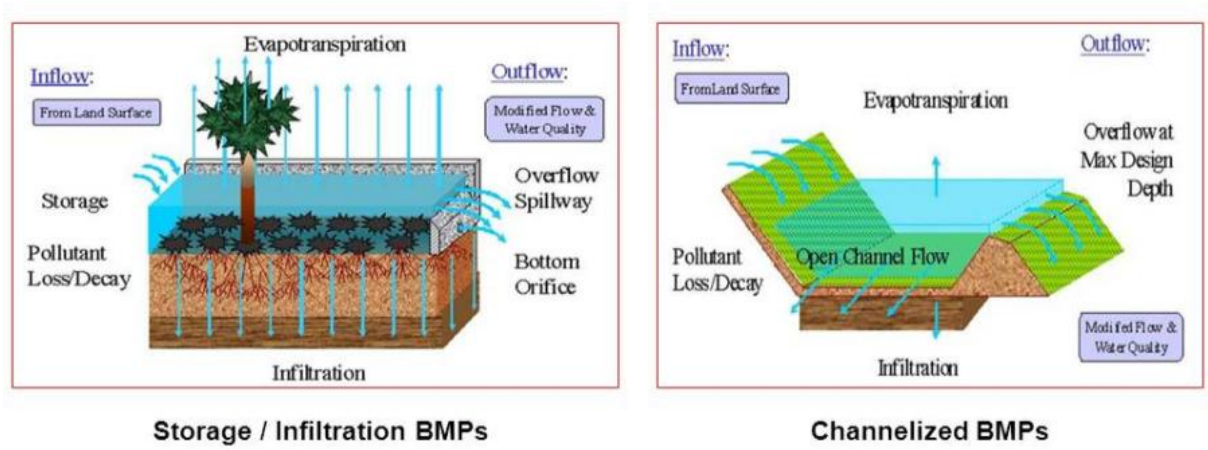


Figure 7-5. Major processes included in urban BMP assessments.

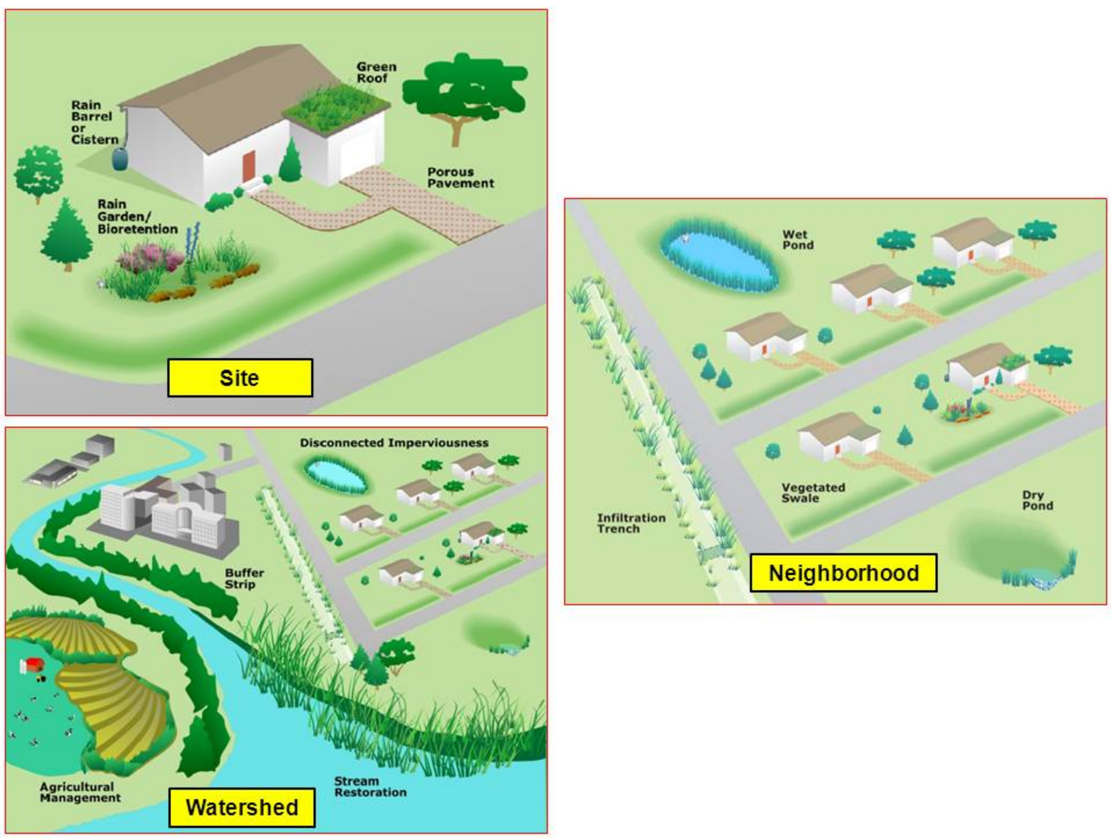


Figure 7-6. Urban BMP assessment scales.

Table 7-4. Example key BMP design parameters -- storage / infiltration processes.

Dimensions	
· Length *(feet)* · Width *(feet)*	· Design drainage area *(acre)*
· Ponding depth defined through one of following options: ü Orifice height *(feet)* ü Weir height *(feet)*	
Substrate Properties	
· Depth of soil *(feet)* · Soil porosity *(0 - 1)* · Soil field capacity	· Soil wilting point · Vegetative parameter A · Soil layer infiltration *(inches / hour)*
· Underdrain structure *(if applicable)* o Storage depth *(feet)* o Media void fraction *(0 - 1)*	o Background infiltration *(inches / hour)*

Figure 7-7 shows a set of example performance curves for an infiltration basin design configuration (infiltration storage depth is three feet; substrate media depth is two feet and assumed to be a sand layer). The x-axis represents different capture depth designs that are a function of the BMP surface area. The three curves reflect assumptions regarding different infiltration rates. The horizontal line at 60 percent represents the needed TP load reduction for subwatersheds in group C. Although volume reduction does not equate to TP load reduction, this line does provide a frame of reference.

Another key question associated with the Blake Road example is uncertainty surrounding the amount of effective impervious area (EIA) contributing stormwater runoff to the proposed regional treatment facility. The estimates presented in Table 7-3 are based on general GIS land use information, which may not reflect how much impervious area is actually connected to the storm sewer system. This uncertainty affects estimates of the volume or load reduction that will be achieved.

Figure 7-8 shows the utility of BMP performance curves in quantifying that uncertainty and highlights the relative importance of EIA as a design parameter. Estimates of EIA can be improved by developing an impervious cover type inventory, as demonstrated in the next section discussing Knollwood Mall area opportunities and constraints. An impervious cover type inventory differentiates parking areas from streets and roads from roof tops. Impervious surface types are a major determinant in identifying specific BMPs that can treat a particular area.

One benefit of developing these curves is that they illustrate the sensitivity of BMP performance to the range of key variables (e.g., infiltration rates, storage depth). The curves also provide a way to quantify uncertainty regarding assumptions. In addition, the performance curves highlight those design parameters that are most important when developing specifications for implementation projects. Finally, the curves can help guide decisions where cost trade-offs are involved (e.g., size of area to treat, amount of amendment material to promote greater infiltration, underdrain system design, etc).

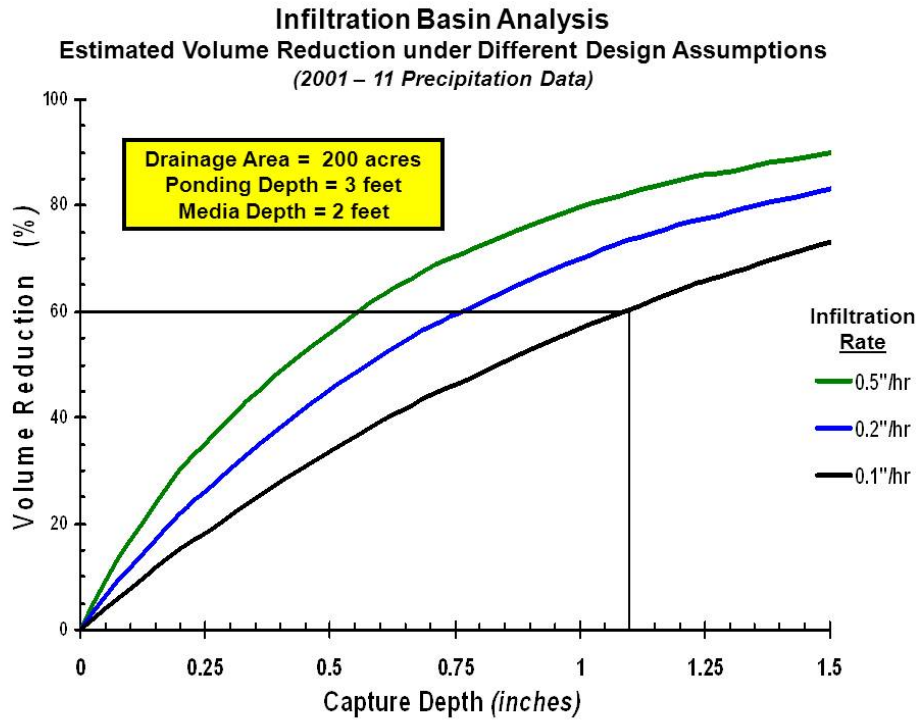


Figure 7-7. General BMP performance curve -- infiltration basin volume reduction.

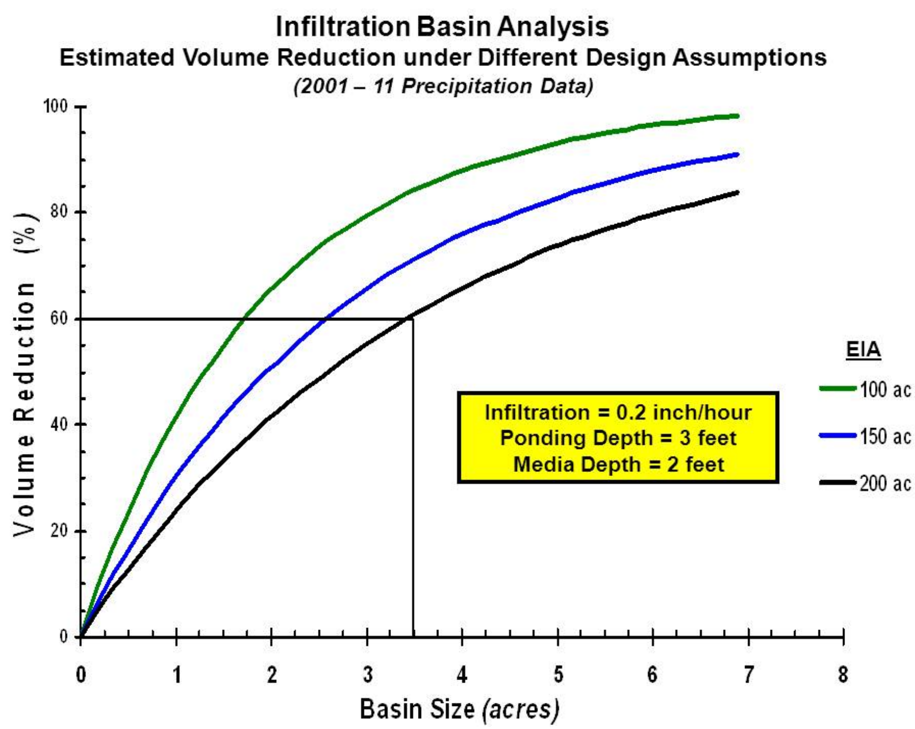


Figure 7-8. Example effect of EIA assumptions on infiltration basin volume reduction.

7.8.3 Opportunities and Constraints (Level of Implementation Curves)

The cluster of subwatersheds in the Knollwood Mall area (Figure 7-4) contains a mix of land uses (Table 7-5) and impervious cover types (e.g., commercial parking, major arterial roads, residential streets, driveways, roofs). Inventorying impervious surface types by land use (Table 7-6) builds a foundation for better targeting of BMPs; this in turn can lead to measurable water quality improvements. By examining the type of development and impervious surfaces present, stormwater volumes produced by various source areas (e.g., parking, roads, roofs) can be estimated.

Potential Options

An important part of evaluating opportunities to implement BMPs is assessing options. This involves examining the level of implementation that may be needed for BMP treatment alternatives by estimating the general performance of these practices beyond the site scale (e.g., catchment or subwatershed levels). Figure 7-9 shows an example schematic that serves as an organizational tool for determining where certain categories of BMPs could actually be implemented (e.g., bioswales along streets; porous pavement for parking and driveways; rain gardens for residential roofs).

In addition to assessing individual practices, options also include the use of treatment trains (e.g., flow from porous pavement systems to bioretention, rain barrels followed by rain gardens, etc.), as illustrated in Figure 7-9. Determining the maximum extent to which BMPs could be used to treat impervious surface types shown in Figure 7-9 is also part of the opportunity assessment.

A preliminary estimate of impervious surface type distribution is provided in Table 7-6. The distribution of surface types can be expanded to also estimate the amount of critical surface areas, such as pavement (Table 7-7); this in turn supports screening analyses. In addition to parking lot size or street lengths and widths, these estimates could include other items such as number of homes, average driveway size, average roof size, etc. The following discussion illustrates factors to consider in evaluating level of implementation questions and determining maximum extents for BMPs.

Table 7-5. Knollwood Mall area subwatershed land use summary (group C).

Unit ID	Size *(acres)*	Land Use Summary (*%*)				Community(s)
		Residential	*Commercial, Industrial, Institutional, & Mixed Use*	*Parks & Recreation, Undeveloped*	*Major Roads*	
MC-54	31.9	*55.6*	*7.4*	*37.0*	*0.0*	St. Louis Park
MC-55	129.0	*92.7*	*4.6*	*2.8*	*0.0*	St. Louis Park
MC-56	45.0	*15.8*	*60.5*	*23.7*	*0.0*	St. Louis Park
MC-57	61.5	*1.9*	*75.0*	*3.9*	*19.2*	St. Louis Park
Total	**267.4**	***54.4***	***30.5***	***10.7***	***4.4***	**St. Louis Park**

Table 7-6. Example template for inventorying impervious surface types.

MLCCS Impervious Cover Range	Land Use		Percent of Category Area	Impervious Surface Type (percent of impervious land use area)				
				Parking	Road	Driveway	Sidewalk	Roof
91-100%	Commercial	Retail	*20%*	50	5		5	40
	Transportation		*5%*		100			
76-90%	Commercial	Office	*5%*	45	5		5	45
	Apartment/Condo		*5%*	35	10		5	50
51-75%	Residential *(based on development age)*	>30 years	*40%*		45	15	5	35
26-50%		<15 years			35	20	5	40
		15-30 years			40	15	5	40
		>30 years	*15%*		45	15	5	35
0-10%	Recreational		*5%*	30	30	5	5	30
0%	Open Space		*5%*					

Note: The values in this table are for illustrative purposes only, based on approximations from GIS data. More detailed estimates can be developed from tools such as LIDAR and / or aerial photos.

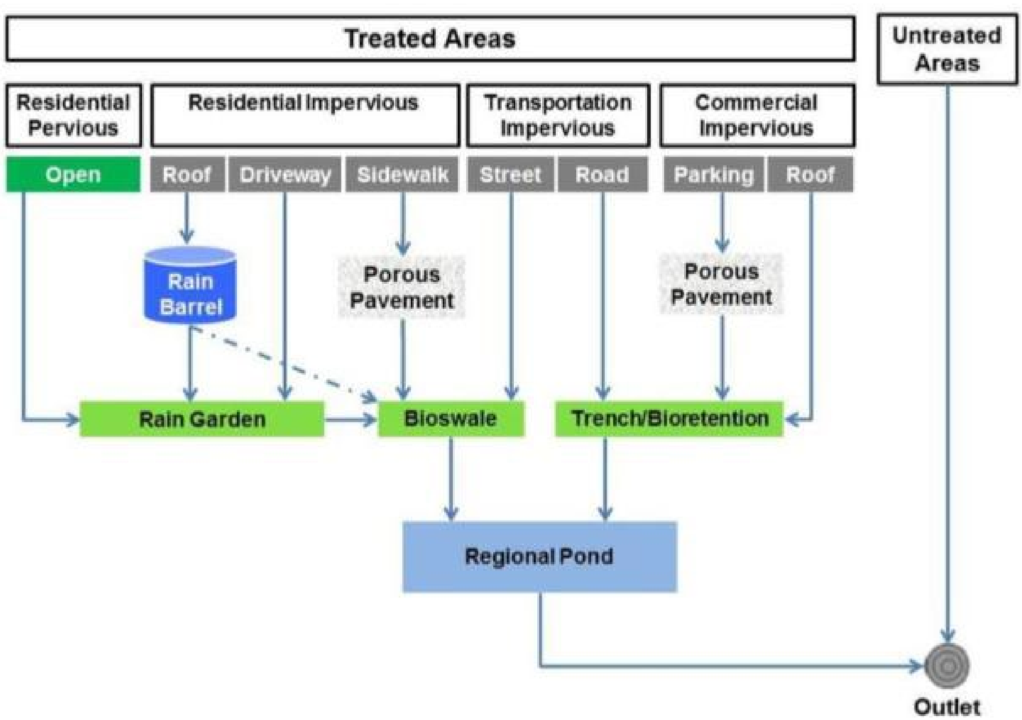


Figure 7-9. Schematic identifying BMP treatment train options for impervious surface types.

Table 7-7. Example impervious surface type summary estimates.

Surface Type	Impervious Area (acres)	Impervious Area (percent)	Average width (ft)	Length (ft)	BMP Options (not all inclusive)
PAVEMENT					
Parking Lots	40	25%			Bioretention, Porous Pavement
Residential Streets	45	27%	30	65,000	Bioswale, Porous Pavement
Arterial Roads	15	9%	50	13,000	Bioswale, Infiltration Trench
Driveways	15	9%			Porous Pavement, Bioswale
Sidewalks	5	3%	4.5	50,000	Porous Pavement, Bioswale
ROOFS					
Commercial Roofs	35	21%			Regional Detention, Green Roofs
Residential Roofs	10 **	6%			Rain Gardens, Green Roofs
TOTAL	165				

Notes: ** Assumes that only 1/3 of total roof area runoff reaches storm sewer system.
Values in this table are for illustrative purposes only, based on approximations from GIS data.
More detailed estimates can be developed from tools such as LIDAR and / or aerial photos.

Screening Analysis

A key part of the MCWD *Water Resources Management Plan* is focused on volume reduction through infiltration practices. As stated earlier, the presumption is that decreased stormwater flows will result in reduced TP loads. Roads and parking areas, for instance, are high priority surfaces for treatment; these represent the greatest proportion of total impervious area and are the surface types most likely to be directly connected to storm sewer systems.

Impervious surface area and dimension (where applicable) estimates are presented in Table 7-7; BMP options for each surface type are also included. As indicated, bioretention and / or porous pavement are one option for parking lots. Bioswales are another viable option for some residential streets in the Knollwood Mall subwatershed cluster area. These linear practices are designed to provide off-line retention for road runoff and surrounding areas.

At a small scale (site or local), the BMP representation framework can be applied using tools to explicitly simulate the benefits of individual practices. However, beyond the site scale, there are more BMP units scattered across the landscape. This poses a challenge in terms of evaluating the collective benefits of distributed BMPs. The required number of simulations for the range of distributed BMP opportunities places a significant burden on the computational time for system modeling. Data and resource constraints often outweigh the benefit of incorporating details for every site into the broader assessment.

Approach: When examining potential options, it is seldom practical (or even necessary) to build an analysis that evaluates every individual BMP in each subwatershed. There are ways, however, to represent a consolidated response for specific BMP categories within a subwatershed. This greatly reduces the computational effort, yet still offers a powerful tool to assess potential BMP performance beyond the site scale.

One approach to address this challenge is to conduct a screening analysis using a *"consolidated network"* of BMPs. The primary focus of the screening analysis is to examine the level of treatment that could be applied in a subwatershed or catchment (e.g., BMP treatment capacity and percent area treated). Treatment capacity is quantified as consolidated storage (e.g., BMP surface area, ponding volume, etc.).

A *"consolidated network"* examines options looking at practices and configurations for various impervious surface types of interest. The screening analysis is structured to evaluate the relative effect of different BMP configurations that focus on treating runoff from specific impervious surface types. A critical aspect is to examine the sensitivity of key design variables and assumptions. In parking lots, this could include the amount of area converted to bioretention or porous pavement, BMP design parameters (e.g., planting mix or media depth, underdrain features, ponding depth), and native soil infiltration rates. For bioswales, these include the percentage of available street length where the practice is installed along with BMP design parameters and infiltration rates.

The following examples illustrate the use of BMP assessment tools to develop curves that describe reductions associated with different management strategies (basically, level of implementation curves). These curves can be used to enhance the MCWD Plan for reducing the effect of stormwater on TP loads in the Minnehaha Creek / Lake Hiawatha TMDL study area.

Detention ponds are a logical starting point for the Knollwood Mall area example, as they are the most prevalent treatment practice in MC-56 and MC-57. These surface water structures provide temporary storage of stormwater runoff to prevent downstream flooding. The primary purpose of a detention pond is the attenuation of stormwater runoff peaks. Detention ponds are commonly used to meet the water quality treatment requirements. However, they do not achieve significant groundwater recharge or volume reduction.

Table 7-7 shows 165 acres of impervious surfaces that could be potentially treated (Note: these values are solely for the purpose of demonstrating the utility of screening analyses to help guide planning efforts to reduce TP loads in group C). Figure 7-10 depicts a set of general BMP performance curves for detention ponds. This shows reduction patterns as a function of the amount of area used for surface detention. In this example, storage depth is assumed to be five feet, while each curve reflects different infiltration rate assumptions.

Little or no infiltration occurs in detention ponds. However, the upper curve in Figure 7-10 shows the critical role of infiltration for volume reduction. The horizontal line drawn at 60 percent in Figure 7-10 represents the TP load reduction needed for subwatersheds in group C. Although the volume reduction shown in Figure 7-10 does not equate to the same TP load reduction, the 60 percent line does provide a frame of reference that highlights the need to include infiltration practices (e.g., bioretention) in the analysis.

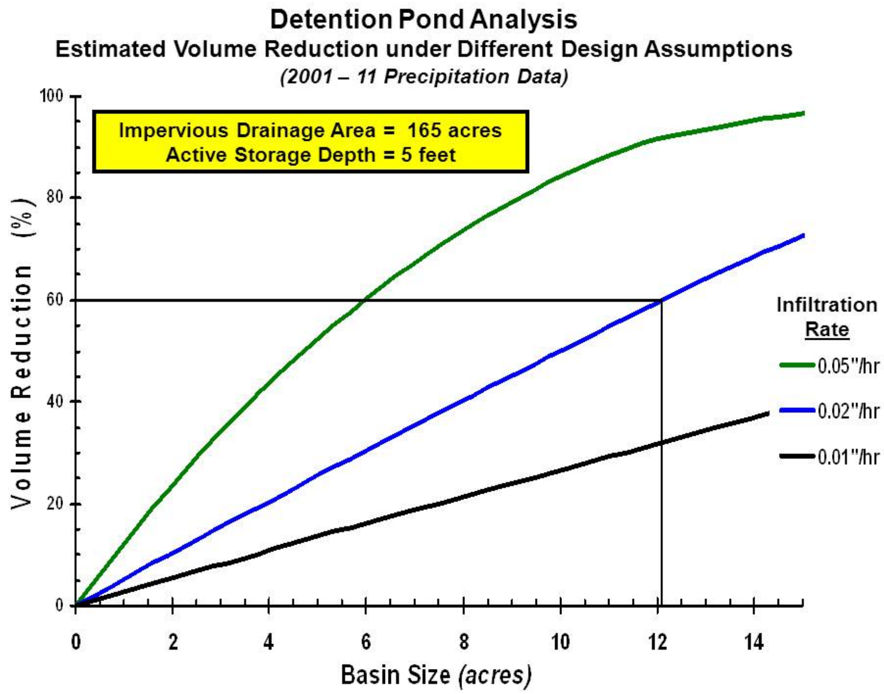


Figure 7-10. Detention volume reduction at different pond sizes and background infiltration rates.

Bioretention practices are basins that utilize a soil media, mulch, and vegetation to treat runoff and improve water quality. The *"The Minnesota Stormwater Manual"* (2005) describes the benefits, limitations, suitable applications, and design data for bioretention practices. A bioretention area is a depression that allows shallow ponding of runoff and gradual percolation through a soil media or uptake by vegetation. Water that percolates either infiltrates through undisturbed soils or enters a storm sewer system through an underdrain system.

Bioretention is able to attenuate flow and reduce volume. These BMPs use biological, chemical, and physical processes to remove a variety of pollutants. Bioretention is generally applicable to highly impervious areas, and provides an option for retrofit situations. Common examples of bioretention are rain gardens, bioswales, and regional facilities to accommodate larger drainage areas.

Numerous design applications exist for bioretention. These include use as off-line facilities within or adjacent to parking lots, on commercial / industrial sites, in residential lots, and along highways and roads. Bioretention practices are typically sized for common storm events (e.g., WQv). In addition to varying the surface area, other design parameters are usually evaluated relative to achieving a performance goal *(Table 7-4)*.

A cursory assessment of impervious surface types in the Knollwood Mall subwatershed cluster area indicates that roughly a quarter of the EIA contributing stormwater runoff is associated with parking lots *(Table 7-7)*. As mentioned above, bioretention is a suitable BMP for parking lots, and has been used in numerous locations across the country (Maplewood Mall is a good example in the Minneapolis Metro area[1]).

Approximately 40 acres of impervious surface in the Knollwood Mall area subwatershed cluster are parking lots (Table 7-7); portions of these could be used as bioretention. As mentioned previously, the screening analysis can be constructed in a way that shows the sensitivity of major design variables (in this case, infiltration rate). Key design variables include the native soil infiltration rate and the fraction of the parking area converted to bioretention, as well as the media and ponding depths.

Screening analysis results for bioretention applied to parking lots is presented in Figure 7-11. This particular graph depicts volume reduction as a function the parking area converted to bioretention (addressing the level of implementation question). Again, these values are solely for the purpose of demonstrating the utility of screening analyses to help guide planning efforts to reduce TP loads in group C.

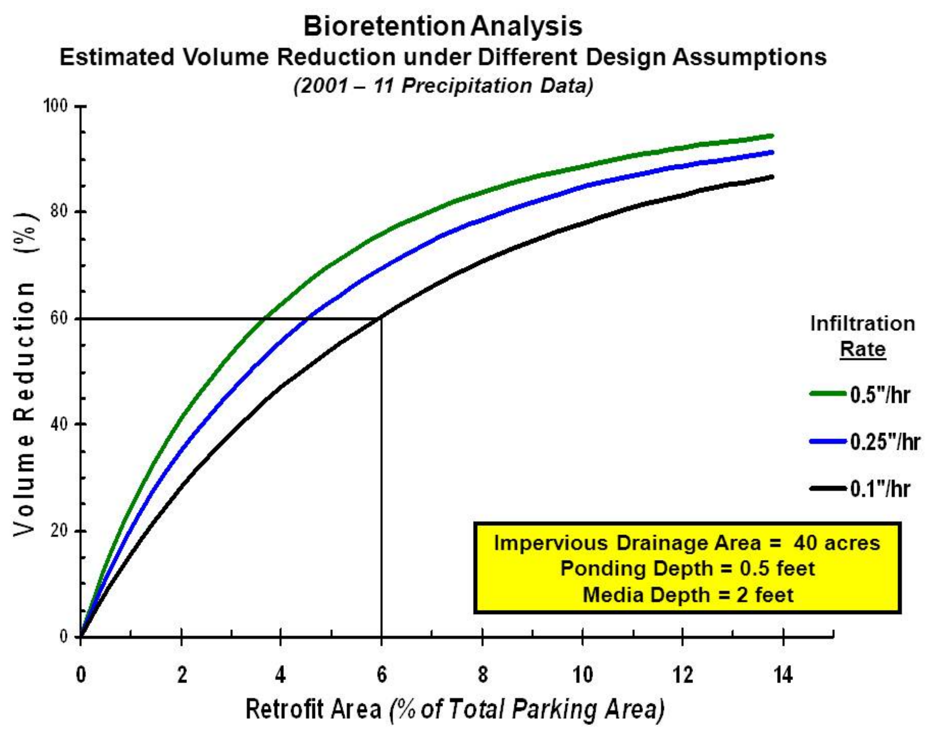


Figure 7-11. Bioretention volume reduction at varying levels of implementation and infiltration rates.

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[1] http://www.rwmwd.org/index.asp?Type=B_BASIC&SEC={DB475310-069F-4230-9E97-01E92FD50527}

In this example, a consolidated network was employed (in practice, however, bioretention would likely be implemented at a variety of points throughout the parking lots). Hourly output from the rainfall – runoff analysis was used to generate stormwater volumes. Under a consolidated network, the entire parking lot runoff was routed to one treatment area. The BMP assessment estimated the amount of water leaving the treated area (either through infiltration or runoff) to determine reduction based on each design configuration.

Bioswales are another viable option for some residential streets in the Knollwood Mall area. These linear practices are designed to provide off-line retention for road runoff and surrounding areas (e.g., sidewalks, driveways). Figure 7-12 presents the results of an example screening analysis for bioswales applied to residential streets, sidewalks, and driveways using the BMP assessment tool combined with Minneapolis climate and soils data. This particular graph depicts volume reduction as a function of the percentage of total residential street length where bioswales are installed (addressing the *"level of implementation"* question). The screening analysis is constructed in a way that shows the sensitivity major design variables (in this case, media depth).

One point worth noting is that the level of implementation results in significant volume reductions when the retrofit area is less than 20 percent of the total street length considered. There are clearly diminishing returns above that level for this particular situation. This reflects the regional nature of the consolidated network; specifically, there are efficiencies gained from central treatment systems. In the case of more dispersed BMPs (e.g., small rain gardens on individual residential yards), the rate of reduction with increased implementation would likely be linear (rather than exponential).

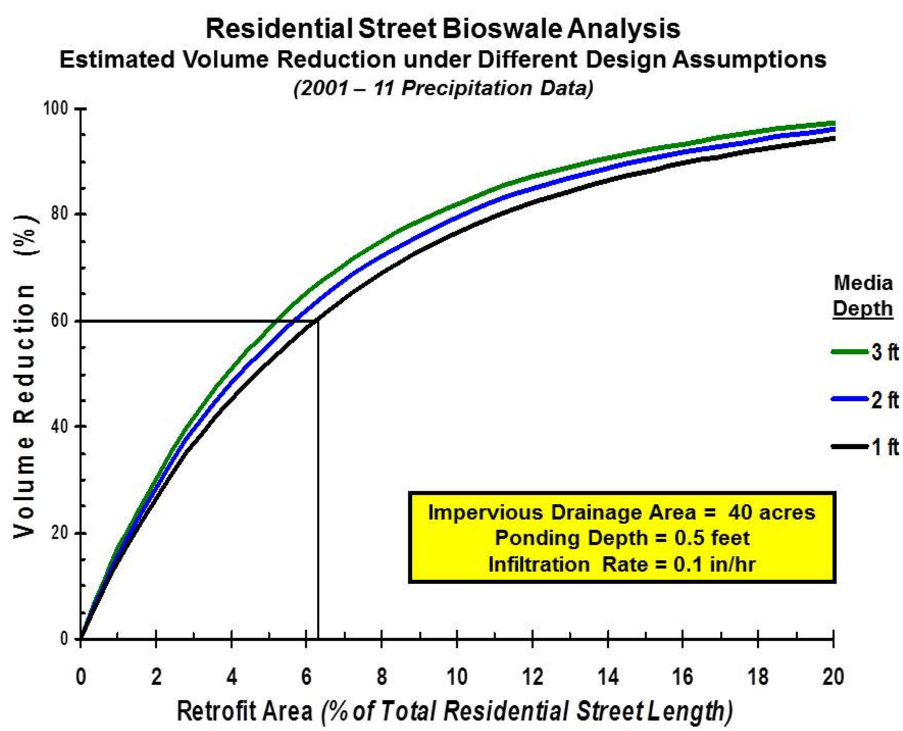

Figure 7-12. Bioswale volume reduction at varying levels of implementation and media depths.

Porous pavement contains small voids that allow stormwater to drain through the surface to an aggregate storage area, then infiltrate into the soil. Site applications include modular paving systems (concrete pavers, grass-pave, gravel-pave) or poured in place solutions (pervious concrete, pervious asphalt).

Porous pavement is an alternative to impervious hardscapes, reducing the effective impervious area. This practice is able to attenuate flow and reduce volume. The pavement layer and aggregate subbase provide rapid infiltration. Total volume retention is dependent on properties of native soils. Porous pavement is generally used to manage rain that falls on the surface, rather than *"run on"* from other areas but can provide treatment for *"run on"* if the available treatment capacity is not fully utilized (e.g., for malls it is assumed that porous pavement in the parking areas could treat *"run on"* from commercial rooftop area).

Porous pavement is typically used to replace traditional impervious pavement for most pedestrian and vehicular applications, other than high-volume / high-speed roadways. Example applications include pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways). Porous pavement systems are typically sized for common storm events.

Screening analysis results for bioretention applied to parking lots is presented in Figure 7-13. This particular graph depicts volume reduction as a function the parking area converted to porous pavement (addressing the level of implementation question). Again, these values are solely for the purpose of demonstrating the utility of screening analyses to help guide planning efforts to reduce TP loads in group C.

7.8.4 Summary

As illustrated through examples for group C, the multi-scale analysis points to priority areas where stormwater management practices under consideration can be evaluated through screening analyses using BMP performance and level of implementation curves. Options were identified for several subwatershed clusters within group C using management practices that are consistent with implementation efforts being applied by MCWD and LGUs in the TMDL study area.

The screening analyses showed that there is an array of different BMP implementation alternatives that could achieve a 60 percent reduction in stormwater volume; a point of reference simply for comparison to the TP reduction target for group C. From a practical perspective, less volume reduction would likely be needed to meet the 60 percent reduction in total phosphorus for group C. In addition, practices other than volume reduction BMPs (e.g., street sweeping) are being implemented in the TMDL study area that would reduce phosphorus loads.

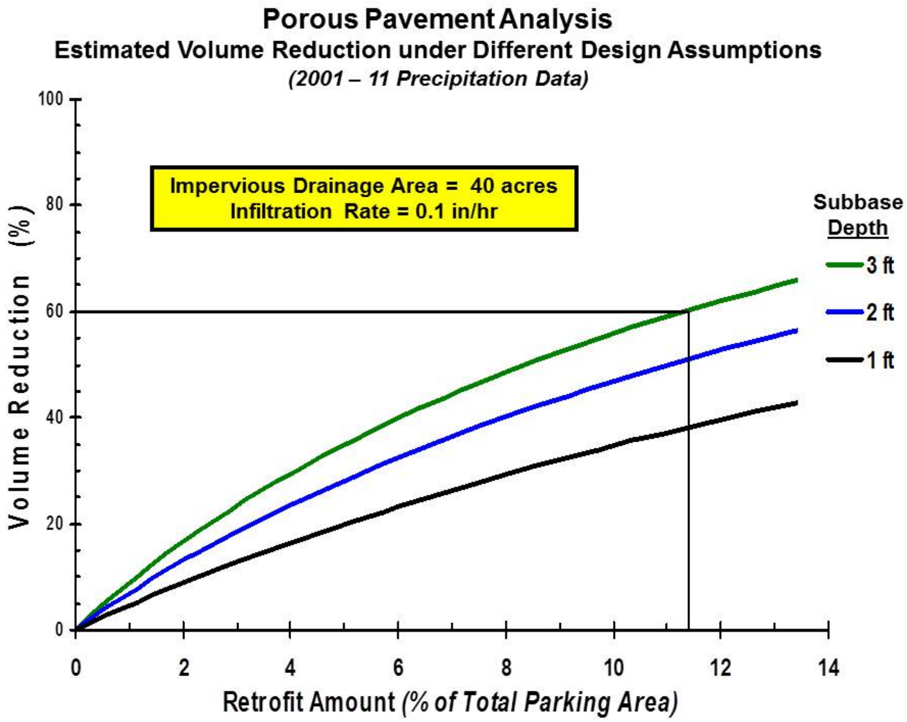

Figure 7-13. Porous pavement volume reduction at varying levels of implementation and media depths.

One objective of the reasonable assurance assessment is to show that WLAs and LAs in the TMDL are not based on overly generous assumptions regarding the amount of phosphorus reductions that will occur. The group C screening analyses demonstrate there are multiple ways to achieve reductions needed to meet WLAs identified in the TMDL. Load reductions needed to achieve LAs identified in the TMDL will be met through stream restoration projects that have been and will continue to be led by MCWD.

In addition, efforts to control stormwater volume in the TMDL study area will ensure that stream restoration efforts will be even more effective in reducing in-channel total phosphorus loads. This is because the magnitude and duration of peak flows that erode, scour, and transport phosphorus in channel related sediment will also be reduced.

Finally, the curves generated in the screening analysis provide a tool that can be used to support advanced planning efforts. The curves define a relative range of volume (or pollutant) reductions that might be expected using BMP configurations of interest. However, ultimate BMP performance is driven by design specifications determined through actual field measurements.

7.9 Costs

A detailed analysis of the cost to implement this TMDL was not conducted. However, as a rough approximation for the Hiawatha phosphorus TMDL one can use some general results from BMP cost studies across the U.S. For example, a USEPA summary of several studies of predominantly developed urban landscapes showed a median cost of approximately $2,200 per pound total phosphorus removed per year (Foraste et.al., 2012). Multiplying that by the needed 1907 pound reduction provides a total cost of approximately $4M. Bacteria cost estimates are even more difficult to generate due to a lack of cost and BMP efficacy analysis for this parameter in the stormwater field. However, TMDL studies in Minnesota with similar sized urban watersheds estimate TMDL implementation in the range of $2-5M.

8. Public Participation

Public participation opportunities were provided during the project in the form of public meetings and information on MCWD's website. Specific project meetings included:

- July 22, 2009 – Project "kick-off" meeting to discuss TMDL process for addressing §303(d) listed impairments in Minnehaha Creek and Lake Hiawatha; review projects goals, background, available data, and timeline for the project; and identify additional information and tools that can support overall effort.
- April 28, 2010 – Stakeholder meeting to provide update on project status, present overview of draft TMDL Source Assessment for questions / feedback, and discuss TMDL implementation issues related to stormwater management.
- April 12, 2012 – Stakeholder meeting to provide update on project status and present overview of draft TMDL Linkage Analysis for questions / feedback.
- June 7, 2012 – Stakeholder meeting to discuss TMDL allocation options for questions / feedback.
- September 27, 2012 – Stakeholder meeting to discuss TMDL allocation options following feedback from June 2012 meeting.
- April 16, 2013 – Stakeholder meeting to present preliminary review draft TMDL document.

The following project partners and stakeholders were invited at various stages to provide input into the project approach and to review draft documents:

- Board of Water and Soil Resources
- City of Edina
- City of Hopkins
- City of Minneapolis
- City of Minnetonka
- City of Plymouth
- City of St. Louis Park
- City of Wayzata
- City of Richfield
- City of Golden Valley
- Hennepin County
- Metropolitan Council Environmental Services
- Minneapolis Park & Recreation Board
- Minnesota Department of Transportation

The draft TMDL report was placed on public notice from August 12 to September 11, 2013, for public review and comment.

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