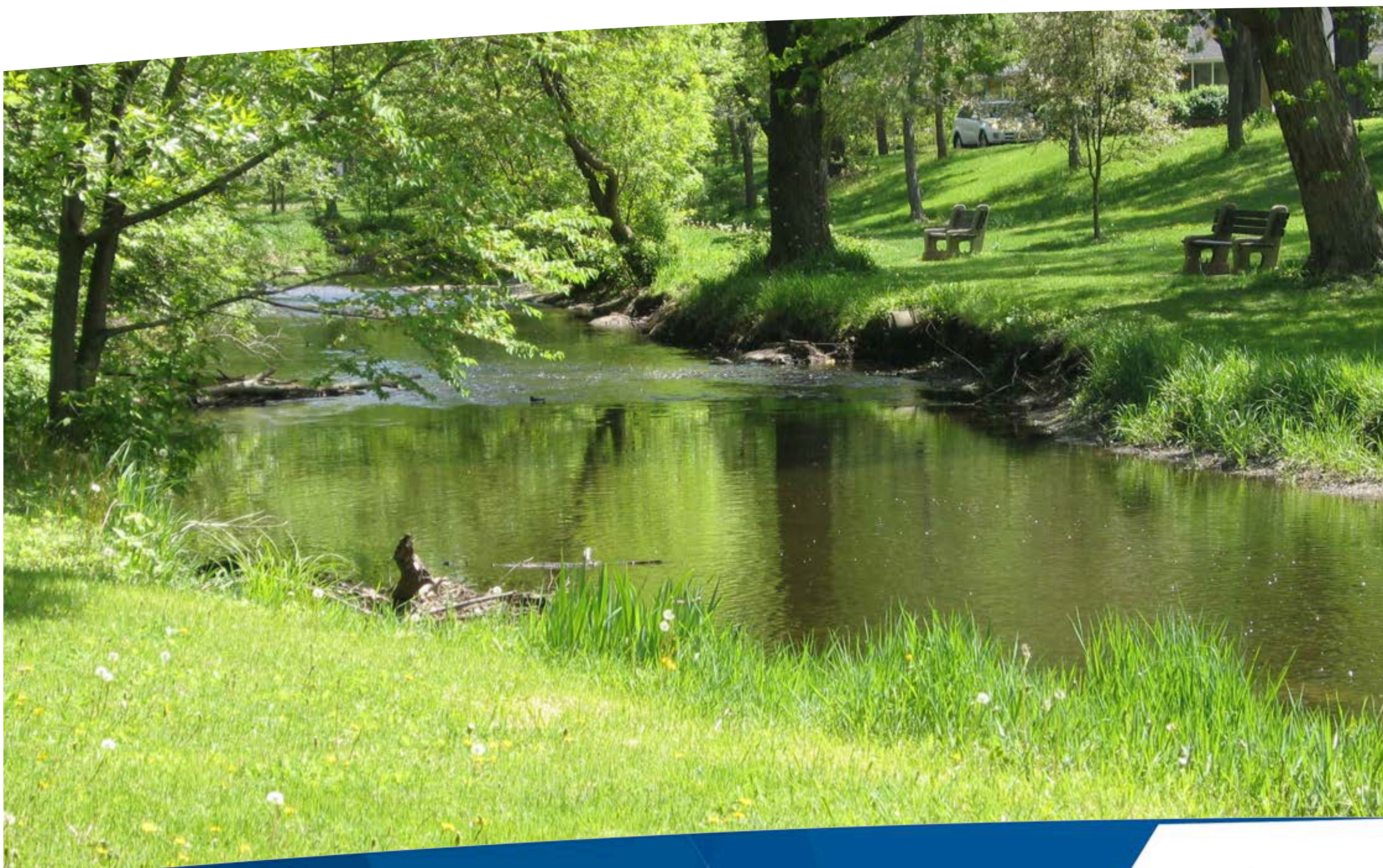
Comprehensive Water Quality Assessment of Select Metropolitan Area Streams

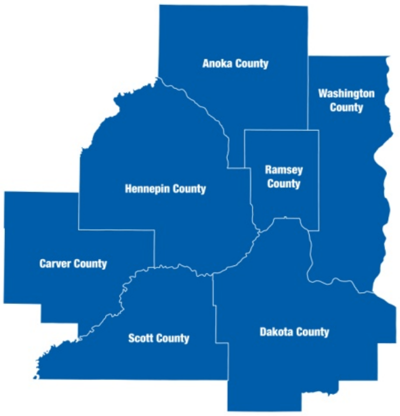
MINNEHAHA CREEK



METROPOLITAN COUNCIL

December 2014

The Council's mission is to foster efficient and economic growth for a prosperous metropolitan region.



The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system, collects and treats wastewater, coordinates regional water resources, plans and helps fund regional parks, and administers federal funds that provide housing opportunities for low- and moderate-income individuals and families. The 17-member Council board is appointed by and serves at the pleasure of the governor.

This publication printed on recycled paper.

On request, this publication will be made available in alternative formats to people with disabilities. Call Metropolitan Council information at 651-602-1140 or TTY 651-291-0904.

About the Study

The Twin Cities metropolitan area has a wealth of streams that traverse its landscape and ultimately flow into one of its three major rivers – the Mississippi, the Minnesota, and the St. Croix. These streams provide rich habitat for aquatic life and wildlife and enhance the recreational and aesthetic value of the metro area.

The Metropolitan Council is committed to the conscientious stewardship of the region's streams and works with its partners to maintain and improve their health and function. The foundation for these efforts is the collection and analysis of high-quality data about their condition over time.

The *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams* is a major study conducted by the Metropolitan Council that examines the water quality of 21 streams or stream segments that discharge into the metropolitan area's major rivers. The study provides a base of technical information that can support sound decisions about water resources in the metro area − decisions by the Council, state agencies, watershed districts, conservation districts, and county and city governments.

All background information, methodologies, and data sources are summarized in *Introduction and Methodologies*, and a glossary and a list of acronyms are included in *Glossary and Acronyms*. Both of these, as well as individual sections for each of the 21 streams, are available for separate download from the report website. The staff of Metropolitan Council Environmental Services (MCES) and local cooperators conducted the stream monitoring work, while MCES staff performed the data analyses, compiled the results and prepared the report.

About This Section

This section of the report, *Minnehaha Creek*, is one in a series produced as part of the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams.* Located in Carver and Hennepin counties, Minnehaha Creek is one of the eight Mississippi River tributaries examined. This section discusses a wide range of factors that have affected the condition and water quality of Minnehaha Creek.

Cover Photo

The photo on the cover of this section depicts Minnehaha Creek along Minnehaha Creek Parkway in Minneapolis, Minnesota.

Recommended Citations

Please use the following to cite this section of the report:

Metropolitan Council. 2014. *Minnehaha Creek*. In *Comprehensive water quality assessment of select metropolitan area streams*. St. Paul: Metropolitan Council.

Please use the following to cite the entire report:

Metropolitan Council. 2014. *Comprehensive water quality assessment of select metropolitan area streams*. St. Paul: Metropolitan Council.

Content

Figures

Tables

Introduction

Minnehaha Creek is located in the west-central part of the metropolitan area and is a tributary to the Mississippi River. It drains 169.5 square miles of wetland, forest, grasses, agricultural, and urban areas (cities of Saint Bonifacius, Victoria, Mound, Shorewood, Orono, Excelsior, Medina, Long Lake, Deephaven, Woodland, Wayzata, Minnetonka, Hopkins, Saint Louis Park, Edina, Richfield, and Minneapolis) through portions of Carver and Hennepin counties.

Figure MH-1: Minnehaha Creek at 32nd Avenue, Minneapolis

This report:

- documents those characteristics of Minnehaha Creek and its watershed most likely to influence stream flow and water quality.
- presents the results from assessments of flow, water quality, and biological data.
- presents statistical assessments of trends in stream chemistry concentrations.
- draws conclusions about possible effects of landscape features, climatological changes, and human activities on flow and water quality.
- compares Minnehaha Creek flow and water quality with other streams within the metropolitan area monitored by Metropolitan Council Environmental Services (MCES).
- makes general recommendations for future monitoring and assessment activities, watershed management, and other potential actions to remediate any water quality or flow concerns.

MCES plans to update this report approximately every five to 10 years, in addition to issuing annual data summary reports.

Partnerships and Funding

MCES has supported water quality monitoring of Minnehaha Creek since 1999 as part of its Watershed Outlet Monitoring Program (WOMP). Funding for this site is provided by the Minnesota Legislature through a Clean Water Fund grant from the Minnesota Pollution Control Agency (MPCA).

MCES partnered with the Minneapolis Park and Recreation Board to operate the Minnehaha Creek monitoring station through June 2012. Subsequently, MCES assumed the sample collection, maintenance, and operation of this site. At the end of the 2013, MCES formed a partnership with the Minnehaha Creek Watershed District (MCWD) and the U.S. Geological Survey (USGS) to jointly continue the monitoring of this stream.

Monitoring Station Description

The MCES monitoring station was located on Minnehaha Creek at 32nd Avenue in Minneapolis, Minnesota. The location is 1.7 miles upstream from the creek confluence with the Mississippi River. During the winter, the stream is often frozen solid with minimal to no flow observed under the ice.

The monitoring station equipment included continuous flow monitoring (Design Analysis H350/H355 Bubbler), baseflow grab-sample collection, event-based composite sample collection (Hach Sigma Sampler), and on-site conductivity and temperature probes (Campbell Scientific Inc.). When possible, MCES performed annual dye tests to confirm water velocities at the monitoring site. The final flow record is often compared to the flows recorded at the USGS site 05289800, at Hiawatha Avenue, to ensure accuracy and consistency. There is no rain gage at the MCES station; however, daily precipitation data for this location is obtained either from the Minnesota Climatology Working Group, MSP airport Station Number 215435, or from the USGS site.

In 2014, MCWD started to collect open water grab samples (March – November) at their Hiawatha Ave. station. In addition, the USGS monitored flow and collected event samples at their station, also located at Hiawatha Ave. Please see our cooperators' websites for a more descriptive explanation of collection methods and equipment.

Daily precipitation totals from this station were used to create the hydrograph in the ***Hydrology*** section of this report. For the analysis of precipitation-weighted loads, MCES used the Minnesota Climatological Working Group's monthly 10-kilometer gridded precipitation data to ensure that the variability of rainfall within the watersheds was represented (Minnesota Climatology Working Group, 2013). This data is generated from Minnesota's HIDEN (High Spatial Density Precipitation Network) dataset. The gridded data was aerially weighted based on the watershed boundaries.

Stream and Watershed Description

The Minnehaha Creek watershed lies inside Hennepin and Carver counties and has a drainage area of 169.5 square miles. The watershed headwaters originate in the area surrounding Lake Minnetonka, which includes 22 smaller lakes, and is identified by the MCWD as the Upper Watershed. The outlet from Lake Minnetonka at Gray's Bay flows through a headwater control structure that was originally built in 1897, and most recently updated in 1979. The outfall from the control structure provides the flow that forms Minnehaha Creek.

After leaving Lake Minnetonka, Minnehaha Creek flows to the east for 22 miles before it discharges into the Mississippi River north of Fort Snelling in Minneapolis. This section of the watershed is called the Lower Watershed by MCWD, and it connects the lakes, parks, and recreational space in southwestern Minneapolis. The Lower Watershed area contributes most of the stream's annual loading into the Mississippi River.

The watershed includes portions of the cities of Victoria, Chanhassen, Minnetrista, Independence, Maple Plain, Medina, Plymouth, Minnetonka, Hopkins, Edina, Golden Valley, Minneapolis, and Richfield: the majority of Shorewood, Deephaven, and St. Louis Park; and all of St. Bonifacius, Mound, Spring Park, Minnetonka Beach, Tonka Bay, Excelsior, Greenwood, Orono, Long Lake, Wayzata, and Woodland. A portion of the Minneapolis-St. Paul International Airport also drains to Minnehaha Creek. Since the Minnehaha Creek watershed is located in the seven-county metropolitan area, it falls within the Metropolitan Council's jurisdiction (Council Districts 1, 3, 4, 5, 6, 7, and 8).

In addition to Minnehaha Creek, there are many other open water bodies within the watershed. The largest is Lake Minnetonka (14,206 acres), located in the Upper Watershed. Other lakes in the western section of the watershed include Christmas Lake (267 acres), Lake Minnewashta (677 acres), Lake Katrina (243 acres), Lake Gleason (165 acres), and many others. In the Lower Watershed, Minnehaha Creek receives discharge from the Minneapolis Chain of Lakes − Lake Harriet (341 acres), Lake Calhoun (419 acres), Cedar Lake (164 acres), and Lake of the Isles (112 acres) − and Lake Nokomis (201 acres). The creek flows through the south end of Lake Hiawatha (53 acres). Another notable water body is the Coldwater Spring located in the southeast part of the watershed. For more information about lakes in the Minnehaha Creek Watershed, please see the Lake Finder website from the Minnesota Department of Natural Resources (MnDNR, 2014).

The Minnehaha Creek watershed encompasses a total of 108,985 acres, of which 108,518 acres (99.6%) are upstream of the monitoring station. The watershed has 40.2% developed urban land (40.1% of the monitored area) and 6.7% agricultural land (6.7% of the monitored area). According to the U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) 2009 Cropland Data Layer, 22% of the agricultural land is planted in corn and 20% in soybeans, all within the monitored portion of the watershed. According to a statewide estimate of potentially draintiled fields by University of Minnesota researchers (D. Mulla, University of Minnesota, personal communication, 2012), 7% of the agricultural land in the monitored watershed is potentially draintiled.

The watershed is 18.4% open water, with the majority of that area covered by Lake Minnetonka in the western portion of the watershed. Land cover in the watershed progresses from less developed in the western upstream portion of the watershed, to heavily urbanized in the eastern downstream portion of the watershed. Other primary land covers in the watershed are forest, grasses/herbaceous, and wetlands. Table MH-1 and Figure MH-2 show the watershed area by land cover.

The geologic history of a watershed dictates the surface topography and the soil and hydrologic properties. The Minnehaha Creek watershed was last glaciated during the Wisconsin Glaciation, approximately 13,000 years BP (MCWD, 2007). Four distinct surface formations are apparent in the Minnehaha Creek watershed. Three moraines were formed in the watershed around Lake Minnetonka: the Emmons-Faribault, the Eastern St. Croix, and the Waconia-Waseca Moraines. The western portion of the watershed is a till plain, called the Lonsdale-Lerdal Till Region, and the Lower Watershed can be described as a glacial outwash plain. A notable subsurface formation in the Lower Watershed is an ancient river valley which underlies the Minneapolis Chain of Lakes (Brownie Lake, Cedar Lake, Lake of the Isles, and Lake Calhoun) and connects the aquifers of the Platteville, St. Peter, Prairie du Chien, and Jordan sandstones under Minneapolis (Wright, 1990).

Table MH-1: Minnehaha Creek Land Cover Classes[1]

Land Cover Class	Monitored		Unmonitored		Total	
	Acres	Percent	Acres	Percent	Acres	Percent
5-10% Impervious	2,008	1.9%	5	1.1%	2,013	1.8%
11-25% Impervious	6,178	5.7%	1	0.2%	6,179	5.7%
26-50% Impervious	14,301	13.2%	0	0.0%	14,301	13.1%
51-75% Impervious	12,523	11.5%	181	38.8%	12,704	11.7%
76-100% Impervious	8,469	7.8%	125	26.9%	8,594	7.9%
Agricultural Land	7,287	6.7%	0	0.0%	7,287	6.7%
Forest (all types)	12,579	11.6%	45	9.6%	12,624	11.6%
Open Water	20,050	18.5%	6	1.3%	20,056	18.4%
Barren Land	0	0.0%	0	0.0%	0	0.0%
Shrubland	123	0.1%	0	0.0%	123	0.1%
Grasses/Herbaceous	11,474	10.6%	86	18.5%	11,561	10.6%
Wetlands (all types)	13,526	12.5%	17	3.6%	13,543	12.4%
Total	**108,518**	**100.0%**	**467**	**100.0%**	**108,985**	**100.0%**

[1] Land cover spatial data file provided by MnDNR. The data is a composite of the 2008 MLCCS (Minnesota Land Cover Classification System), which covered primarily the 7-county metro area; and the 2001 NLCD (National Land Cover Data), which covered the outstate areas not included in the 2008 MLCCS.

The topography of the watershed is greatly influenced by the glacial formations (Figure MH-3). The moraines help form the rolling hills throughout the Upper Watershed. The Lower Watershed is primarily a flat glacier outwash plain with some terraces, before the creek goes over Minnehaha Falls and into the Mississippi River. The maximum watershed elevation is 1122.7 MSL and the minimum elevation is 808.6 MSL. Within the monitored area 4% of the slopes are considered steep, and an additional 1% is considered very steep. Steep slopes are those of 12-18%, and very steep slopes are those 18% or greater (MnDNR 2011).

According to the USDA Natural Resources Conservation Service (NRCS) STATSGO soils data, the majority of native soils in the watershed are predominately Type A (5%) and B (83%) soils, which have low to moderately low runoff potential. The Lower Watershed soils are difficult to quantify because the majority of the soils in this portion of the watershed have been greatly impacted by urban development, thus the STATSGO soil survey may not be representative of actual conditions. For installation of infiltration practices, soil borings should be taken from the exact location of the proposed site location to assess level of soil filling or disturbance.

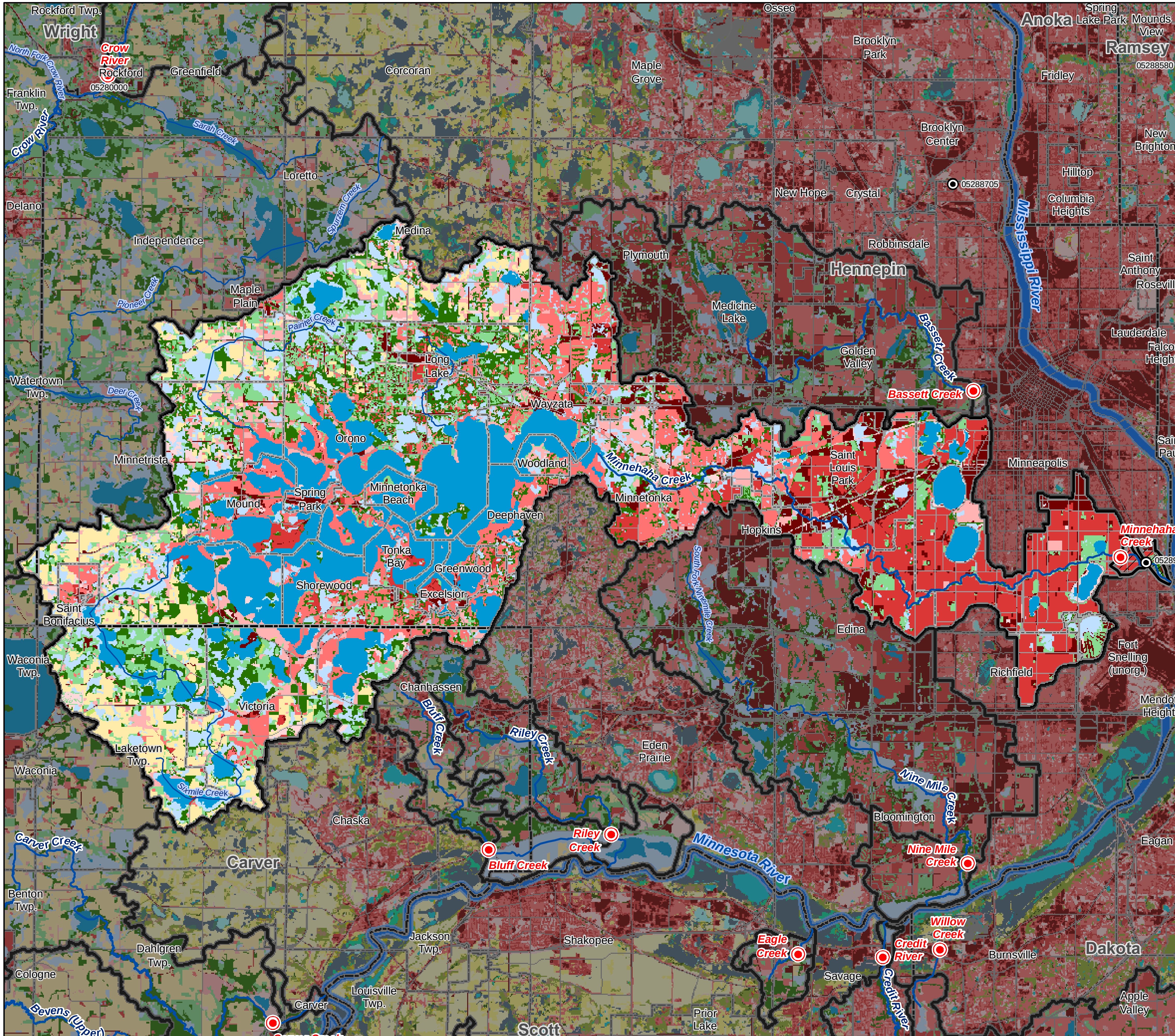


Figure MH-2

METROPOLITAN COUNCIL

MLCCS-NLCD Hybrid Land Cover

Minnehaha Creek

- MCES Stream Monitoring Sites
- USGS Flow Stations
- Mainstems (Monitored and Unmonitored)
- Major Mainstem Tributaries
- Monitored Watershed Boundaries
- Unmonitored Portion of Watersheds
- Highways and Other Major Roads (NCompass, 2012)
- County Boundary
- City and Township Boundaries

MLCCS-NLCD Hybrid Land Cover

- 5-10% Impervious
- 11-25% Impervious
- 26-50% Impervious
- 51-75% Impervious
- 76-100% Impervious
- Agricultural Land
- Barren Land (rock, mud)
- Forest (all types)
- Grasses/Herbaceous
- Open Water
- Shrubland
- Unknown, or No Data
- Wetlands (open water, forest, shrub and emergent)

Data Source: MnDNR

MLSSC/NLCD Hybrid Land Cover
Minnehaha Creek

Land Cover Class	Monitored Acres	Monitored Percent	Unmonitored Acres	Unmonitored Percent	Total Acres	Total Percent
5-10% Impervious	2,008	1.9%	5	1.1%	2,013	1.8%
11-25% Impervious	6,178	5.7%	1	0.2%	6,179	5.7%
26-50% Impervious	14,301	13.2%	0	0.0%	14,301	13.1%
51-75% Impervious	12,523	11.5%	181	38.8%	12,704	11.7%
76-100% Impervious	8,469	7.8%	125	26.9%	8,594	7.9%
Agricultural Land	7,287	6.7%	0	0.0%	7,287	6.7%
Forest (all types)	12,579	11.6%	45	9.6%	12,624	11.6%
Open Water	20,050	18.5%	6	1.3%	20,056	18.4%
Barren Land	0	0.0%	0	0.0%	0	0.0%
Shrubland	123	0.1%	0	0.0%	123	0.1%
Grasses/Herbaceous	11,474	10.6%	86	18.5%	11,561	10.6%
Wetlands (all types)	13,526	12.5%	17	3.6%	13,543	12.4%
Total	**108,518**	**100.0%**	**467**	**100.0%**	**108,985**	**100.0%**

0 1 2 3 4 5 6 7 8

Miles

The Minnehaha Creek watershed is a large watershed and it contains a number of permitted dischargers (see Figure MH-4), including:

- One domestic wastewater treatment plant,
- Nine cooling, potable, treatment and dewatering facilities,
- Five industrial wastewater permit holders,
- 15 industrial stormwater permit holders

The Laketown Community WWTP is a Class D facility with a designed flow of 0.004 MGD. It is in the Upper Watershed, and likely does not affect the water quality of Minnehaha Creek. All permit holders are located within the monitored part of the watershed.

Table MH-2: Permitted Domestic Wastewater Treatment Facilities Discharging to Minnehaha Creek

Permit #	Permit Holder	Design Flow (mgd)	Class	Phosphorus removal[1]	General Notes[1]
MN0054399	Laketown Community WWTP	0.004	D	NA	NA

[1] Information provided by MPCA, April 2013. Information was not tabulated for smallest facilities, and thus labeled “NA.”

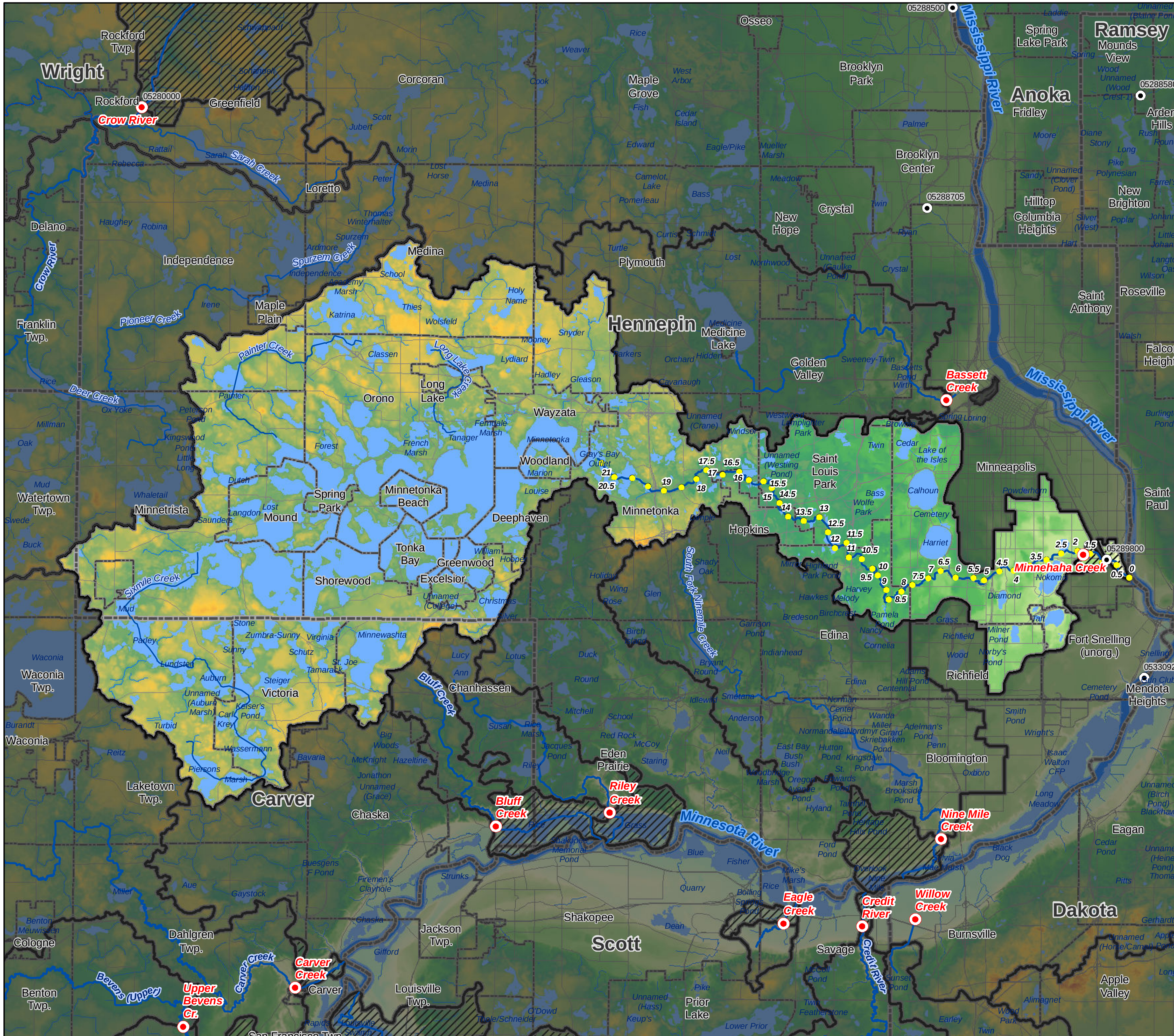
The Minnehaha Creek watershed has 17 registered feedlots, with a total of 2,883 animal units (AUs), all within the monitored part of the watershed. Four of the feedlots in the monitored area have 100 or more AUs, all in the Upper Watershed, and likely do not affect the water quality of Minnehaha Creek. The largest feedlot is a pig farm with 4,420 AUs.

Figure MH-3

METROPOLITAN COUNCIL

Watershed Topography

Minnehaha Creek



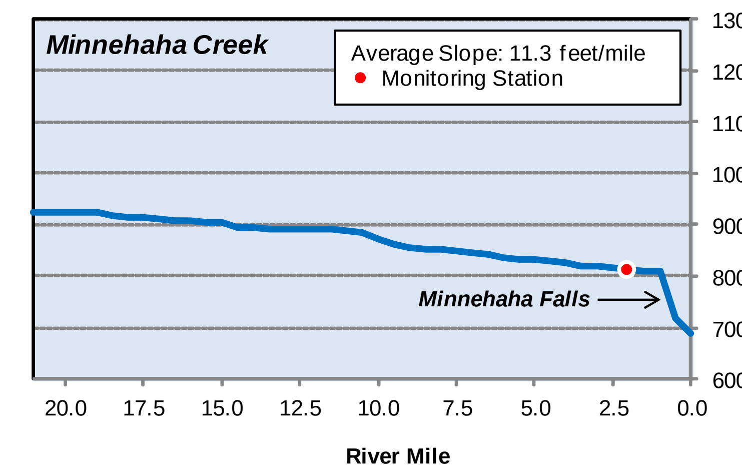
- MCES Stream Monitoring Sites
- USGS Flow Stations
- Stream Mile Markers
- Mainstems (Monitored and Unmonitored)
- Monitored Watershed Boundaries
- Unmonitored Watershed Areas
- County Boundary
- City and Township Boundaries
- Highways and Other Major Roads
- Public Waters Inventory
- Other Rivers and Streams

Elevation
Feet Above Mean Sea Level

High : 1594
1400
1200
1000
800
Low : 643

Source: USGS National Elevation Dataset, 1/3 arc-second, 10-meter resolution

Mainstem Elevation (Feet Above Mean Sea Level)



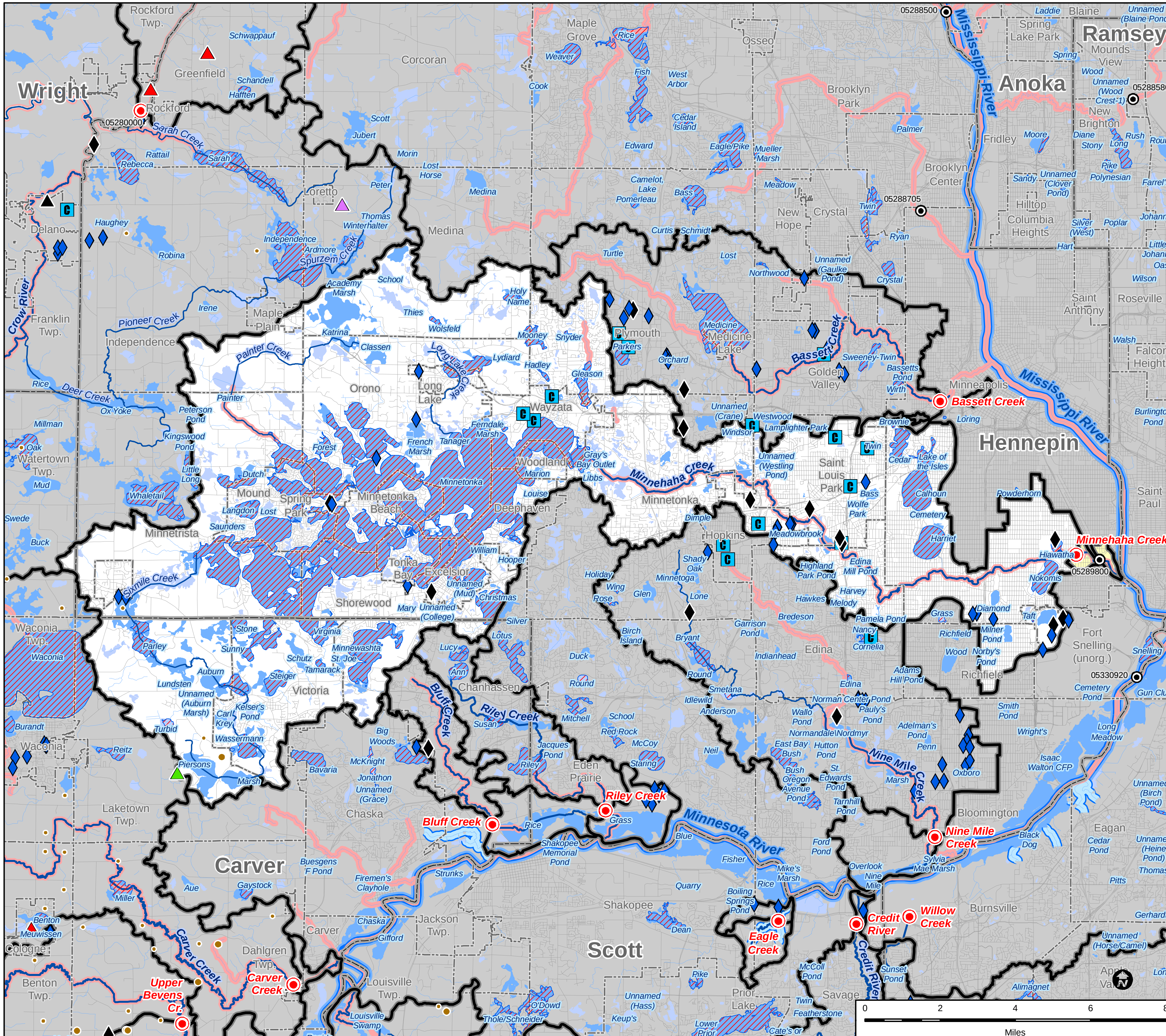
0 2 4 6 8
Miles

Figure MH-4

METROPOLITAN COUNCIL

Public and Impaired Waters and Potential Pollution Sources

Minnehaha Creek



- MCES Stream Monitoring Sites
- USGS Flow Stations
- Mainstems (Monitored and Unmonitored)
- Monitored Watershed Boundaries
- Unmonitored Portion of Watersheds

Industrial Discharges **

- Industrial Stormwater
- Industrial & Individual Wastewater
- Cooling, Potable Treatment & Dewatering

Domestic Wastewater Discharges **

- Class A
- Class B
- Class C
- Class D
- Class Unknown

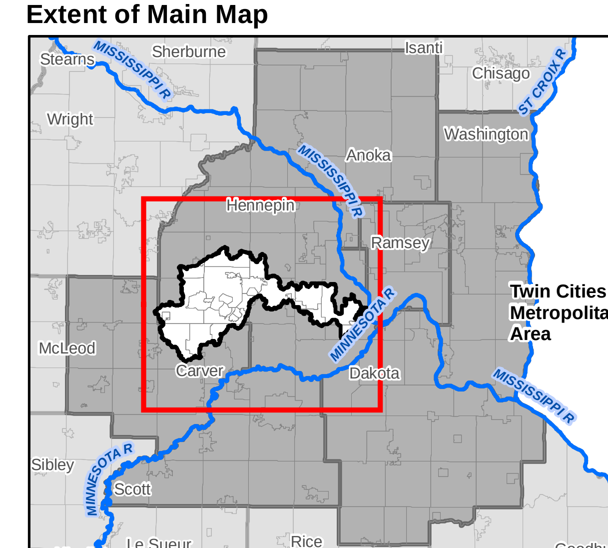
Feedlots with 100 or more animal units **

- 100 - 249
- 250 - 499
- 500 - 999
- 1000 or more

- Impaired Lakes (2014 Draft MPCA 303(d) List) **
- Impaired Streams (2014 Draft MPCA 303(d) List) **
- Other Rivers and Streams *
- Lakes and Other Open Water (PWI) *
- Wetlands (PWI) *
- Designated Trout Streams *
- NCompass Street Centerlines, 2013
- County Boundary
- City and Township Boundaries

Data Sources: * MN DNR, ** MPCA, *** MN DOT

Extent of Main Map



Water Quality Impairments

The Minnehaha Creek watershed includes five streams that are included on the MPCA 2014 303d (Impaired Waters) list (Figure MH-4, Table MH-3). Minnehaha Creek was originally impaired for fecal coliform; however, since the listing, the U.S. Environmental Protection Agency (USEPA) and MPCA shifted their impairment standards to using *E. coli* as the bacterial indicator. The change has resulted in a need for an *E. coli* TMDL instead of a fecal coliform TMDL. The MCWD has prepared TMDLs to address the *E. coli* impairments in each stream (Tetra Tech, Inc., 2013; Wenck and Associates, Inc., 2013). The Painter Creek TMDL is currently in review by the USEPA. The Minnehaha Creek bacteria TMDL was approved by the USEPA in 2014.

Table MH-3: Impaired Reaches Minnehaha Creek Watershed as Identified on the MPCA 2014 Impaired Waters List

Reach Name	Reach Description	Reach ID	Affected Use(s)[1]	Approved Plan	Needs Plan[2]
Diamond Creek	Headwaters (French Lake to unnamed lake)	07010206-525	AQR, AQL	--	M-IBI, F-IBI, *E. coli*, DO
Minnehaha Creek	Lake Minnetonka to Mississippi River	07010206-539	AQR, AQL	Bacteria	Cl, F-IBI, DO, M-IBI
Painter Creek	Unnamed creek to Lake Minnetonka	07010206-700	AQR	--	*E. coli*
Unnamed Creek	Unnamed creek to Gleason Lake	07010206-704	AQL	--	Cl
Unnamed Creek	Headwaters to unnamed ditch	07010206-718	AQL	--	Cl

[1] AQR = Aquatic Recreation; AQL = Aquatic Life;

[2] Cl = Chloride; F-IBI = Fisheries Bioassessment; DO = Dissolved Oxygen; M-IBI = Aquatic Macroinvertebrates Bioassessment.

The Minnehaha Creek watershed has 50 lakes (all within the monitored part of the watershed) included on the MPCA 2014 303d (Impaired Waters) list (Figure MH-4, Table MH-4). These lakes are primarily in the Upper Watershed; however six lakes are in the Lower Watershed. Twenty-nine lakes have been identified as impaired for aquatic consumption due to mercury in fish tissue; all but four have been covered by the statewide TMDL addressing this concern. Two other consumption impairments have been identified in the watershed. Lake Calhoun, Lake Harriet, and Lake of the Isles have exceeded the threshold for PFOS (perfluorooctane sulfonate) concentration in fish tissue, and Lake Nokomis is impaired for PCBs (polychlorinated biphenyls) in fish tissue. Twenty-eight lakes have also been identified as impaired for aquatic recreation due to high nutrient levels or eutrophication.

The MCWD has been actively working on many TMDLs to address the elevated levels of nutrient concentrations. A TMDL involving four lakes (Lake Nokomis, Parley Lake, Lake Virginia, and Wassermann Lake) was approved by the USEPA in 2011 (Emmons & Olivier, Inc., 2011). One other TMDL (Wenck and Associates, Inc., 2013) is in the review process to address the nutrient concern for 19 other lakes. As part of the approved Lake Hiawatha TMDL (Tetra Tech, Inc., 2013), the USEPA has approved a site-specific TP standard of 50ug/l on the basis that the lake functions more like a reservoir than a true lake. Once both TMDLs are fully approved, there are five remaining lakes in the watershed without nutrient TMDLs as of the writing of this report.

Table MH-4: Impaired Lakes in the Minnehaha Creek Watershed as Identified on the MPCA 2014 Impaired Waters List

Lake Name	Lake ID	Affected Use(s)[1]	Approved Plan[2]	Needs Plan[2]	Notes
Bass	27-0015-00	AQR	--	Nutrients	Removed from list in 2014; designated a wetland.
Brownie	27-0038-00	AQC	HgF	Cl	Delisted for Nutrients in 2009.
Calhoun	27-0031-00	AQC	--	HgF, PFOS, Cl	--
Cedar	27-0039-00	AQC	--	HgF	--
Christmas	27-0137-00	AQC	HgF	--	--
Dutch	27-0181-00	AQR	--	Nutrients	--
East Auburn	10-0044-02	AQR	--	Nutrients	--
Forest	27-0139-00	AQR	--	Nutrients	--
Gleason	27-0095-00	AQR	--	Nutrients	--
Hadley	27-0109-00	AQR	--	Nutrients	--
Harriet	27-0016-00	AQC	--	HgF, PFOS	--
Hiawatha	27-0018-00	AQR	Nutrients	Cl	--
Holy Name (Hausman)	27-0158-00	AQR	--	Nutrients	--
Katrina	27-0154-00	AQR	--	Nutrients	Removed from list in 2014; designated a wetland.
Lake of the Isles	27-0040-00	AQC	HgF	PFOS	--
Langdon	27-0182-00	AQR	--	Nutrients	--
Long	27-0160-00	AQC, AQR	HgF	Nutrients	--
Minnetonka (Black Lake)	27-0133-06	AQC	HgF	--	--
Minnetonka (Carsons Bay)	27-0133-03	AQC	HgF	--	--
Minnetonka (Crystal Bay)	27-0133-10	AQC	HgF	--	--
Minnetonka (Emerald Lake)	27-0133-08	AQC	HgF	--	--
Minnetonka (Grays Bay)	27-0133-01	AQC	HgF	--	--
Minnetonka (Halsteds Bay)	27-0133-09	AQC,	HgF	Nutrients	--

		AQR			
Minnetonka (Jennings Bay)	27-0133-15	AQC, AQR	HgF	Nutrients	--
Minnetonka (Lower Lake)	27-0133-02	AQC	HgF	--	--
Minnetonka (Maxwell Bay)	27-0133-11	AQC	HgF	--	--
Minnetonka (North Arm)	27-0133-13	AQC	HgF	--	--
Minnetonka (Seton Lake)	27-0133-07	AQC	HgF	--	--
Minnetonka (St. Albans Bay)	27-0133-04	AQC	HgF	--	--
Minnetonka (Stubbs Bay)	27-0133-12	AQC, AQR	HgF	Nutrients	--
Minnetonka (Upper Lake)	27-0133-05	AQC	HgF	--	--
Minnetonka (West Arm)	27-0133-14	AQC, AQR	HgF	Nutrients	--
Minnewashta	10-0009-00	AQC	HgF	--	--
Mooney	27-0134-00	AQR	--	Nutrients	--
Mud	27-0816-00	AQR	--	Nutrients	Removed from list in 2014; designated a wetland.
Nokomis	27-0019-00	AQC, AQR	HgF, Nutrients	PCBF	--
Parley	10-0042-00	AQR	Nutrients	--	--
Peavey	27-0138-00	AQR, AQL	--	Nutrients, Cl	--
Powderhorn	27-0014-00	AQL	HgF	Cl	--
Snyder	27-0108-00	AQR	--	Nutrients	--
Steiger	10-0045-00	AQC	--	HgF	--
Stone	10-0056-00	AQR	--	Nutrients	--
Taft	27-0683-00	AQL	--	Cl	--
Tamarack	10-0010-00	AQR	--	Nutrients	--
Tanager	27-0141-00	AQR	--	Nutrients	--
Turbid	10-0051-00	AQR	--	Nutrients	--
Twin	27-0656-00	AQR	--	Nutrients	--
Unnamed (Cobblecrest)	27-0053-00	AQR	--	Nutrients	--
Virginia	10-0015-00	AQC, AQR	HgF, Nutrients	--	--
Wassermann	10-0048-00	AQC, AQR	HgF, Nutrients	--	--

Windsor	27-0082-00	AQR	--	Nutrients	--
Wolsfeld	27-0157-00	AQR	--	Nutrients	--
Zumbra-Sunny	10-0041-00	AQC	HgF	--	--

[1] AQC = aquatic consumption; AQL= aquatic life; AQR = aquatic recreation

[2] HgF = mercury in fish tissue; PFOS = perfluorooctane sulfonate in fish tissue; PCBF = PCB in fish tissue

Hydrology

MCES has monitored flow on Minnehaha Creek at 32nd Avenue in Minneapolis since 1999. Flow measurements are collected at 15-minute intervals and converted to daily averages. The hydrograph of Minnehaha Creek, which displays daily average flow, daily precipitation, and the flow associated with grab and composite samples, indicates the variations in flow rates from season to season and from year to year (Figure MH-6), and the effect of precipitation events on flow.

The MCES sampling program specifies collection of baseflow grab samples between events and event-based composites. The hydrograph indicates samples were collected during most events and that baseflow was also adequately sampled.

The Minnehaha Creek hydrograph is not characteristic of a small, lake-fed stream system. The headwaters control structure at Gray's Bay discharges lake water only when the lake depth is higher than the Ordinary High Water (929.4 NGVD, 1929 datum (MCWD, 2014a)). This policy helps to reduce flooding for both Lake Minnetonka and Minnehaha Creek by storing the snowmelt pulse in the lake and slowly releasing the water over the course of the year. During wetter years the policy helps to sustain controlled creek flow; however, during drier years the stream flows may be greatly restricted. Nine of the last 13 years have had drought-induced no-flow periods in Minnehaha Creek (Moore et al., 2013).

The mean average daily flow of Minnehaha Creek from 1999 to 2012 was 55.8 cubic feet per second (cfs), which was substantially higher than the median average daily flow of 17.0 cfs. The difference between the mean and median average daily flows highlights the greater prevalence of lower flows in the creek. Minnehaha Creek does not maintain a year-round baseflow and freezes during the winter months or runs dry during prolonged periods with little precipitation.

Analysis of the duration of daily average flows indicates that the upper 10th percentile flows for the period 1999-2012 ranged between approximately 174 and 691 cfs, while the lowest 10th percentile flows ranged from 0 to 4 cfs (See Figure MH-13 in the ***Flow and Load Duration Curves*** section of this report).

Figure MH-5: Minnehaha Falls

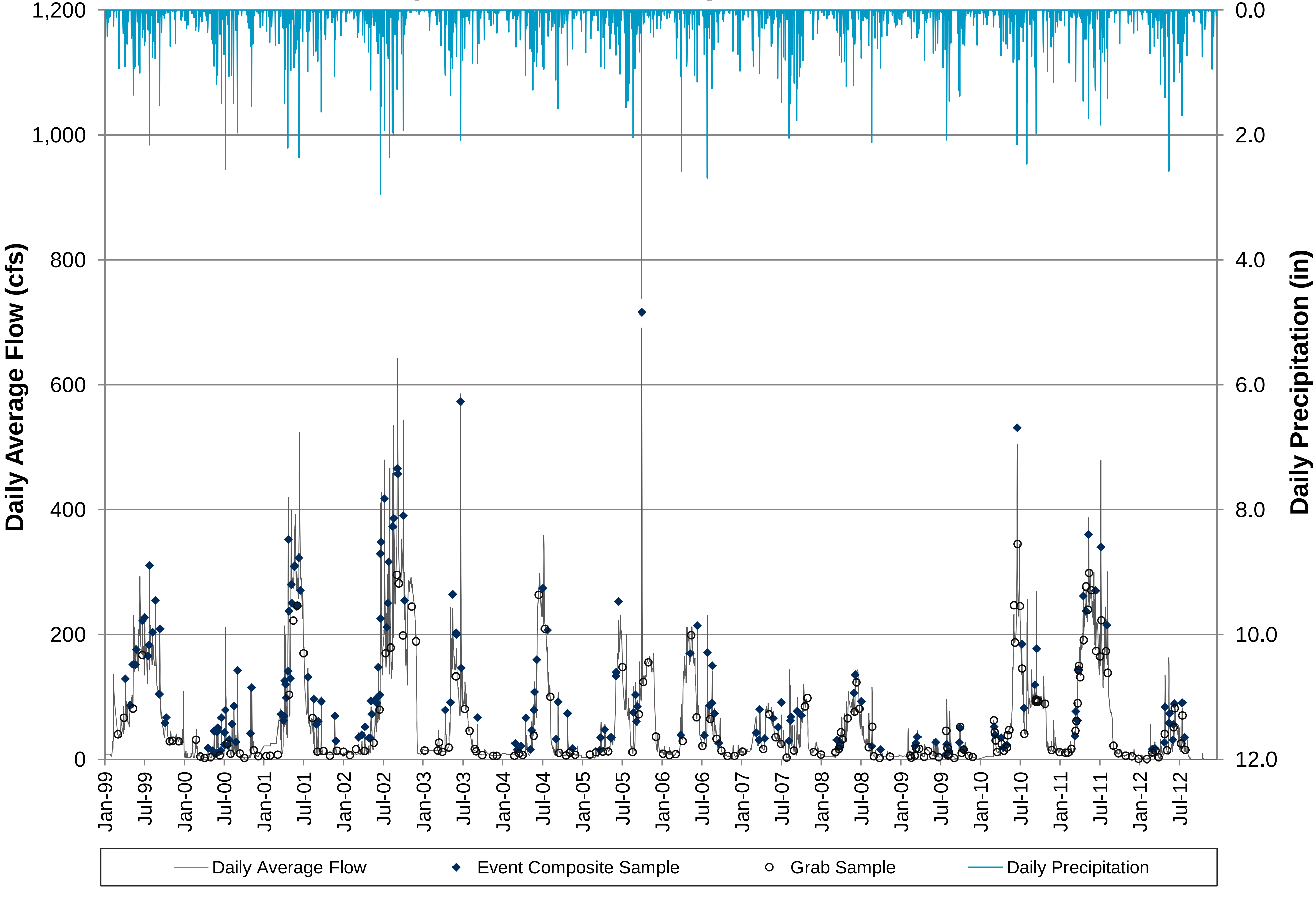
Periods of low or zero flow are not just a recent occurrence for Minnehaha Creek. Flows in the creek, or lack thereof, are subject to precipitation patterns. As early as 1900, President Benjamin Harrison said, “Minnehaha Falls would undoubtedly be very beautiful if there was water in the stream,” (Smith, 2008). The City of Minneapolis did not want to suffer another presidential disappointment when President Lyndon B. Johnson visited the falls in 1964. Prior to the president’s arrival at the falls, the City opened numerous upstream fire hydrants, which released six million gallons of municipal water into Minnehaha Creek and created a “beautiful display,” (MPRB, n.d.; Nieber, 2014).

As the primary source of water, the outflow of Lake Minnetonka at Gray’s Bay Dam is strongly correlated with Minnehaha Creek streamflow (Emmons and Olivier Resources, Inc. 2003). In 2003, Wenck and Associates (2004) estimated that 78% of the annual flow over Minnehaha Falls (Figure MH-5) was originally from Lake Minnetonka. More recently, Moore and others (2013) have estimated an average of 69% of the annual flow at the MCES monitoring site was released from Gray’s Bay Dam during 1999-2012. The remainder of the water in Minnehaha Creek is derived from stormwater channeled by storm sewers and baseflow from connected lakes (Brownie Lake , Cedar Lake, Lake of the Isles, Lake Calhoun, Lake Harriet, Lake Nokomis, and Lake Hiawatha) and from groundwater inputs.

Minnehaha Creek receives stormwater runoff from 178 sewer outflows as it runs from Lake Minnetonka to the Mississippi River (Wenck and Associates, 2004). These stormwater inputs account for 18% of the flow at the MCES monitoring station (Moore et al., 2013) and create significant, sudden responses in the Minnehaha Creek hydrograph. The creek’s Flashiness Index was calculated as 0.5, which is twice as expected for a watershed of its size (Nieber, 2014). Generally, the storm event daily average flows were less than 500 cfs; 10 spring rains or snowmelt-driven events exceeded this in the 13 years during 1999-2012. Of those events, the highest recorded daily average flow in Minnehaha Creek, 691.1 cfs, occurred in 2005.

The baseflow contributions from connected lakes and groundwater account for 13% of the flows at the MCES station, with the groundwater component more pronounced during snowmelt and early summer (Moore et al., 2013). Broadly, the groundwater enters the stream from Lake Minnetonka to near St. Louis Park (the gaining reach), and the creek water infiltrates the groundwater between St. Louis Park and the Mississippi River (losing reach) due to differences in underlying geology (Nieber, 2014). MCWD partnered with the Mississippi Watershed Management Organization (WMO) and the University of Minnesota to identify gaining and losing reaches and to analyze potential stormwater infiltration solutions to augment baseflows (MCWD, 2014b).

Figure MH-6: Minnehaha Creek Daily Average Flow, Sample Flow, and Precipitation, 1999-2012*



*Precipitation record was acquired from NWS COOP station 215435-Minneapolis/St. Paul AP

Vulnerability of Stream to Groundwater Withdrawals

Regional analysis (Metropolitan Council, 2010) of hydrogeologic conditions in the seven-county metropolitan area suggests that some surface water features are in direct connection with the underlying regional groundwater flow system and may be impacted by groundwater pumping. While regional in nature, this analysis serves as a screening tool to increase awareness about the risk that groundwater pumping may have for surface water protection and to direct local resources toward monitoring and managing the surface waters most likely to be impacted by groundwater pumping. Additional information, including assumptions and analytical methodologies, can be found in the 2010 report.

To assess the vulnerability of Minnehaha Creek to groundwater withdrawals, MCES staff examined spatial datasets of vulnerable stream segments and basins created as part of the 2010 regional groundwater analysis. Within Hennepin and Carver counties, the majority of waterbodies in the Minnehaha Creek watershed are located at or below the water table, indicating a groundwater connection. The length of Minnehaha Creek is identified as being susceptible to groundwater pumping, and a significant number of wetlands are also susceptible to groundwater pumping.

MCES is continuing to evaluate the effects of groundwater withdrawal on surface waters, including updating analyses with the best available data and linking results to predictive groundwater modeling and the comprehensive planning process involving local communities.

Pollutant Loads

The U.S. Army Corps of Engineers program Flux32 (Walker, 1999) was used to convert daily average flow, coupled with grab and event-composite sample concentrations, into annual and monthly loads and flow-weighted mean concentrations. Loads were estimated for total suspended solids (TSS), total phosphorus (TP), total dissolved phosphorus (TDP), nitrate (NO_3), ammonia (NH_3), and chloride (Cl) for each year of monitored data in Minnehaha Creek (1999-2012). Figures MH-6 to MH-9 illustrate annual loads expressed as mass, as flow-weighted mean (FWM) concentration, as mass per unit of area (lb/ac), and as mass per unit of area per inch of precipitation (lb/ac/in), as well as two hydrological metrics (annual average flow rate and runoff ratio). A later section in this report (***Comparison with Other Metro Area Streams***) offers graphical comparison of the Minnehaha Creek loads and FWM concentrations with the other MCES-monitored metropolitan area tributaries.

The first charts in Figures MH-7 and MH-8 plot the annual flows from 1999-2012. The flow metrics indicate large year-to-year variations in annual flow rate, as expected with the variation in water released from Lake Minnetonka. The highest average annual flow, and thus the highest volume of flow, occurred during 2002 (approximately 135 cfs average annual flow); the lowest average annual flow and lowest volume of flow occurred in 2009 (approximately 10.2 cfs average annual flow). The mean average annual flow was 55.8 cfs, which is greater than the median average annual flow of 49.8 cfs, suggesting the annual mean flow was skewed by high annual flows.

The annual mass loads for all of the monitored chemistry except NH_3 exhibited significant year-to-year variation, mirroring the pattern in annual flow. The NH_3 loads did have peaks in loads when the annual flow was the high, but did not show much variation in load from 2003 to 2007, when there were distinct variations in annual flow. This indicates a greater influence of varying NH_3 concentrations on an annual basis.

The annual FWM concentrations reinforce and emphasize the observations from the annual mass loads. The TSS, TP, TDP, and NO_3 FWM concentrations fluctuated year-to-year, and were likely influenced by the frequency, magnitude, timing, and the routing of precipitation and the volume of water released from Lake Minnetonka. All four pollutants had the highest FWM concentration in the year 2000. This corresponds with the lowest recorded Minnehaha Creek annual flow and was likely due to in-stream evapoconcentration. The annual NH_3 FWM concentrations showed an inverse relationship with the annual flows. As the annual flows increased, most likely from surface water sources, NH_3 concentrations decreased. This suggests the NH_3 is derived primarily from a groundwater source.

Figures MH-9 and MH-10 present the areal- and precipitation-weighted loads, respectively. These graphics are presented to assist local partners and watershed managers, and will not be discussed here.

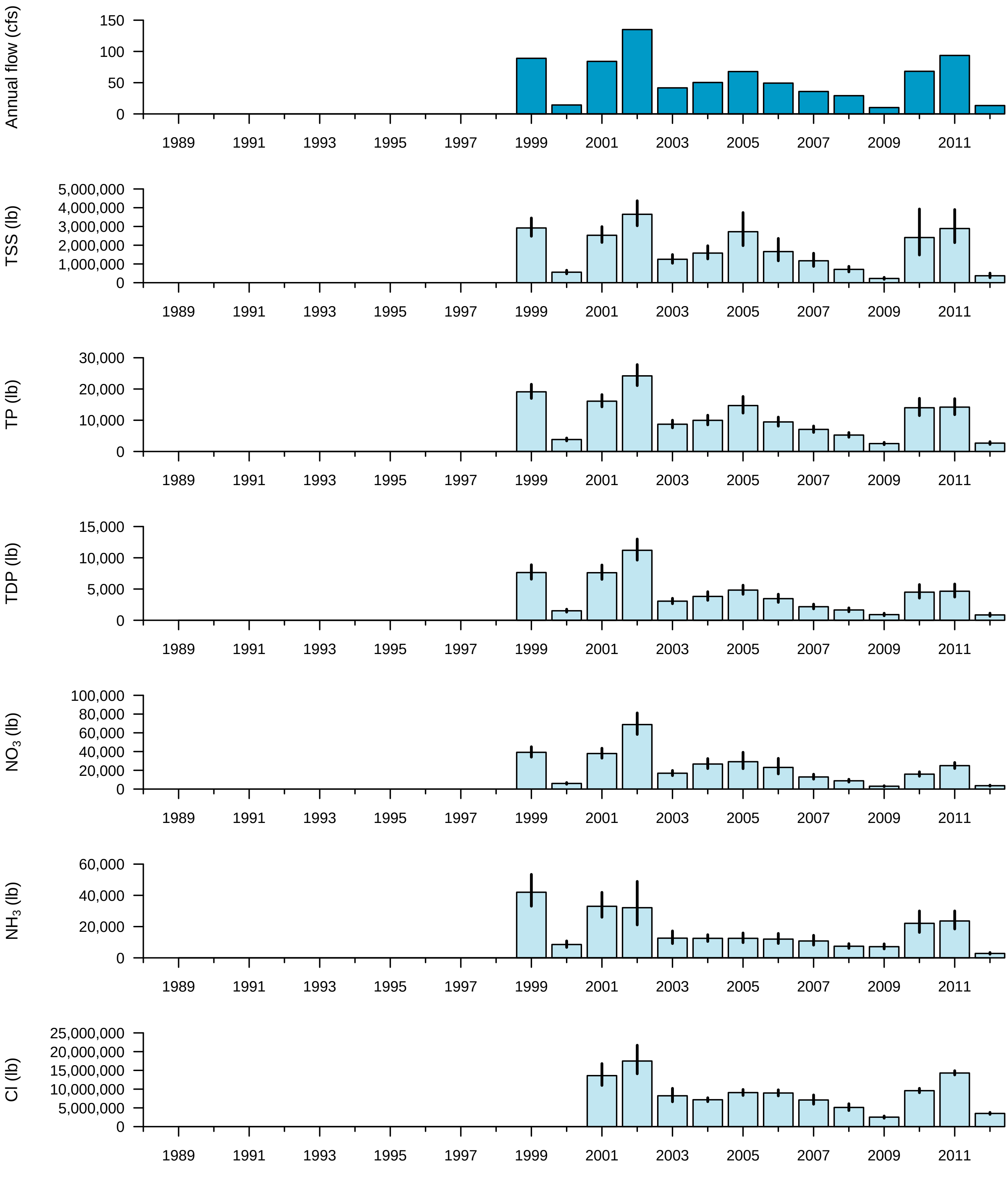
The Flux32 loads and FWM concentrations were also compiled by month to allow analysis of time-based patterns in the loads in Minnehaha Creek (Figure MH-11 and MH-12). The results for each month are expressed in two ways: the monthly results for the most recent year of data (2012 for Minnehaha Creek) and the monthly average for 2003-2012 (with a bar indicating the maximum and minimum value for that month).

It is apparent that the highest 10-year average mass loads of TSS, TP, TDP, NO_3, and Cl in Minnehaha Creek occurred in May and/or June, likely due to effects of the opening of the Gray's Bay Dam and early summer rains (Figure MH-11). According to the data on the MCWD's webpage, the average opening for the dam occurred in the end of April and the average closing occurred in the end of September (MCWD, 2014c). The 2012 open dam season, 25 May 2012-20 August 2012, was shorter than the average period, and resulted in no estimated loads from September through December, as there was no flow in the creek.

The 10-year average NH_3 mass load appeared to peak in March (snowmelt) and June, with lower loads throughout the remainder of the year. It is widely accepted that soil microbes are insulated under snow cover and accumulate large stores of NH_3 in the riparian soils (Brooks et al., 2011). A large snowmelt event may produce a large volume of water to flow over the thawed soils that flush and transport the NH_3 into the stream. It is difficult to assign a cause for the June peak in NH_3 loads. MCES should continue to monitor the creek for repetition of high early summer loads in the future.

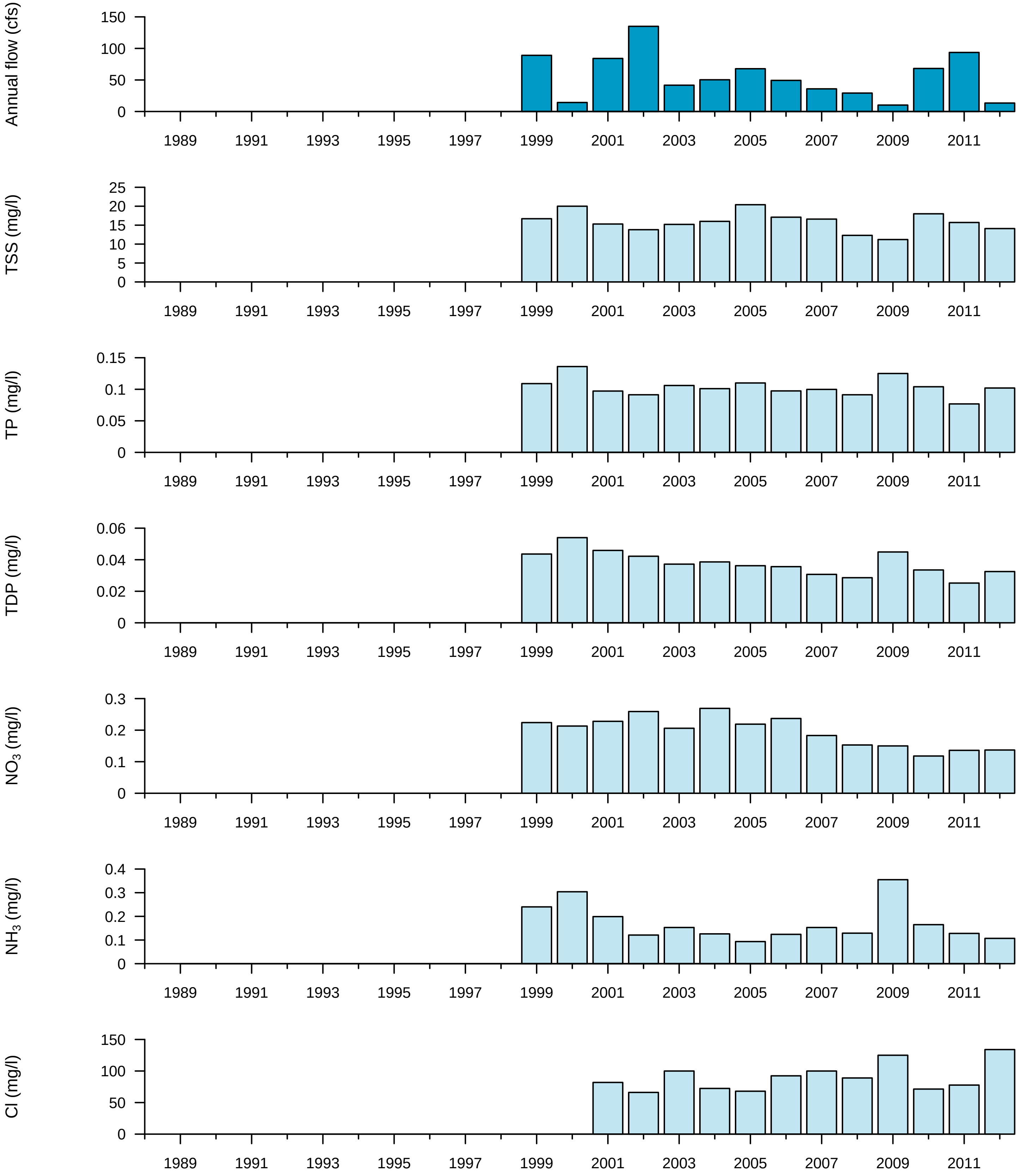
The FWM concentrations showed less month-to-month variability than the loads (Figure MH-12). TSS concentrations were highest in May, corresponding to the typical dam opening date time and higher flows. The TP and TDP monthly concentration remain fairly stable and were likely influenced, even during low flow periods, by storm sewer discharges. The NO_3 concentrations were highest during early spring, but then show a reduction during June through August, most likely attributable to biological uptake. Cl concentrations were highest in January through March, likely reflecting the impact of road, parking lots, and sidewalk de-icers during winter months.

Figure MH−7: Minnehaha Creek*
Annual Mass Load



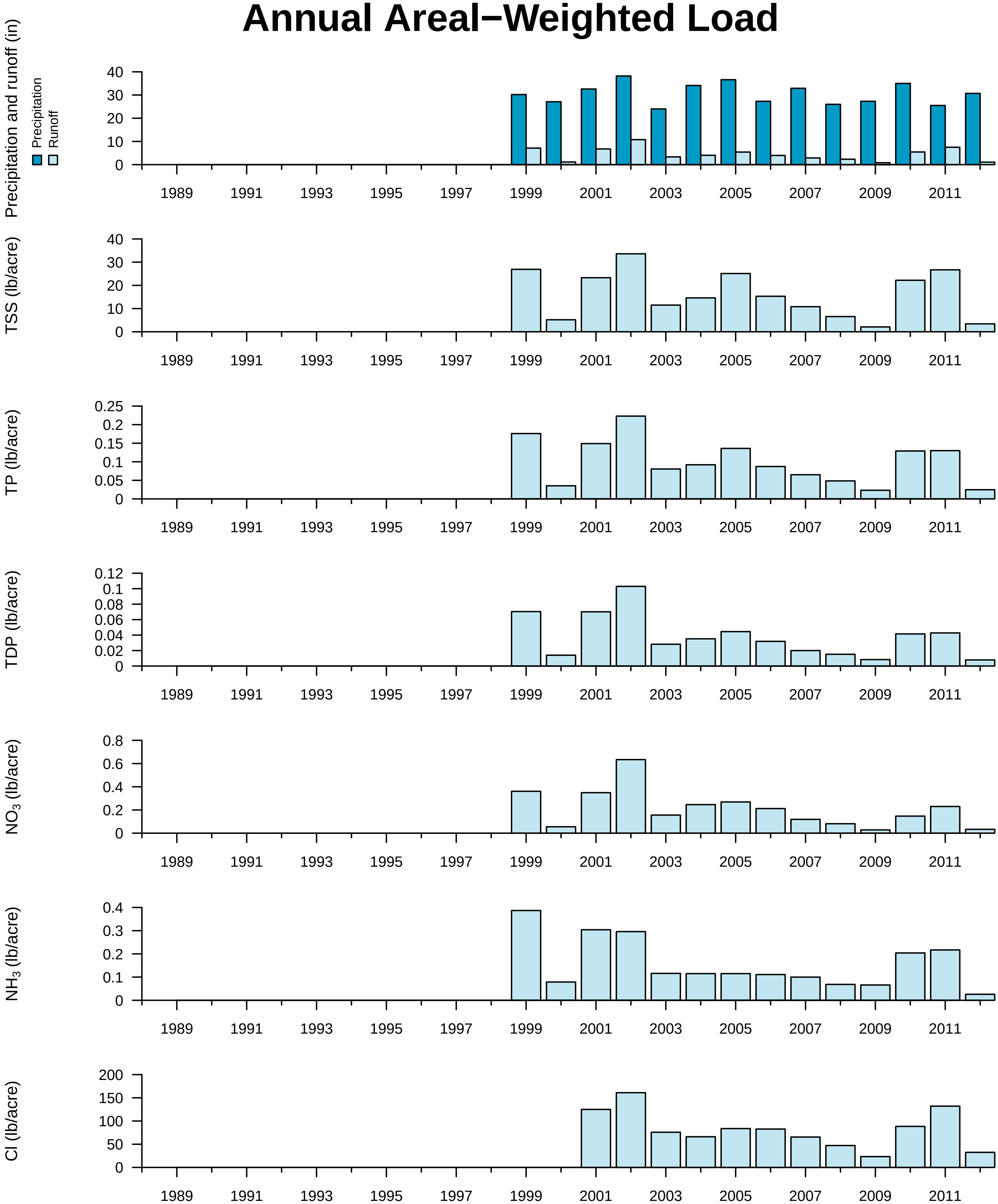
*First full year of sampling for TSS, TP, TDP, NO3, and NH3 began in 1999, Cl began in 2001.
Bars represent 95% confidence intervals as calculated in Flux32.

Figure MH−8: Minnehaha Creek*
Annual Flow−Weighted Mean Concentration



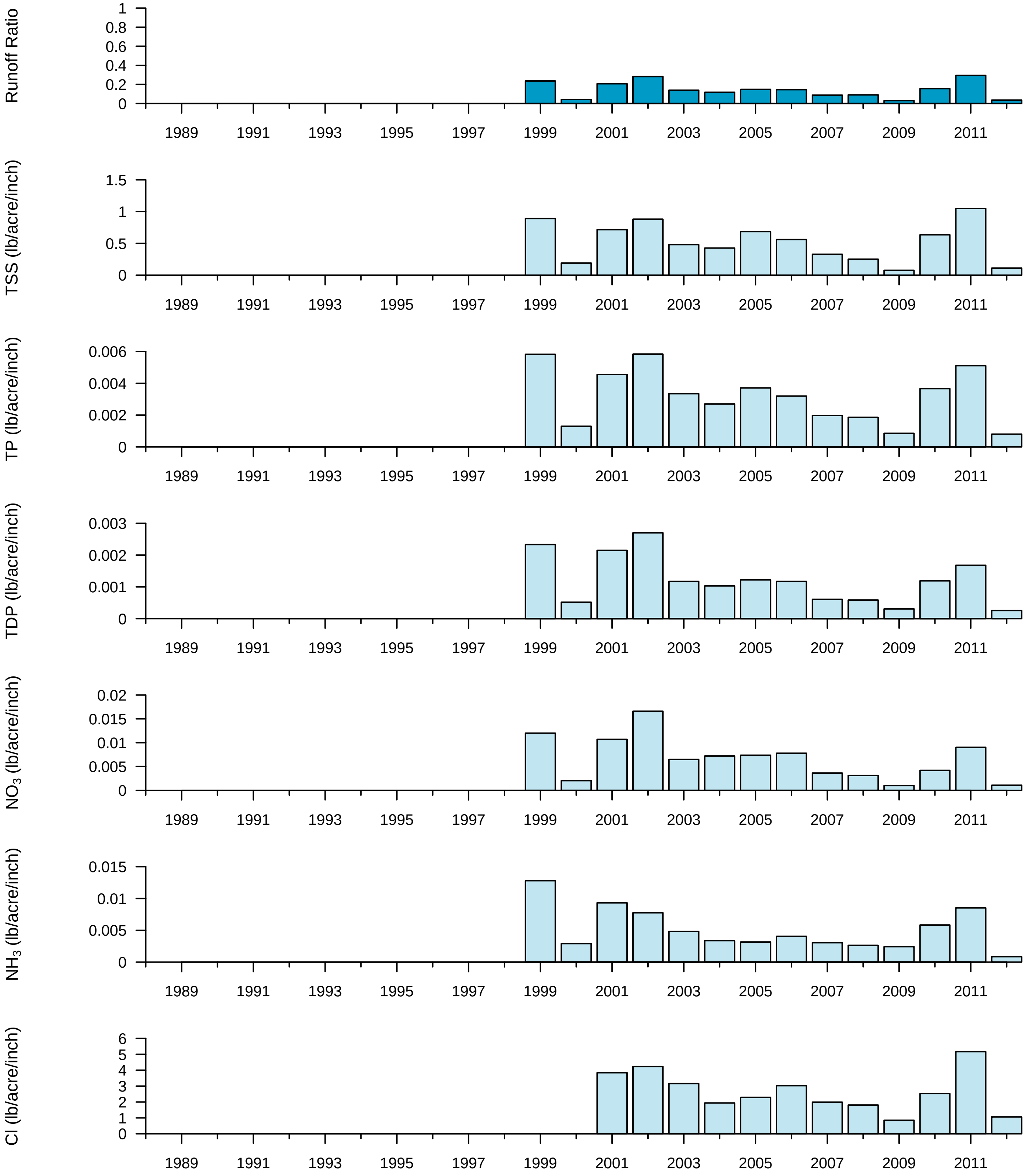
*First full year of sampling for TSS, TP, TDP, NO3, and NH3 began in 1999, Cl began in 2001.

Figure MH−9: Minnehaha Creek*
Annual Areal−Weighted Load



*First full year of sampling for TSS, TP, TDP, NO3, and NH3 began in 1999, Cl began in 2001.

Figure MH−10: Minnehaha Creek* Annual Precipitation−Weighted Areal Load



*First full year of sampling for TSS, TP, TDP, NO3, and NH3 began in 1999, Cl began in 2001.

Figure MH−11: Minnehaha Creek Mass Load by Month

Most Recent Year (2012) of Data Compared to 2003−2012 Average

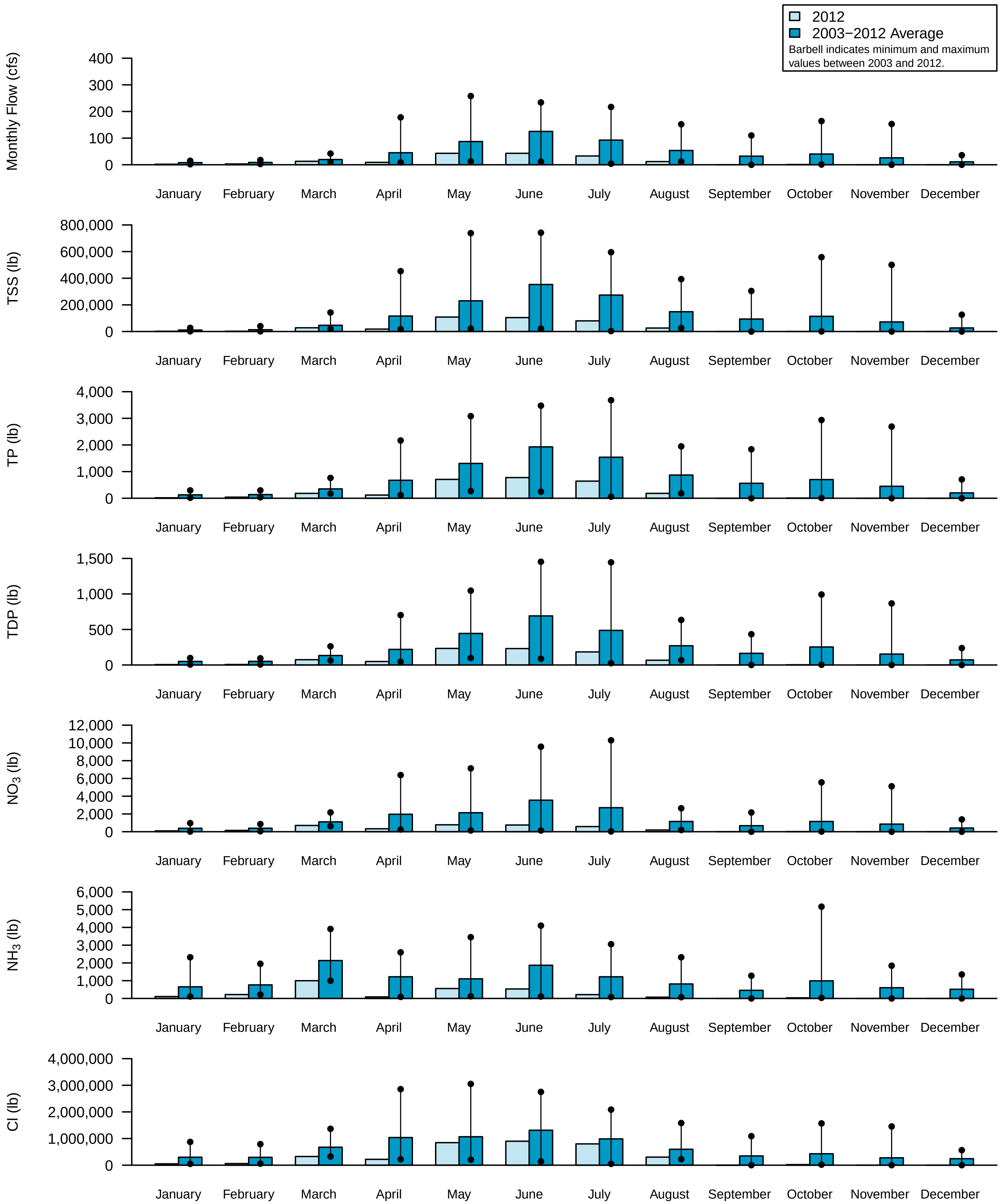
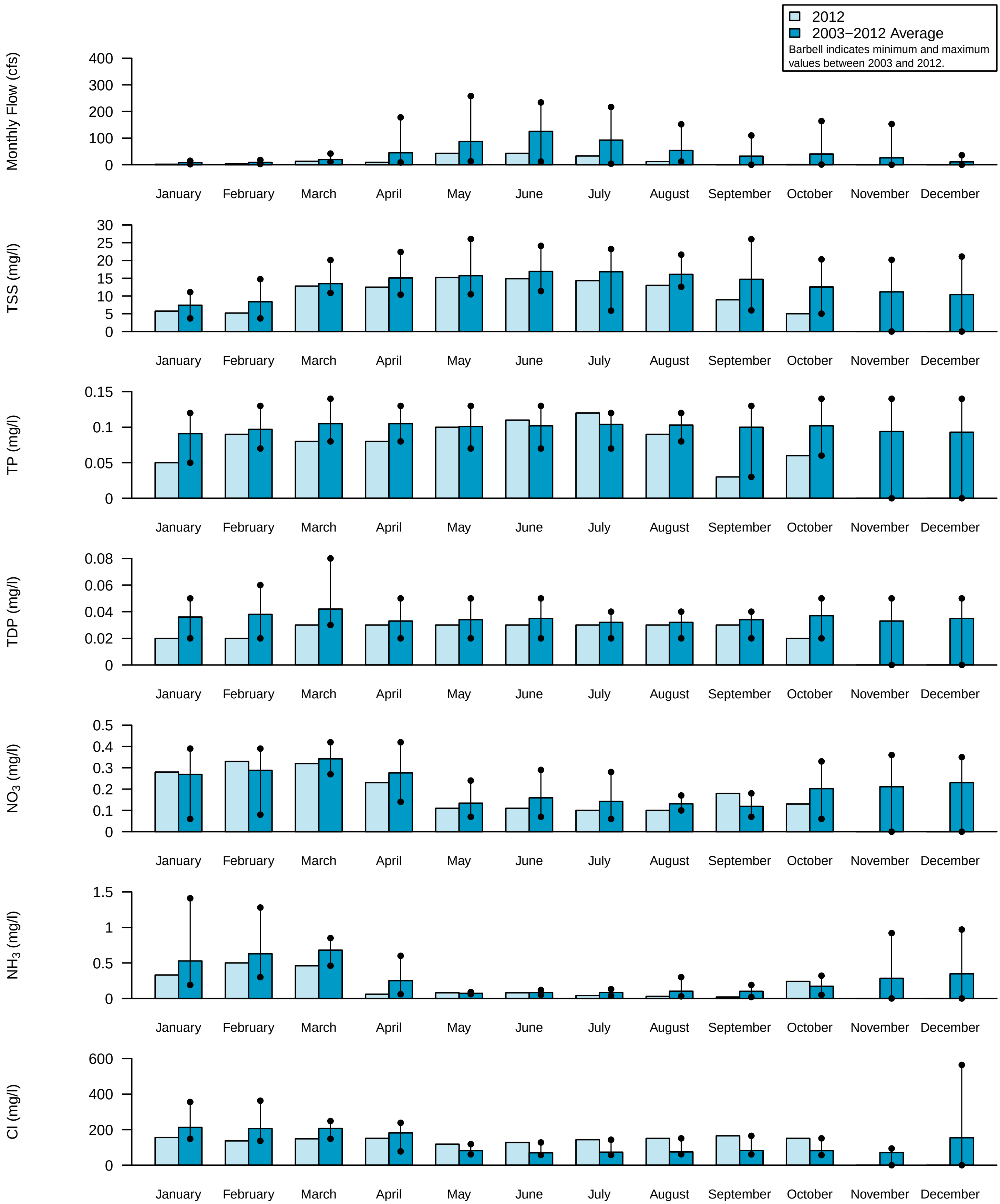


Figure MH−12: Minnehaha Creek
Flow−Weighted Mean Concentation by Month

Most Recent Year (2012) of Data Compared to 2003−2012 Average



Flow and Load Duration Curves

Load duration curves are frequently used to assess water quality concentrations occurring at different flow regimes within a stream or river (high flow, moist conditions, mid-range, dry conditions, and low flow). The curves can also be used to provide a visual display of the frequency, magnitude, and flow regime of water quality standard exceedances if standard concentrations are added to the plots (USEPA, 2007).

MCES developed flow and load duration curves for each stream location using USEPA recommendations, including:

- Develop flow duration curves using average daily flow values for the entire period of record plotted against percent of time that flow is exceeded during the period of record.
- Divide the flow data into five zones: high flows (0-10% exceedance frequency); moist conditions (10-40%); mid-range flows (40-60%); dry conditions (60-90%); and low flows (90-100%). Midpoints of each zone represent the 5^{th}, 25^{th}, 50^{th}, 75^{th}, and 95^{th} percentiles, respectively.
- Multiply concentration and flow for each sampling event for period of record, to result in approximate daily mass loads included on the curve as points.
- Multiply water quality standard concentration and monitored flow to form a line indicating allowable load. Sample load points falling below the line meet the standard; those falling above the line exceed the standard.

The final load duration curves provide a visual tool to assess if standard exceedances are occurring, and if so, at which flow regimes.

MCES selected four parameters to assess using load duration curves: TSS, TP, NO_3, and Cl. Each of the parameters was plotted using Minnehaha Creek monitoring station daily average flows and sample data, along with the most appropriate MPCA draft numerical standard as listed in Table MH-5. No draft standard has been set for NO_3, so MCES used the drinking water standard of 10 mg/l.

Most of the draft standards proposed by MPCA have accompanying criteria that are difficult to show on the load duration curves. For example, for a water body to violate the draft TP river criteria, the water body must exceed the causative variable (TP concentration), as well as one or more response variables: sestonic (suspended) chlorophyll, biochemical oxygen demand ($BOD_{5)}$, dissolved oxygen (DO) flux), and/or pH (MPCA, 2013). Thus for this report, the load duration curves are used as a general guide to identify flow regimes at which water quality violations may occur. The MPCA is responsible for identifying and listing those waters not meeting water quality standards; the results of this report in no way supersede MPCA’s authority or process.

The 1999-2012 flow duration curve and load duration curves for TSS, TP, NO_3, and Cl for the Minnehaha Creek monitoring station (mile 1.7, at 32^{nd} Avenue) is shown in Figure MH-13. TSS concentrations have mostly remained below the draft standard at low flow and dry conditions; during moist conditions and high flow, a greater portion of samples collected exceed the draft standard. This response is consistent with other urban streams in the metropolitan area, where high flow leads to streambank erosion and high levels of suspended solids in stormwater runoff.

TP concentration exceeds the draft standard nutrient concentration consistently at all flows. The pattern did not closely correspond to TSS concentrations, suggesting suspended solids were not the primary source of TP. Urban runoff carries high levels of TP from grass-clippings, garden litter, fallen leaves, lawn fertilizers, sanitary wastes, and animal wastes (MPCA, 2014b). It is very likely that the extensive network of stormwater sewers within the Minnehaha Creek watershed transported phosphorus-rich runoff to the creek.

All NO_3 concentrations at all flow regimes met the drinking water standard of 10 mg/l. The final river nutrient standard for NO_3 will likely be much less than that and likely will be exceeded at the higher flow regimes.

The majority of Cl concentrations in Minnehaha Creek were below the draft standard Cl concentrations at all flow regimes. However, there were samples at all flow conditions that met the draft standard and two data points (in mid-range and moist conditions) that exceeded the standard. Concentrations are highest at the highest flows, most likely from spring snowmelt carrying dissolved road salt.

Table MH-5 : Minnehaha Creek Beneficial Use and River Nutrient Region (RNR) Classifications and Pollutant Draft Standards

Monitoring Station	Use Classification[1] for Domestic Consumption (Class 1) and Aquatic Life and Recreation (Class 2)	River Nutrient Region (RNR)[2] of Monitoring Station	Cl Draft Stnd[3] (mg/l)	TSS Draft Stnd[4] (mg/l)	TP Draft Stnd[5] (ug/l)	NO_3 DW Stnd[6] (mg/l)
Minnehaha Creek at 32nd Ave. (MH1.7)	2B	Central	230	30	100	10

[1] Minn. Rules 7050.0470 and 7050.0430

[2] MPCA, 2010.

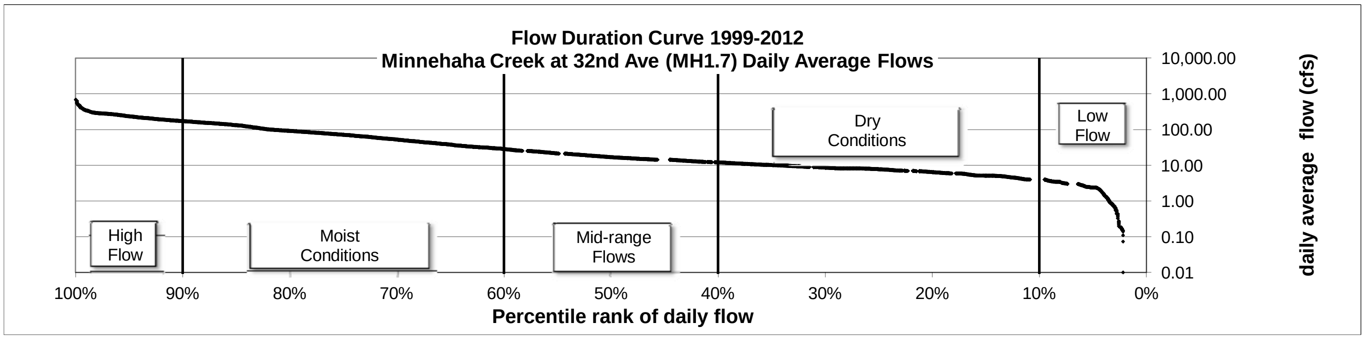
[3] Mark Tomasek, MPCA, personal communication, March 2013. MCES used 230 mg/l as the draft Cl standard pending results of USEPA toxicity tests.

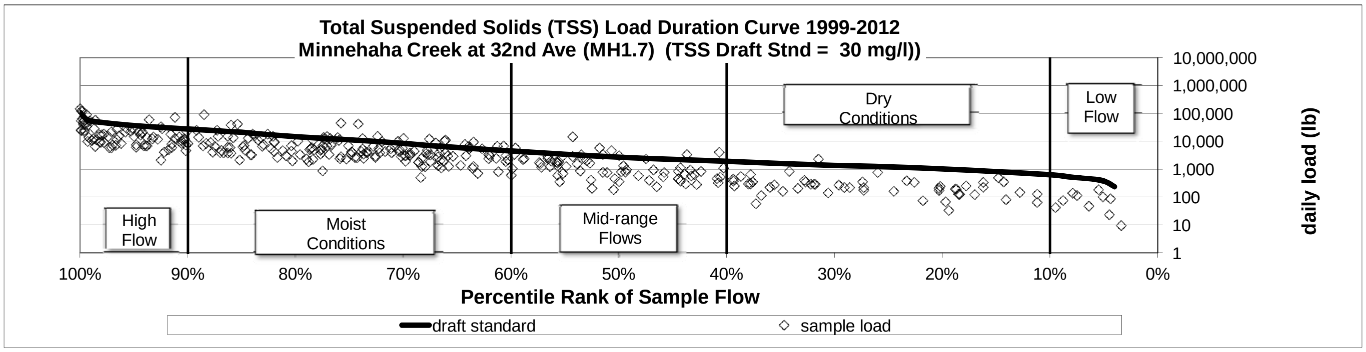
[4] MPCA, 2011a. Draft standard states TSS standard concentration for Class 2A and 2B water must not be exceeded more than 10% of the time over a multiyear data window, with an assessment period of April through September.

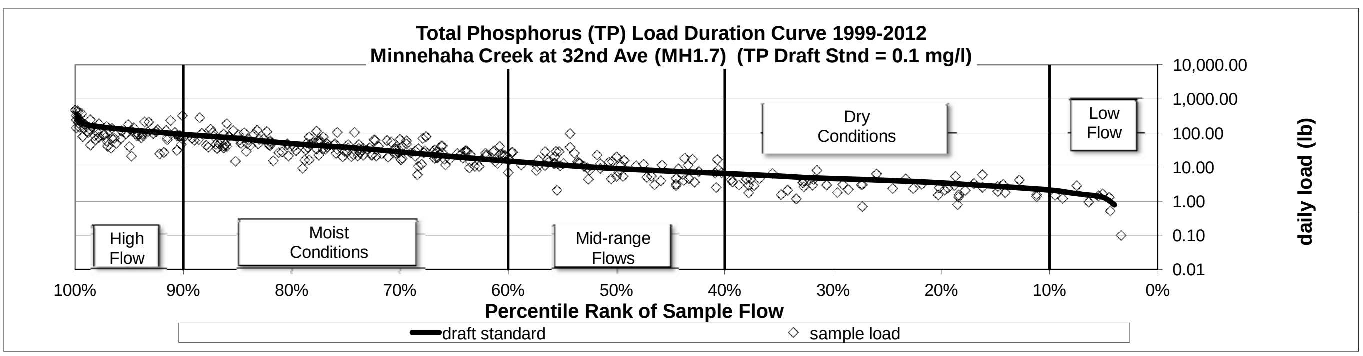
[5] MPCA, 2013.

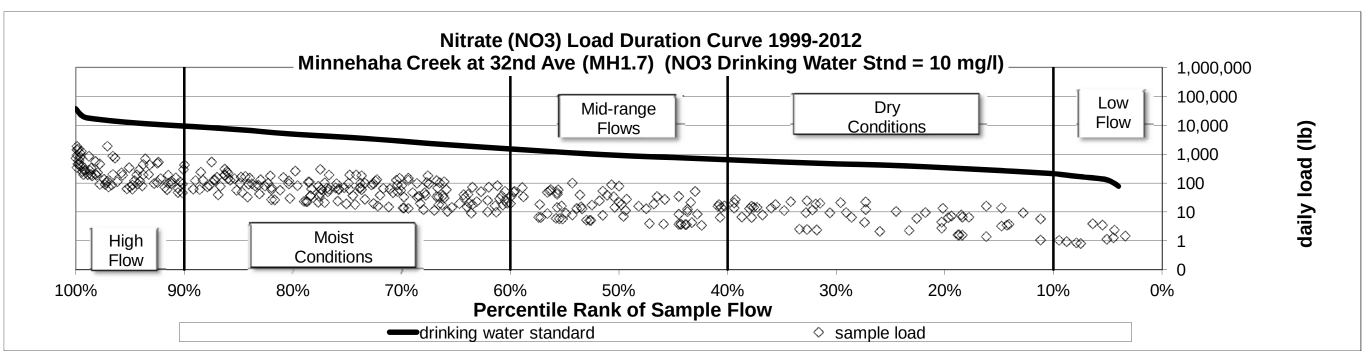
[6] MCES used the NO_3 drinking water standard of 10 mg/l pending results of USEPA toxicity tests and establishment of a draft NO_3 standard for rivers and streams.

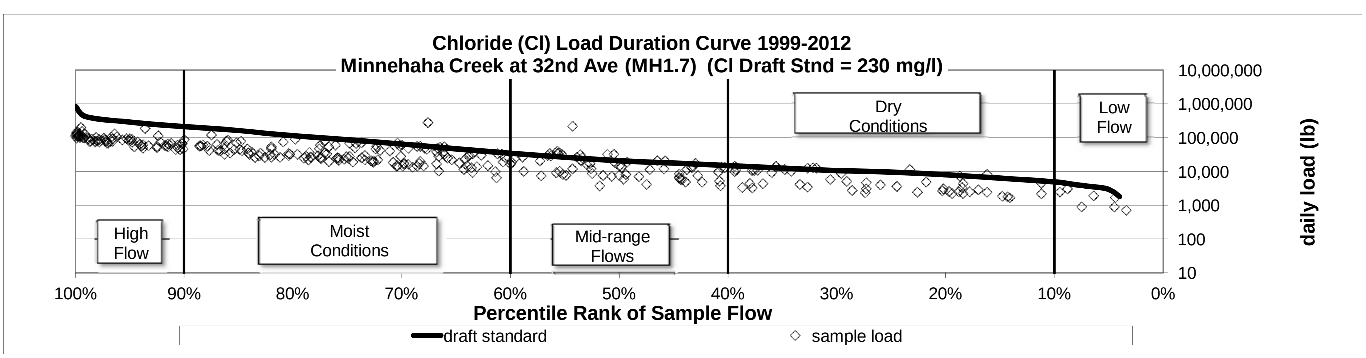
Figure MH-13: Minnehaha Creek Flow and Load Duration Curves, 1999-2012











Aquatic Life Assessment Based on Macroinvertebrates

Macroinvertebrates, including aquatic insects, worms, snails, crustaceans, and bivalves, are important indicators of water quality. Different types of macroinvertebrates have differing sensitivities to changes in pollution levels, habitat, flows, energy, and biotic interactions. As these environmental attributes change over time, they shape the composition of the macroinvertebrate community. Metrics have been developed that relate these community shifts with human-caused stresses.

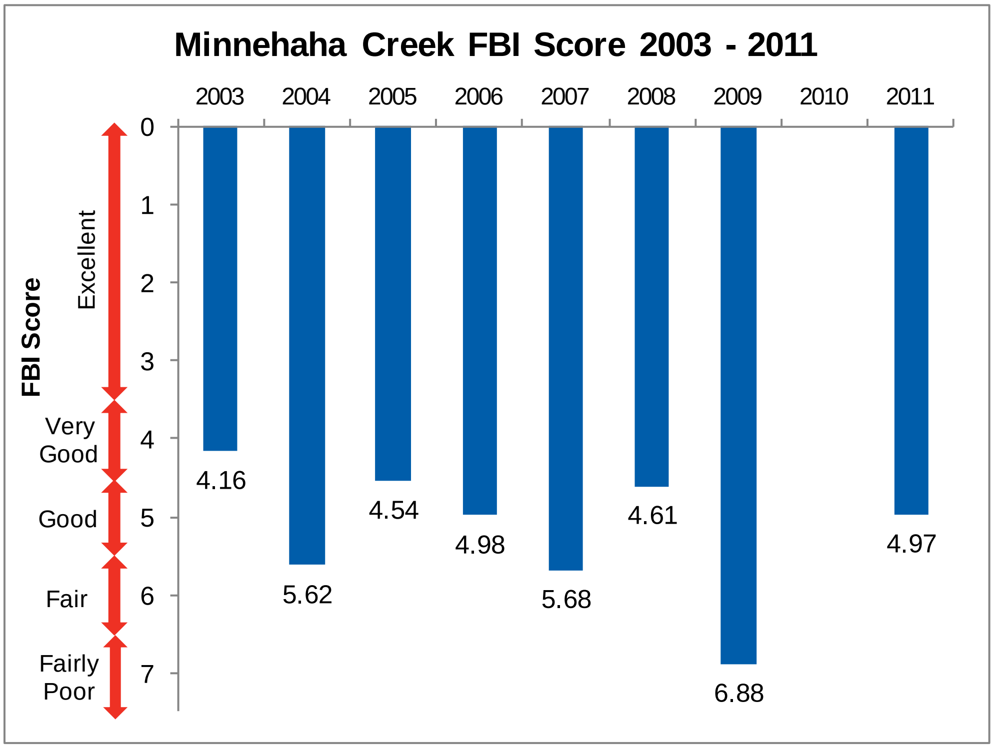
Each metric is independently important and clarifies one aspect of the ecosystem health: species richness, community diversity, water quality, and other factors. The results may have conflicting conclusions when comparing the single metric results. However, integrating the individual metrics into a multi-metric analysis provides a holistic assessment of the stream system.

MCES has been sampling for macroinvertebrates in Minnehaha Creek since 2003. The entire dataset was analyzed with three metrics: Family Biotic Index (FBI), Percent Intolerant Taxa, and Percent POET Taxa. A subset of data, 2004-2009 and 2011, was analyzed using the multi-metric, Minnesota-specific, MPCA 2014 Macroinvertebrate Index of Biological Integrity (M-IBI).

Family Biotic Index (FBI)

FBI is a commonly used water quality assessment. Each family is assigned a tolerance value that describes its ability to tolerate organic pollution. The values range from 0 to 10; zero is intolerant to pollution; 10 is quite tolerant of pollution. The tolerance values are used to calculate a weighted average tolerance value for the sample, allowing for comparisons from year to year. The Minnehaha Creek FBI scores ranged from very good water quality (2003) to fairly poor water quality (2009), indicating the presence of some organic pollution during most years, possibly significant organic pollution (Figure MH-14).

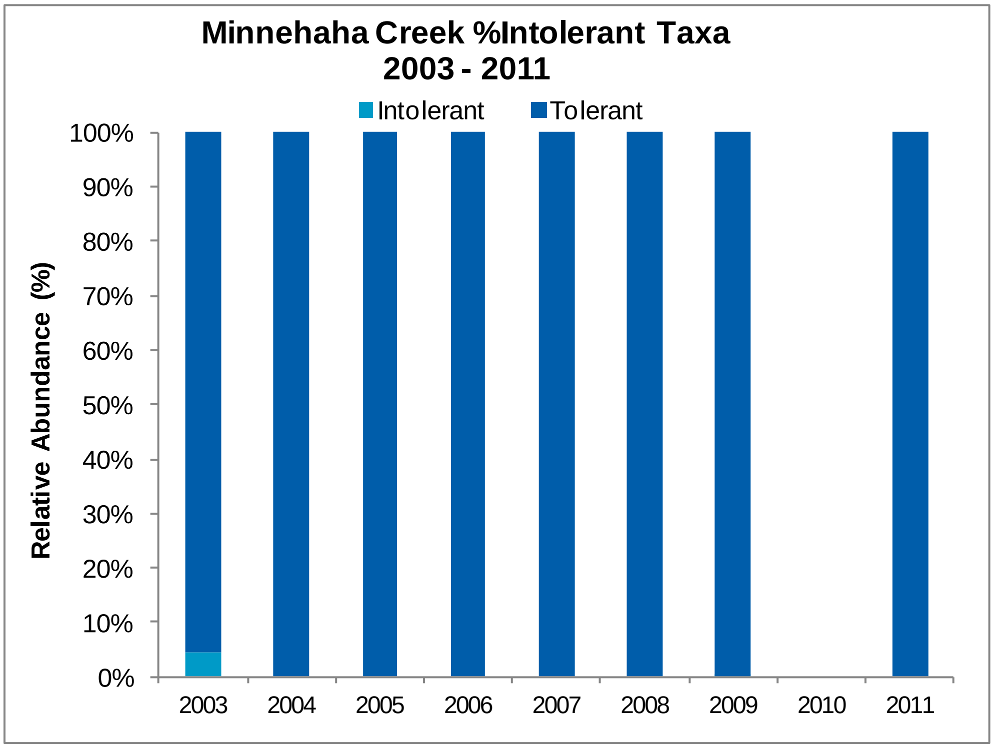
Figure MH-14: Minnehaha Creek Annual Family Biotic Index (FBI) Scores, 2003-2011



Percent Intolerant Taxa

The Percent Intolerant Taxa is another assessment to evaluate the degree of pollution at the monitoring reach. This metric identifies the percent of taxa with a tolerance value of two or less (Figure MH-15). The presence of moderate numbers of intolerant taxa is an indicator of good aquatic health (Chirhart, 2003). In Minnehaha Creek, intolerant taxa were present in 2003 when they accounted for only 5% of the sample.

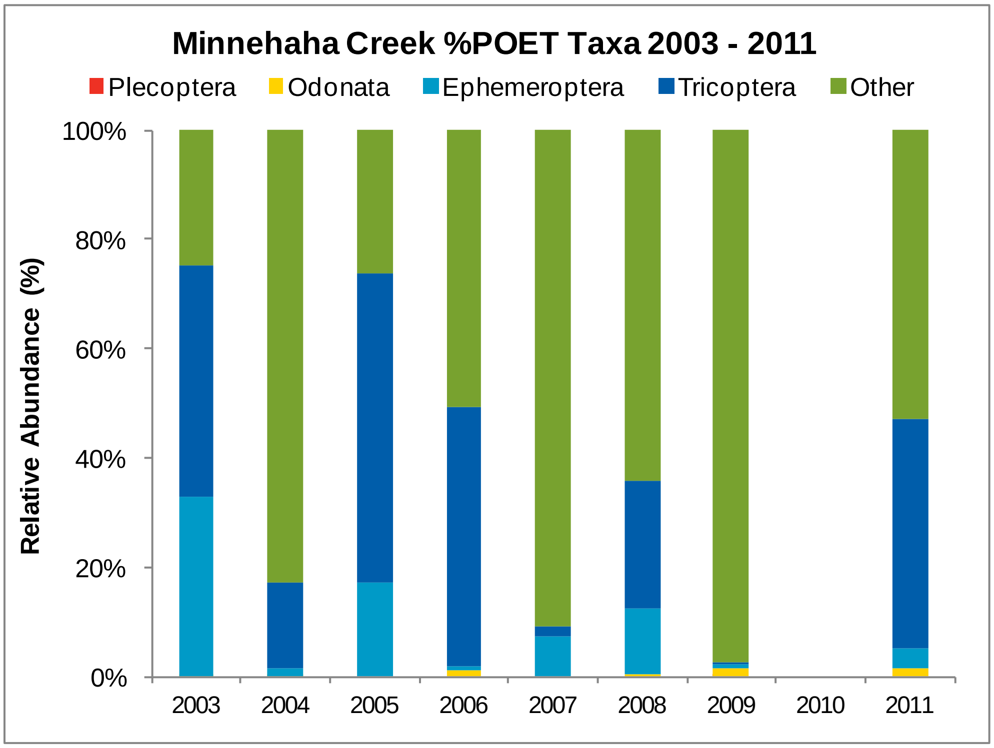
Figure MH-15: Minnehaha Creek Percent Abundance of Pollution Intolerant Taxa, 2003-2011



Percent POET Taxa

The taxonomic richness metric, Percent POET Taxa (Figure MH-16), is the percent of individuals in the sample that belong to the orders **P**lecoptera (stoneflies), **O**donata (dragonflies and damselflies), **E**phemeroptera (mayflies), and **T**richoptera (caddisflies). Individuals in these orders vary in sensitivity to organic pollution and sedimentation. High percent POET values indicate high community diversity due to good water quality. The percent POET taxa values were highest in 2003, followed closely by 2005 (75% and 74%, respectively).

Figure MH-16: Minnehaha Creek Percent Abundance of POET Taxa, 2003-2011



Macroinvertebrate Index of Biotic Integrity (M-IBI)

The M-IBI score integrates community richness and composition, pollution tolerance, life histories, trophic interactions, and physical and other parameters that all are components of the biological integrity of the stream. These composite scores are usually shown in context with a threshold value and confidence levels to aid in the assessment of the water quality.

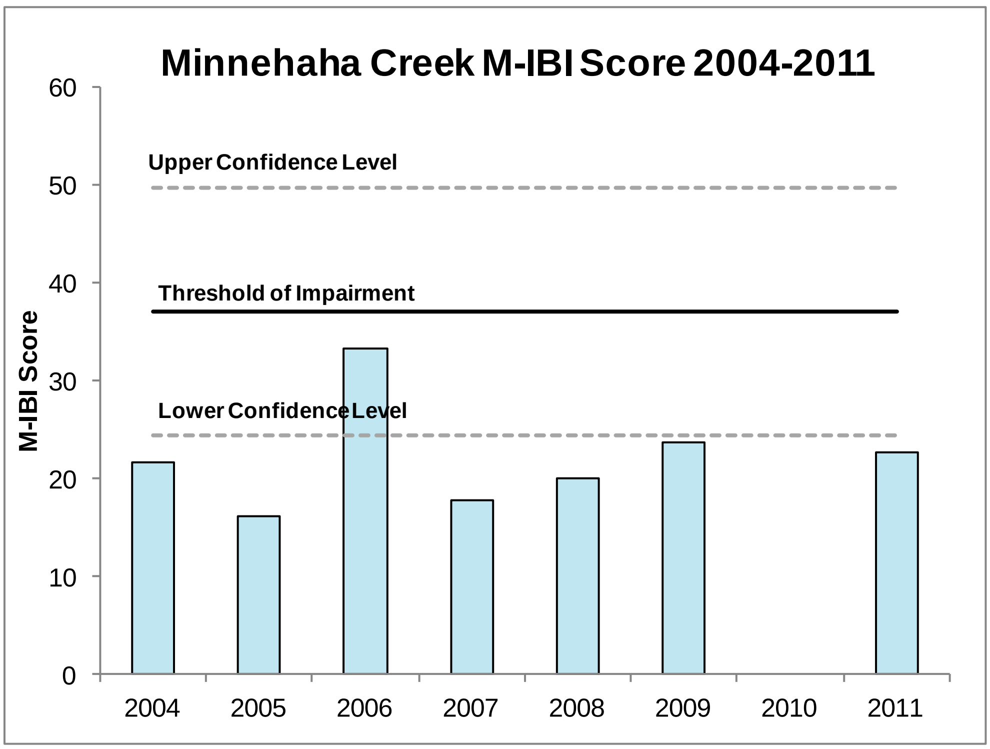
All seven years of monitoring Minnehaha Creek resulted in M-IBI scores below the impairment threshold (Figure MH-17). Five scores, 2004, 2005, 2007, 2008, and 2011, were below the lower confidence level of impairment. This suggests the stream reach during those years may not have been able to sustain the needs of aquatic life.

In 2006 and 2009, the M-IBI scores were between the threshold of impairment and the lower confidence level. When the scores fall between the confidence levels, it is difficult to confidently assess the water quality by biological assessment alone, and it is necessary to incorporate other monitoring information, such as hydrology, water chemistry and land use change (MPCA 2014c). Understanding physical and chemical influences on M-IBI scores leads to a more complete assessment of water quality. When plausible physical or chemical explanations exist for M-IBI scores between the confidence levels, these scores may be assigned more or less weight in the final evaluation.

Wenck and Associates (2004) found that the variation in Minnehaha Creek flows had a large influence on the habitat quality. In 2006, the stream maintained a summer minimum flow of at least 10 cfs. This consistency in flow provided a stream habitat with flowing waters for a longer period of time than a typical year. The higher base flows also likely diluted the influence of pollutants and allowed the macroinvertebrate community to thrive. The 2006 M-IBI score was barely above the lower confidence level, most likely due to the drought throughout the entire open water period, which was accompanied by very low flows and occasional dry streambeds. Wenck and Associates also pointed to the lack of woody debris, low stream gradients causing low dissolved oxygen, the impervious cover throughout the watershed, the stormwater inputs, lack of riparian vegetation, and sedimentation as additional stressors affecting the macroinvertebrate community.

The most recent M-IBI scores, 2009 and 2011, are near or below the lower confidence level. Most likely, environmental and chemical stressors are negatively affecting the macroinvertebrate community. MCES is planning additional future analysis to fully investigate our biological monitoring data.

Figure MH-17: Minnehaha Creek Annual Macroinvertebrate Index of Biological Integrity (M-IBI) Scores, 2004-2011



Trend Analysis

Trend analysis was completed for the historical record of TP, NO_3, and TSS using the USGS program QWTREND (Vecchia, 2003).QWTREND removes the variability of annual flow and seasonality from the statistical analysis; thus any trend identified should be independent of flow or seasonal variation.

Due to relatively short flow record for the monitored streams, MCES did not attempt to assess increases or decreases in flow. However other researchers have performed regional assessments of alterations in flow rate; their results can be used to form general assumptions about changes in flows in the metropolitan area streams. Novotny and Stefan (2007) assessed flows from 36 USGS monitoring stations across Minnesota over a period of 10 to 90 years, finding that peak flow due to snowmelt was the only streamflow statistic that has not changed at a significant rate. Peak flows due to rainfall events in summer were found to be increasing, along with the number of days exhibiting higher flows. Both summer and winter baseflows were found to be increasing, as well. Novotny and Stefan hypothesized that increases in annual precipitation, larger number of intense precipitation events, and more days with precipitation are driving the increased flows.

Alterations in land use and land management have also likely contributed to increasing flow rates. For example, Schottler et.al. (2013) found that agricultural watersheds with large land use changes have exhibited increases in seasonal and annual water yields, with most of the increase in flow rate due to changes in artificial drainage and loss of depressional storage. MCES staff plan to repeat the following trend analyses in five years. At that time, we anticipate sufficient data will have been collected for us to assess changes in flow rate, as well as to update the pollutant trends discussed below.

MCES staff assessed trends for the period of 1999-2012 on Minnehaha Creek for TSS, TP, and NO_3, using daily average flow, baseflow grab sample, and event composite sample data. The results are presented below. Readers should note that while QWTREND allows identification of changes of pollutant concentration with time, it does not identify causation. MCES staff have not attempted to identify changes in watershed management, climactic changes, or any other actions which may affected concentration in the stream. A recommendation of this report is for MCES staff to work with local partners to identify causative actions which will aid in interpretation when MCES repeats the trend analysis in five years.

Total Suspended Solids (TSS)

One downward trend was identified for TSS flow-adjusted concentrations in Minnehaha Creek from 1999 to 2012 (Figure MH-18, top panel). Based on the QWTREND run without five-year flow precedent, the trend was statistically significant (p-value= 0.0027). TSS flow-adjusted concentration decreased gradually from 11.3 mg/l to 6.4 mg/l (-44%) from 1999 to 2012 at a rate of -0.35 mg/l/yr.

In order to compare the TSS trends in Minnehaha Creek with other MCES-monitored streams in report section ***Comparison with Other Metro Area Streams***, MCES calculated the five-year trend for the period 2008-2012. TSS flow-adjusted concentration decreased from 7.5 mg/l to 6.4 mg/l (-15%) at a rate of -0.22 mg/l/yr. Based on the QWTREND results, the water quality in Minnehaha Creek in terms of TSS improved during 2008-2012.

Total Phosphorus (TP)

One downward trend was identified for TP flow-adjusted concentrations in Minnehaha Creek from 1999 to 2012 (Figure MH-18, middle panel). The statistically significant trend was based on the QWTREND run without five-year flow precedent (p-value = $1.2x10^{-6}$). TP flow-adjusted concentration decreased gradually from 0.12 mg/l to 0.06 mg/l (-46%) from 1999 to 2012 at a rate of -0.004 mg/l/yr.

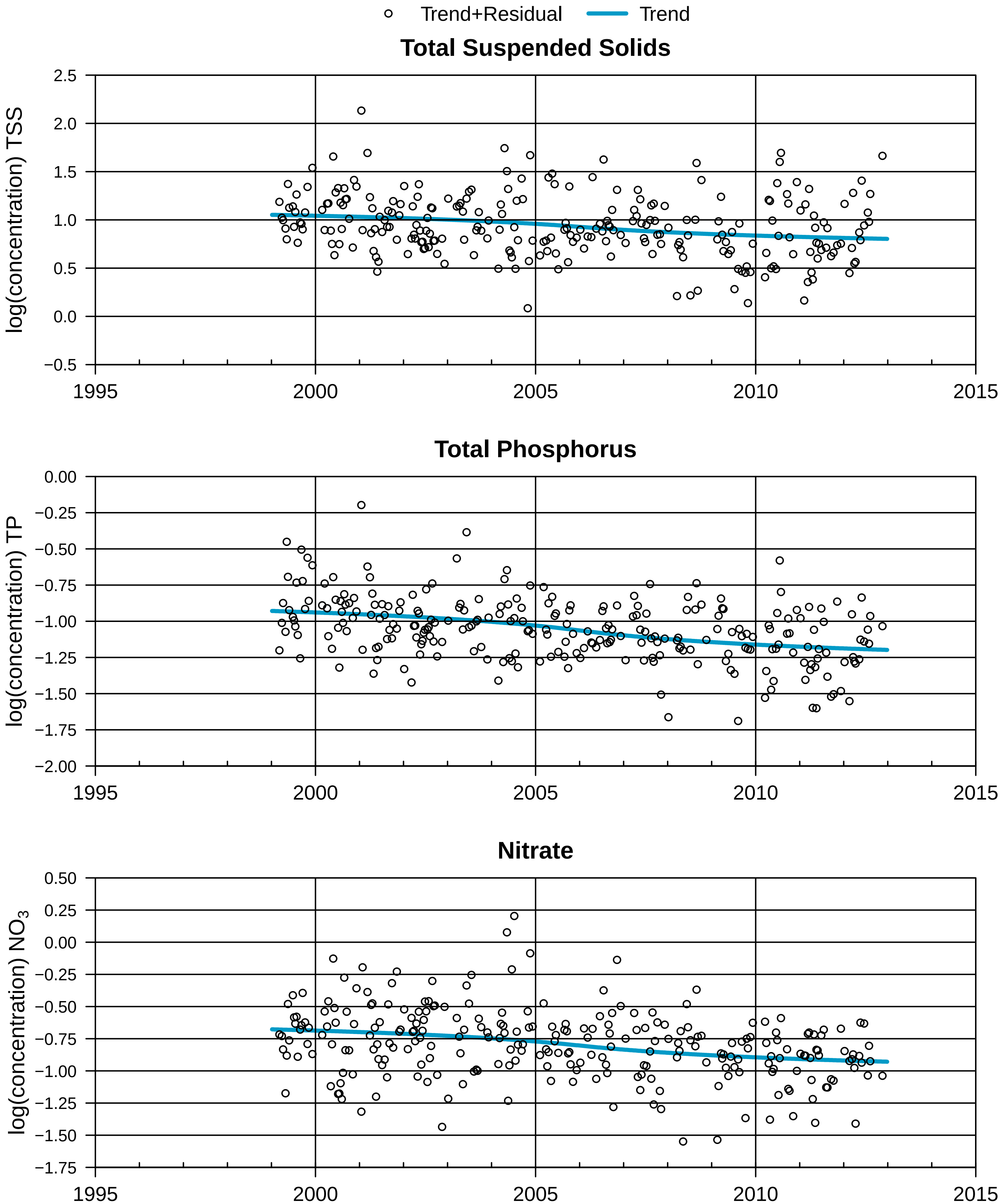
In order to compare the TP trends in Minnehaha Creek with other MCES-monitored streams in report section ***Comparison with Other Metro Area Streams***, MCES calculated the five-year trend for the period 2008-2012. TP flow-adjusted concentration decreased from 0.08 mg/l to 0.06 mg/l (-16%) at a rate of -0.002 mg/l/yr. Based on the QWTREND results, the water quality in Minnehaha Creek in terms of TP improved during 2008-2012.

Nitrate (NO_3)

One downward trend was identified for NO_3 flow-adjusted concentrations in Minnehaha Creek from 1999 to 2012 (Figure MH-18, lower panel). Based on the QWTREND run without five-year flow precedent p-value is 0.001, indicating the trend identified is statistically significant. NO_3 flow-adjusted concentration decreased gradually from 0.21 mg/l to 0.12 mg/l (-44%) from 1999 to 2012 at a rate of -0.0066 mg/l/yr.

In order to compare the NO_3 trends in Minnehaha Creek with other MCES-monitored streams in report section ***Comparison with Other Metro Area Streams***, MCES calculated the five year trend for period 2008-2012. NO_3 flow-adjusted concentration decreased from 0.14 mg/l to 0.12 mg/l (-15%) at a rate of -0.004 mg/l/yr. Based on the QWTREND results, the water quality in Minnehaha Creek in terms of NO_3 improved during 2008-2012.

Figure MH−18: Minnehaha Creek Trends for TSS, TP and NO_3



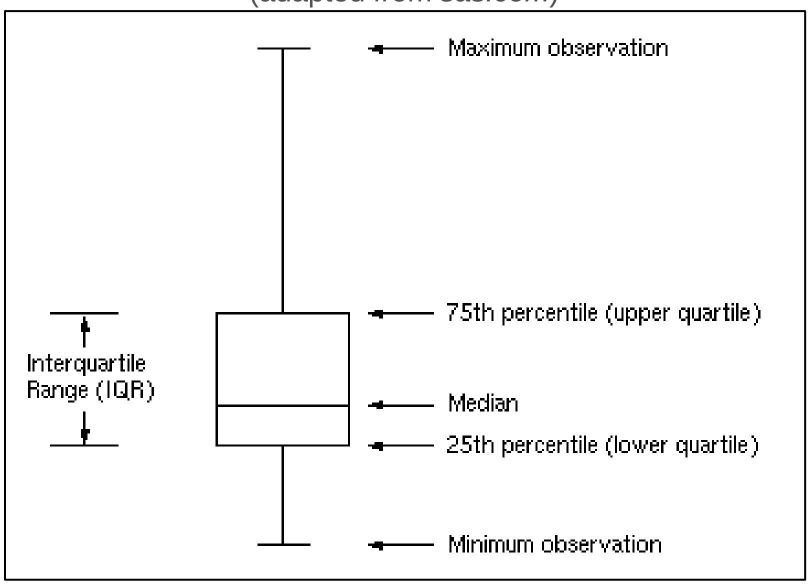
Comparison with Other Metro Area Streams

Chemistry

Box-and-whisker plots are used to summarize the comparison of the historical flow, TSS, TP, and NO_3, and Cl data for Minnehaha Creek with those of the other metropolitan area streams monitored by MCES and with the major receiving water (in this case the Mississippi River). The comparisons are shown in Figure MH-20 to Figure MH-24.

Figure MH-19 shows the formatted legend of the box-and-whisker plots used in this report. Note that 50% of data points fall within the box (also known as the interquartile range), with the centroid delineated by the median line. The outer extent of the whiskers designates the maximum and minimum values.

Figure MH-19: General Schematic of a Box-and-Whisker Plot
(adapted from *sas.com*)



Comparisons for each chemical parameter for the period 2003-2012 are shown using box-and-whisker plots of four metrics − annual flow-weighted mean (FWM) concentration, annual runoff ratio (volume/precipitation, which are identical on each of the four parameter pages), total annual load, and annual areal yield. The comparisons are grouped on one page, with streams grouped by major receiving river and listed in order of upstream-to-downstream. In addition, the plot of FWM concentration includes the 2003-2012 FWM concentration for the three receiving rivers (Mississippi, St. Croix, and Minnesota), shown as a dashed line.

Total Suspended Solids. The median annual FWM concentration for TSS in Minnehaha Creek was lower than the majority of other Mississippi River tributaries, with the exception of the primarily forested Rum River (Figure MH-20). It was lower than the Mississippi River (as measured at Anoka, Minnesota; 18 mg/l vs. ~16 mg/l, respectively), indicating that Minnehaha Creek was at times serving to decrease the TSS concentration in the Mississippi. It is apparent that those tributaries entering the Mississippi River above the confluence with the Minnesota River have lower FWM TSS concentrations and annual yields (expressed in lb/acre) than the MCES-monitored Minnesota River tributaries near Jordan, Minnesota, and are similar to the

MCES-monitored tributaries entering the St. Croix River. This reflects the geologic differences in landforms between the Mississippi and St. Croix River watersheds and the Minnesota River tributaries, which are still down-cutting towards geographic equilibrium (Jennings, 2010).

Median annual runoff ratio for Minnehaha Creek was lower than most of the metropolitan area streams. However, this is expected of a stream that is highly influenced by lakes and other impoundments on the stream channel. If the Minnehaha Creek flow was highly influenced by shallow groundwater inflow, one would expect a relatively higher runoff ratio (as with Eagle Creek or Valley Creek).

Total Phosphorus. As with TSS, the FWM TP concentration in Minnehaha Creek was lower than the Mississippi River and thus served to decrease the TP concentration in the river (Figure MH-21). Minnehaha Creek has the lowest TP FWM and annual yield of all of the Mississippi River metropolitan area tributaries, and was lower than all of the other MCES- monitored streams, with the exception of Carnelian-Marine and Silver Creek. This is not expected as the Minnehaha Creek watershed is highly urbanized and should have values similar to the other MCES-monitored urbanized watersheds (for example, Willow, Bluff, Bassett, Nine Mile, Fish, or Battle creeks).

Nitrate. NO_3 FWM concentration in Minnehaha Creek was lower than in the Mississippi River, and thus served to dilute the river concentration (Figure MH-22). The areal load in Minnehaha Creek is lower than most other MCES-monitored tributaries, with the Carnelian-Marine watershed as the exception.

Chloride. Cl FWM concentration in Minnehaha Creek was higher than in the Mississippi River, and was likely to increase the concentration of Cl in the river. While the concentrations are similar to the other urban watersheds, the annual yield is lower and more similar to the St. Croix watersheds (Figure MH-23). This suggests the lack of consistent annual flow greatly reduces the amount of pollutant loads transported by Minnehaha Creek, and the importance of storm events that may mobilizes pollutants after prolonged dry periods.

Macroinvertebrates

The historical biomonitoring data, summarized as the M-IBI metric scores, are also shown as box-and-whisker plots. However, the streams are divided by stream type because the MPCA impairment thresholds are type-specific and this attribute does not correlate with major river basins.

The M-IBI scores for Minnehaha Creek were below the MPCA impairment threshold (Figure MH-24). This includes the median, which suggests that the habitat and water quality of this stream reach typically were unlikely to sustain all of the needs for aquatic life. These results are similar to the other urban watersheds in the Mississippi River basin, like Nine Mile and Battle creeks. The only urban watershed in the metropolitan area that does not score below the threshold is Eagle Creek, a spring-fed system. The surface water-fed, urban watersheds, like Minnehaha Creek, clearly have negative stressors affecting the macroinvertebrate communities.

Figure MH−20: Total Suspended Solids for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

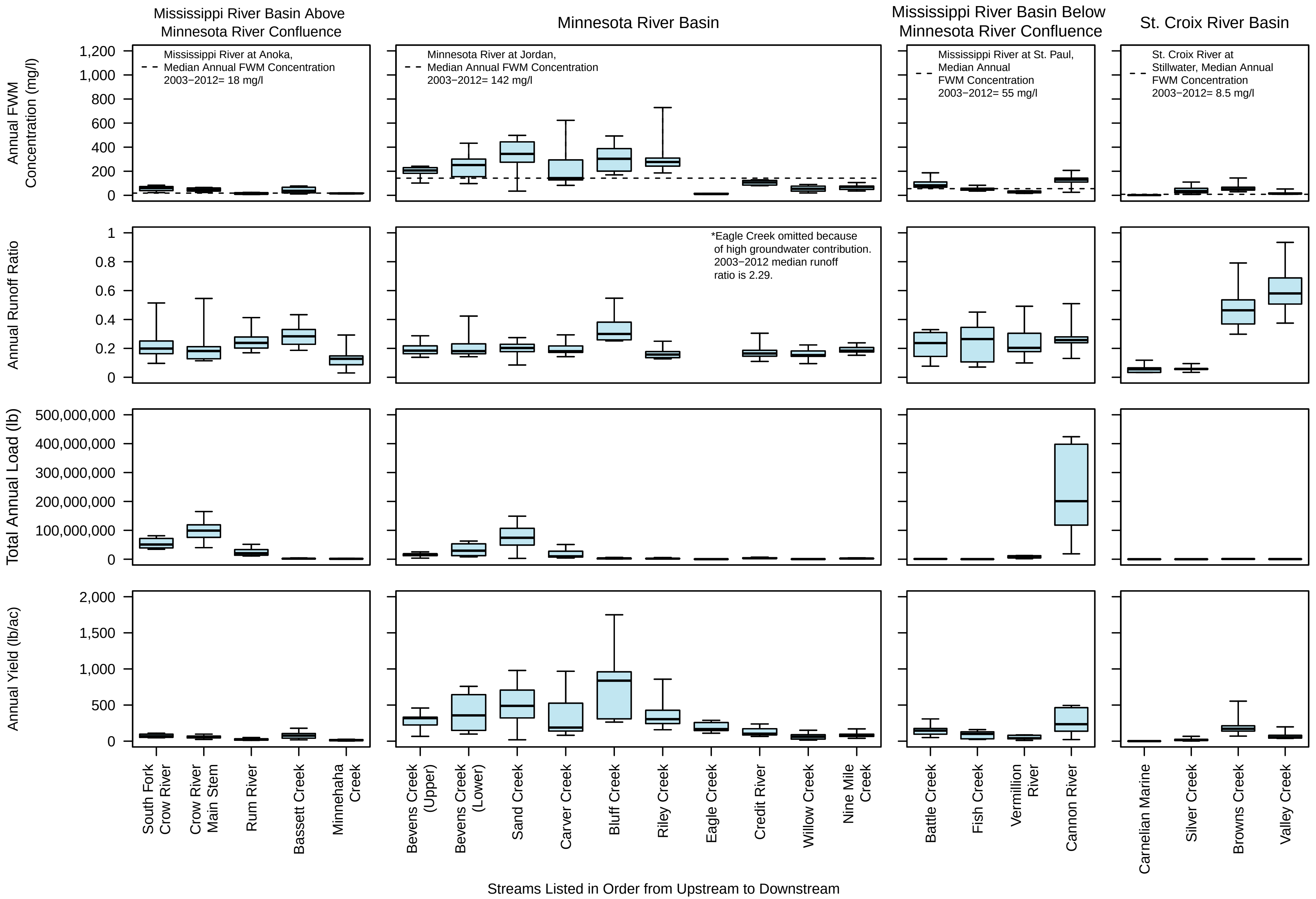


Figure MH−21: Total Phosphorus for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

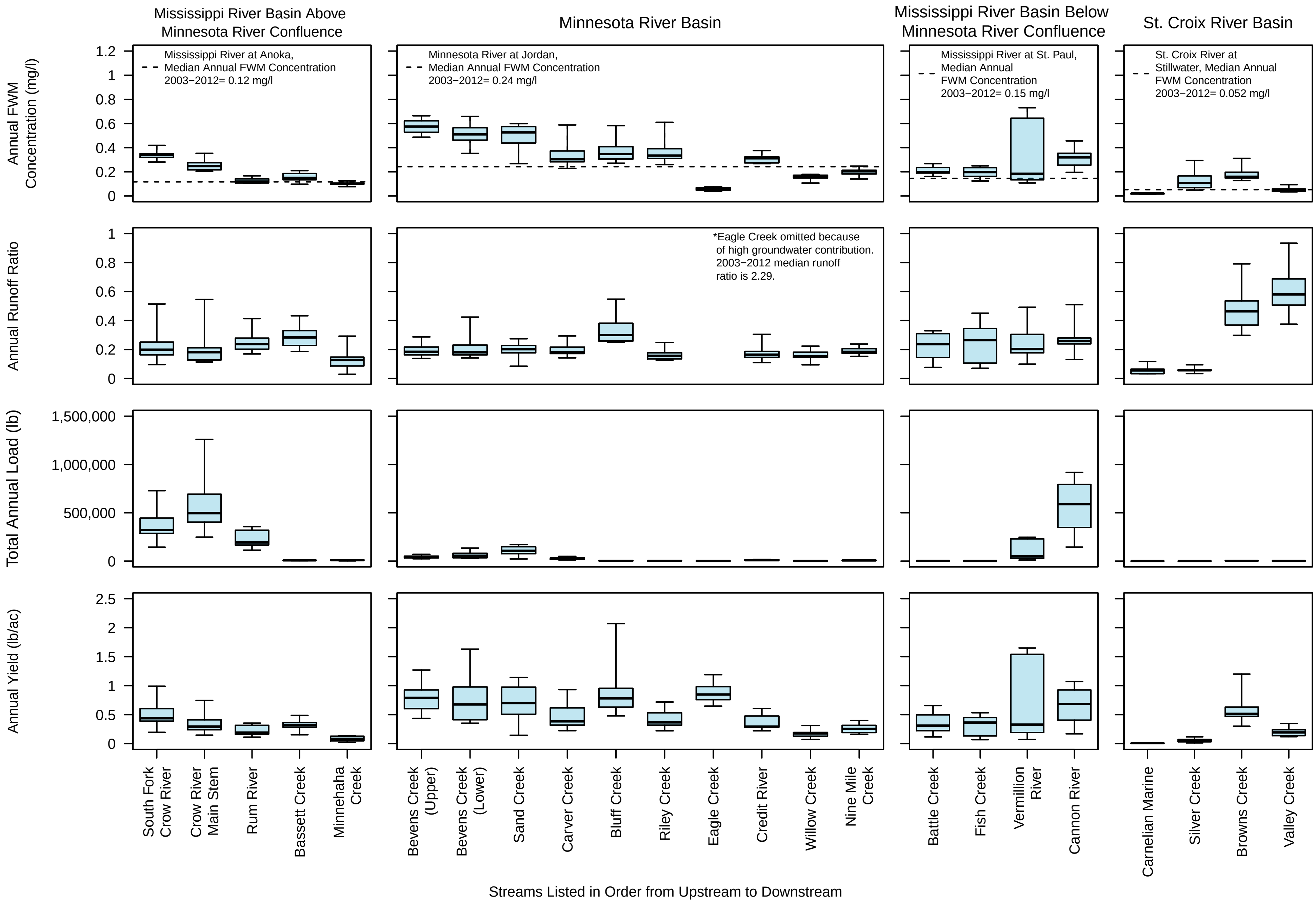


Figure MH−22: Nitrate for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

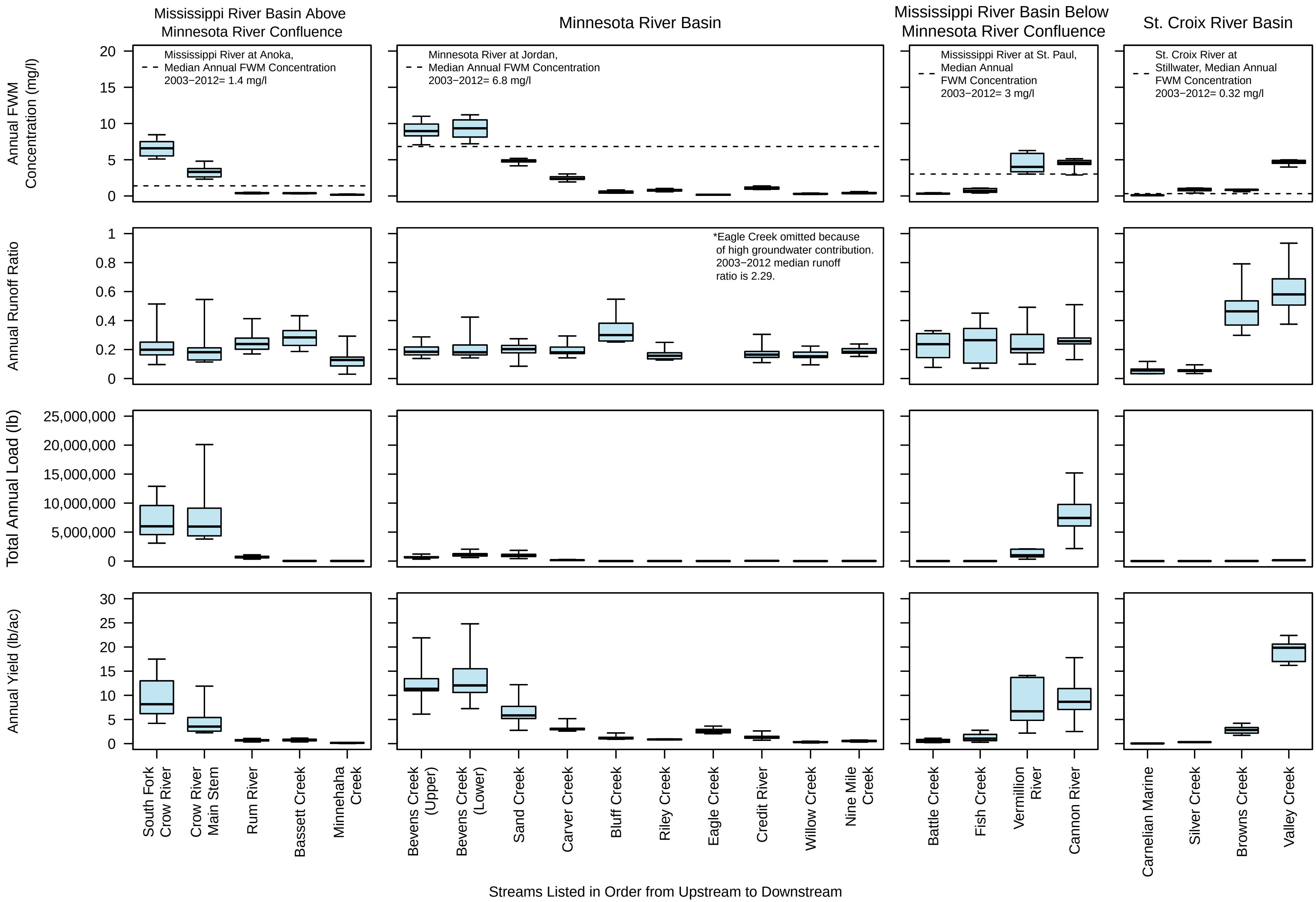


Figure MH−23: Chloride for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

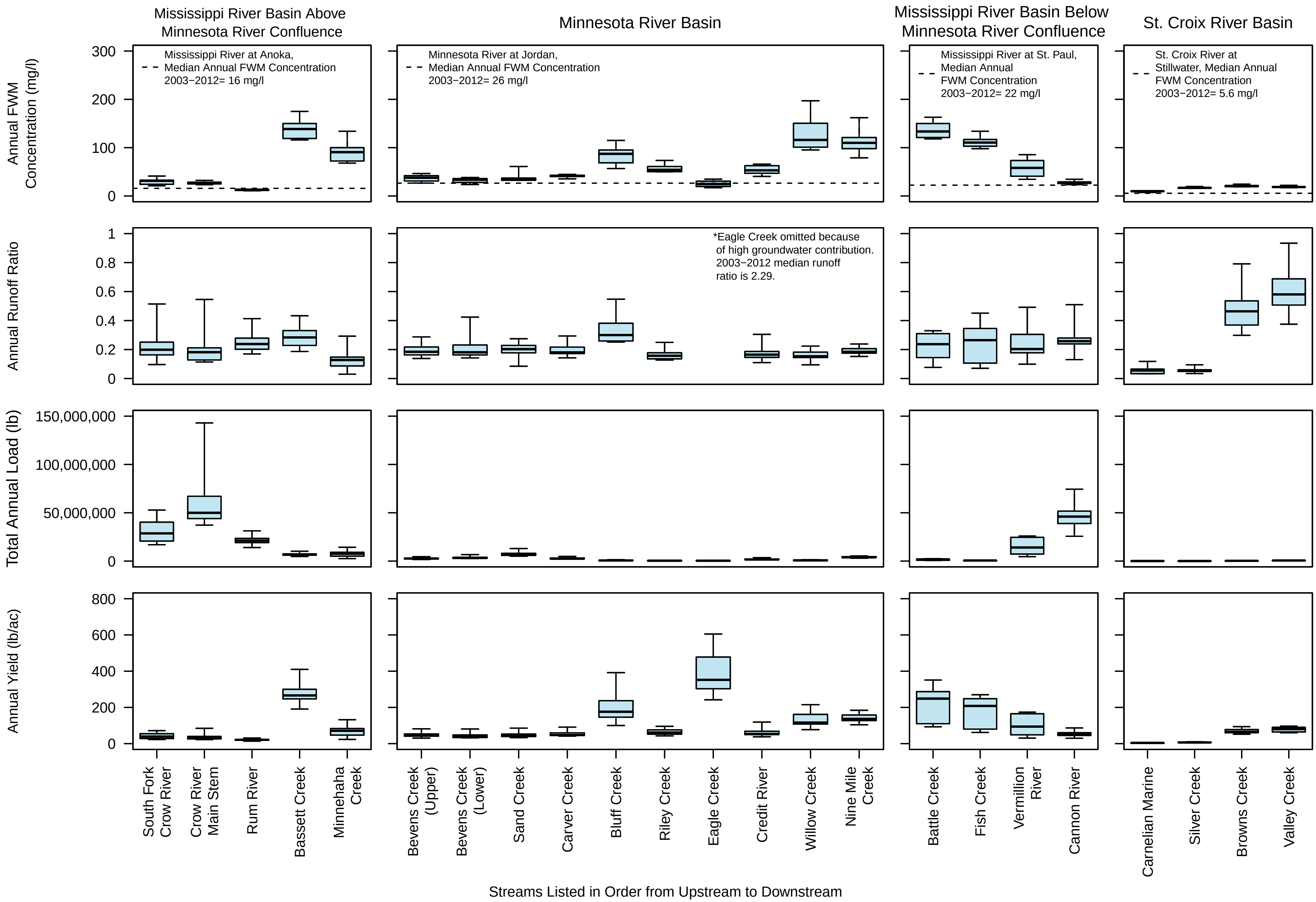


Table MH-6: Annual Median Concentrations, Loads, and Yields for MCES-Monitored Streams, 2003-2012

Station	Stream Name	Major Watershed	Median Runoff Ratio[1]	TSS Median Annual FWM Conc[2] (mg/l)	TSS Median Annual Load[3] (lb/yr)	TSS Median Annual Yield[4] (lb/ac/yr)	TP Median Annual FWM Conc[2] (mg/l)l	TP Median Annual Load[3] (lb/yr)	TP Median Annual Yield[4] (lb/ac/yr)	NO_3 Median Annual FWM Conc[2] (mg/l)	NO_3 Median Annual Load[3] (lb/yr)	NO_3 Median Annual Yield[4] (lb/ac/yr)	Cl Median Annual FWM Conc[2] (mg/l)	Cl Median Annual Load[3] (lb/yr)	Cl Median Annual Yield[4] (lb/ac/yr)
BE5.0	Bevens Creek (Upper)	Minnesota	0.18	207	17,600,000	319	0.575	43,650	0.791	8.95	628,000	11.4	38	2,600,000	47.2
BE2.0	Bevens Creek (Lower)	Minnesota	0.18	252	29,550,000	357	0.511	55,950	0.677	9.34	996,500	12.1	34	3,395,000	41.1
SA8.2	Sand Creek	Minnesota	0.20	344	74,200,000	489	0.526	106,000	0.700	4.85	886,000	5.8	36	6,980,000	46.0
CA1.7	Carver Creek	Minnesota	0.18	143	9,870,000	188	0.304	20,200	0.385	2.35	157,000	3.0	41	2,500,000	47.5
BL3.5	Bluff Creek	Minnesota	0.30	304	3,025,000	838	0.348	2,820	0.782	0.61	4,405	1.2	87	635,500	176.0
RI1.3	Riley Creek	Minnesota	0.16	277	2,025,000	305	0.335	2,440	0.367	0.79	5,840	0.9	54	407,000	61.3
EA0.8	Eagle Creek	Minnesota	2.29	11	181,000	167	0.055	918	0.848	0.17	2,760	2.6	25	381,000	352.0
CR0.9	Credit River	Minnesota	0.16	107	3,090,000	103	0.312	8,800	0.293	1.15	37,400	1.3	53	1,590,000	53.1
WI1.0	Willow Creek	Minnesota	0.15	54	391,000	61	0.161	1,130	0.175	0.28	1,980	0.3	116	750,000	116.0
NM1.8	Nine Mile Creek	Minnesota	0.18	70	2,520,000	88	0.205	7,335	0.255	0.38	15,750	0.5	110	3,930,000	136.5
CWS20.3	Crow River (South)	Mississippi	0.20	60	50,800,000	69	0.339	322,500	0.438	6.58	5,995,000	8.2	31	28,650,000	39.0
CW23.1	Crow River (Main)	Mississippi	0.18	46	98,950,000	59	0.248	496,000	0.294	3.33	5,960,000	3.5	27	49,950,000	29.6
RUM0.7	Rum River	Mississippi	0.24	12	20,700,000	21	0.119	193,000	0.191	0.38	654,000	0.6	13	21,150,000	21.0
BS1.9	Bassett Creek	Mississippi	0.28	37	1,905,000	77	0.150	8,090	0.325	0.38	19,350	0.8	139	6,620,000	266.0
MH1.7	Minnehaha Creek	Mississippi	0.13	16	1,415,000	13	0.102	9,095	0.084	0.17	16,400	0.2	91	7,700,000	71.0
BA2.2	Battle Creek	Mississippi	0.24	83	1,043,000	146	0.197	2,220	0.311	0.32	3,945	0.6	134	1,775,000	248.5
FC0.2	Fish Creek	Mississippi	0.26	55	296,500	101	0.198	1,066	0.364	0.71	3,035	1.0	111	610,000	208.0
VR2.0	Vermillion River	Mississippi	0.20	29	6,025,000	40	0.185	49,000	0.328	4.02	1,001,500	6.7	58	14,050,000	94.1
CN11.9	Cannon River	Mississippi	0.26	130	201,000,000	235	0.320	589,000	0.687	4.59	7,435,000	8.7	28	46,050,000	53.8
CM3.0	Carnelian-Marine Outlet	St. Croix	0.06	2	7,570	0.4	0.022	156	0.009	0.10	701	0.04	10	69,500	3.9
SI0.1	Silver Creek	St. Croix	0.06	35	80,700	15	0.108	235	0.042	0.83	1,765	0.3	17	37,100	6.7
BR0.3	Browns Creek	St. Croix	0.46	51	785,500	172	0.160	2,355	0.514	0.86	12,900	2.8	20	300,000	65.6
VA1.0	Valley Creek	St. Croix	0.58	14	392,500	54	0.047	1,415	0.193	4.74	145,500	19.9	19	589,500	80.4

[1] Runoff ratio = annual flow volume at monitoring station / annual area-weighted precipitation. Area-weighted precipitation for each watershed provided by Minnesota Climatological Working Group (2013)

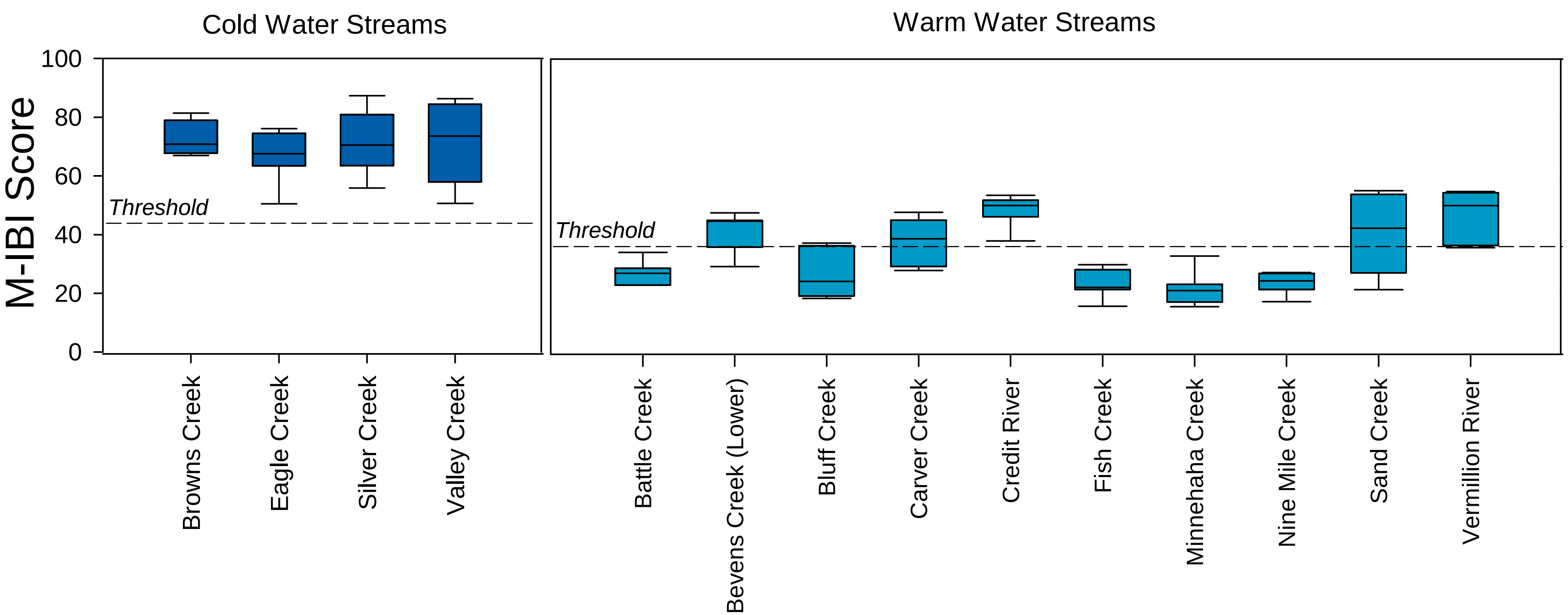
[2] FWM conc = annual flow-weighted mean concentration estimated using Flux32 (Walker, 1999).

[3] Load = annual pollutant load mass estimated using Flux32 (Walker, 1999).

[4] Yield = watershed pollutant yield calculated from annual pollutant load mass estimated using Flux32 (Walker, 1999) divided by area of watershed upstream of MCES monitoring station

Figure MH-24: M-IBI Results for MCES-Monitored Streams, 2004-2011

Organized by Stream Type



Higher M-IBI scores are indicative of a better water quality.
Each stream type has system-specific impairment thresholds set by the MPCA (2014b).
If a portion of the box plot is below the threshold, the stream may not have supported the needs of aquatic life during the study period.

Metropolitan Area Trend Analysis

Statistical trend analysis for each MCES stream monitoring station was performed using QWTREND (Vecchia, 2003). Trend estimates were calculated for 2008-2012 (the last five years of available data) to allow comparison of changes in water quality between streams. A similar approach was used in the 2013 MPCA nitrogen study (MPCA, 2013b) to compare QWTREND assessments in statewide streams and rivers.

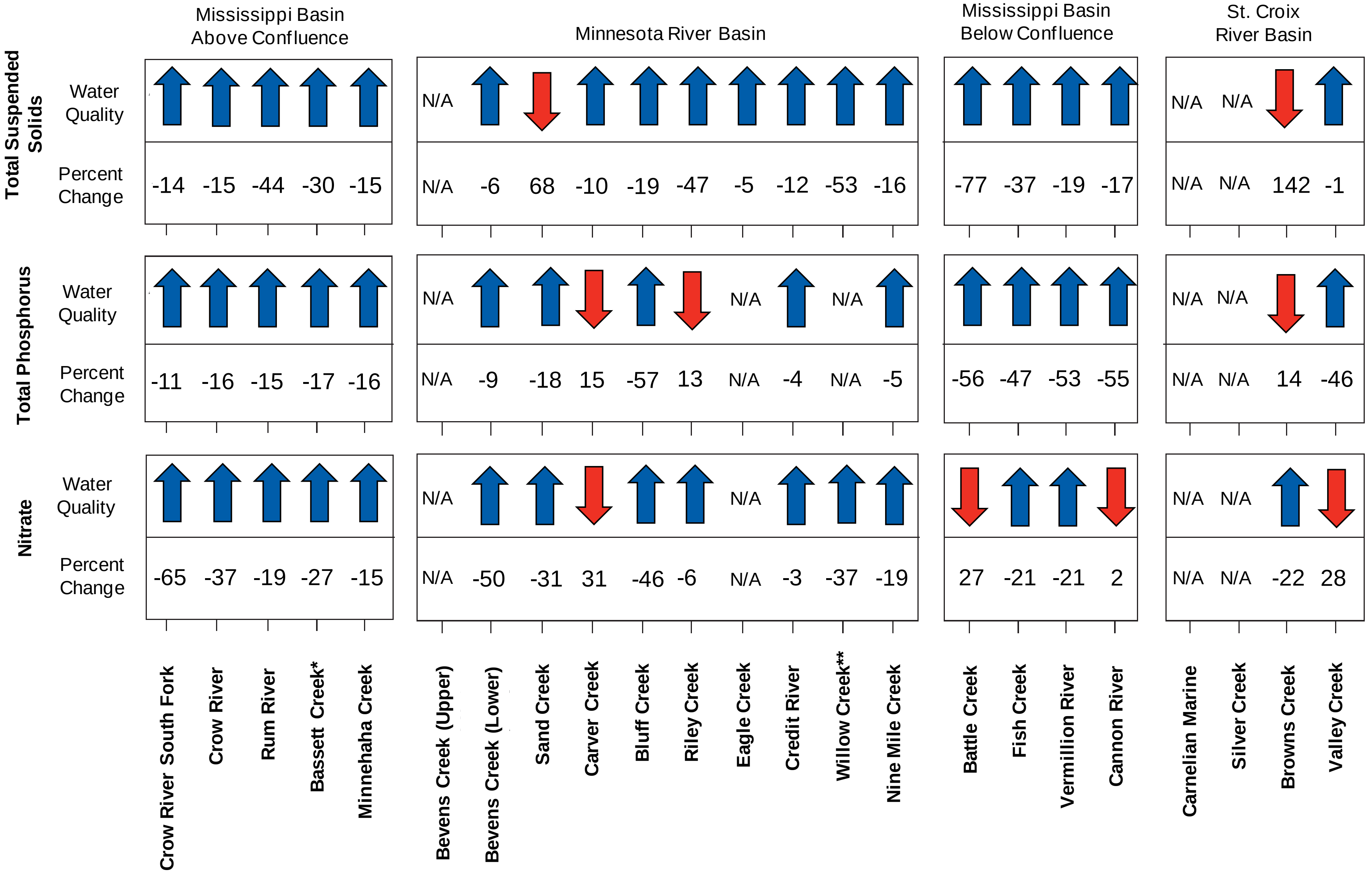
Estimated changes for TSS, TP, and NO_3 in MCES-monitored streams are presented below in two ways. First, tabulated results with directional arrows indicate increasing (blue upward arrow) and decreasing (red downward arrow) water quality, paired with percent change in flow-adjusted concentration estimated for 2008-2012 (Figure MH-25). Second, changes are shown by three seven-county metropolitan area maps (one each for TSS, TP, and NO_3 trends) with colored watersheds representing improving and declining water quality (Figure MH-26). In both figures no trend was reported for those QWTREND analyses with poor quality of statistical metrics (for example, $p>0.05$).

In general, of the 20 monitoring stations assessed, most exhibited improving water quality (and thus decreasing flow-adjusted concentration) for TSS, TP, and NO_3. There does not appear to be a spatial pattern for those few stations with decreasing water quality. There is no station with declining water quality for all three parameters, although both TP and NO_3 flow-adjusted concentrations increased in Carver Creek (a Minnesota River tributary) and TSS and TP increased in Browns Creek (a St. Croix River tributary).

The Mississippi River and its tributaries above the confluence with the Minnesota River typically had lower TSS flow-adjusted concentrations than the Minnesota River and associated tributaries, but higher pollutant flow-adjusted concentrations than the waters in the St. Croix River Basin. The trend analysis results indicate decreasing TSS flow-adjusted concentrations in all Mississippi River tributaries above the confluence with the Minnesota River. All of the Mississippi River tributaries above the Minnesota River had decreasing trends in both TP and NO_3 from 2008 to 2012.

Figure MH-25: Regional Estimated Trends in Flow-Adjusted Stream Concentrations of TSS, TP, and NO_3, 2008-2012

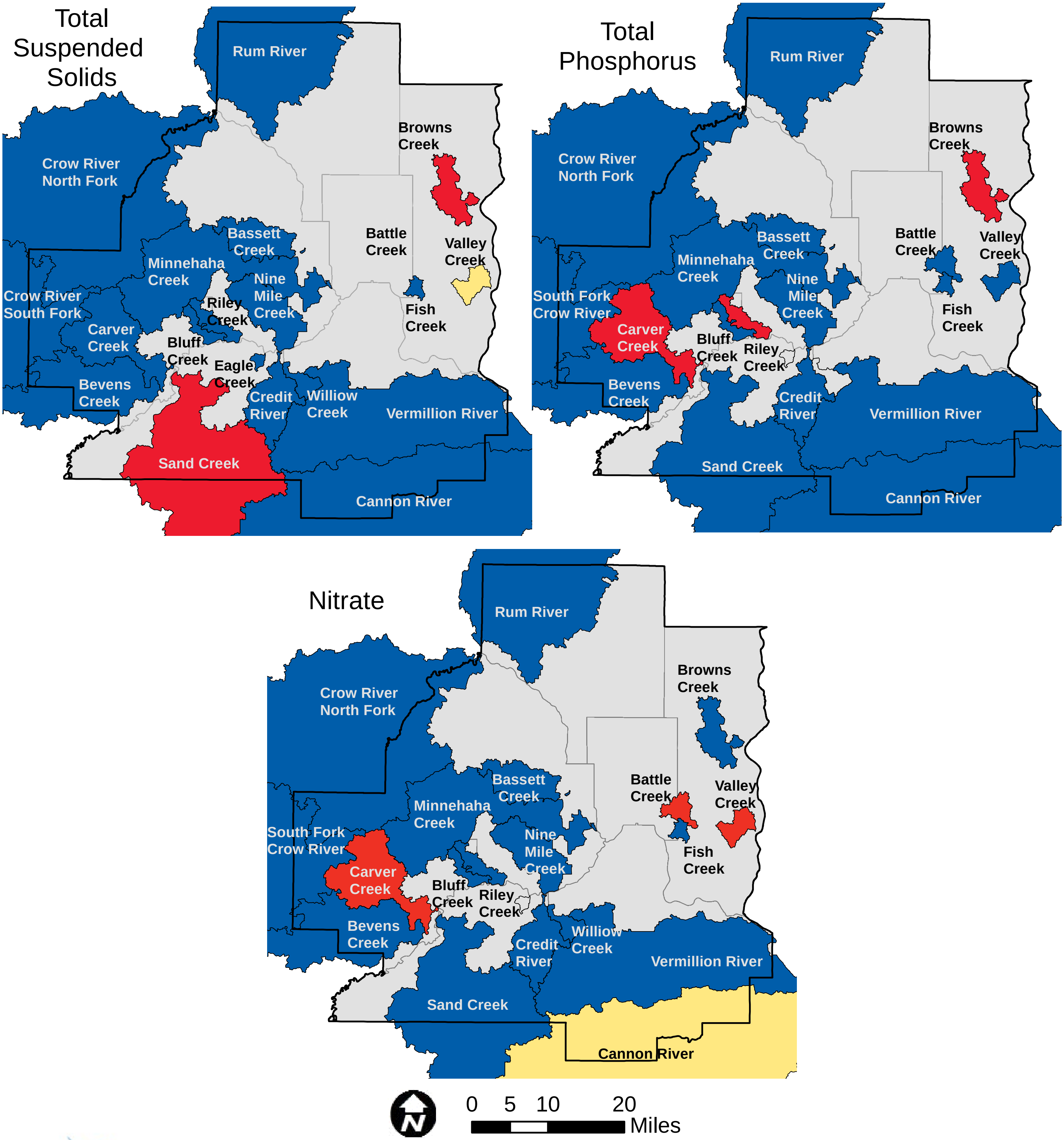
(Grouped by Major River Basin; As estimated by QWTrend)



Blue arrows indicate improved water quality; Red arrows indicate declining water quality.
"N/A" indicates analysis was not performed as data were not appropriate for analysis by QWTrend.
* Bassett Creek TSS Trends were assessed over 2009-2013. **Monitoring at Willow Creek was suspended in 2009.

Figure MH-26: Regional Maps of Estimated Trends in Flow-Adjusted Stream Concentrations of TSS, TP, and NO3, 2008-2012

(As estimated by QWTrend)



Less than -3% Change (Indicates Increasing Water Quality)

-3% to 3% Change

Greater than 3% Change (Indicates Decreasing Water Quality)

METROPOLITAN COUNCIL

Conclusions

Minnehaha Creek is a tributary to the Mississippi River and drains portions of Carver and Hennepin counties. It contains runoff from the cities of Saint Bonifacius, Victoria, Mound, Shorewood, Orono, Excelsior, Medina, Long Lake, Deephaven, Woodland, Wayzata, Minnetonka, Hopkins, Saint Louis Park, Edina, Richfield, and Minneapolis. The watershed is primarily urban, with small pockets of agricultural areas. The east portion of the watershed is intensively urban as it drains through the core of the metropolitan area. One WWTP discharges in the Upper Watershed, and most likely does not affect the water quality of Minnehaha Creek. The Upper Watershed is relatively hilly, while the topography steepens as Minnehaha Creek enters the Mississippi River Gorge at Minnehaha Falls. The monitoring station is located in Minneapolis, Minnesota. Downstream of the monitoring station, the creek flows over the Minnehaha Falls and then flows for another mile; thus the monitoring data presented in this report does not reflect the potential increases or decreases in water quality that may occur downstream of the monitoring station.

The water quality in Minnehaha Creek is affected by numerous factors: water releases from Lake Minnetonka; urban stormwater runoff; prevalence of impervious cover that reduces infiltration to groundwater; and the area geology. TSS in the stream (both FWM concentration and load) was low, both in comparison to the Mississippi River and the other MCES-monitored metropolitan area tributaries. The load values are low due to the intermittent flows in the creek which do not continually transport pollutants to the Mississippi River. Additionally, MCWD is working on many stream rehabilitation projects, which will stabilize stream banks and increase riparian areas to buffer upland runoff. All of these outcomes will reduce the in-stream TSS concentration (MCWD, 2014d).

The NO_3 and TP loads and concentrations are likely driven by urban stormwater runoff in the watershed. The most common causes of these nutrients in runoff is from fertilizers, lawn clippings, and pet wastes (MPCA, 2014b). The concentration and loads in Minnehaha Creek are lower than those in the Mississippi River and most of the other MCES-monitored metropolitan area tributaries. Trend analysis indicates one continual period of falling NO_3 and TP concentrations in the creek, suggesting educational outreach regarding the implementation of rain gardens, the proper use of fertilizers, and other techniques, is having an effect in improving stream water quality.

The Cl loads and concentrations in Minnehaha Creek were higher than the agricultural and low-density residential watersheds monitored by MCES, reflecting the high level of development and road density in the watershed and thus the relatively high input of Cl from road de-icers.

Trend analysis indicated downward trends in flow-adjusted concentrations of TSS, TP, and NO_3 since 1999, thus indicating improving water quality. This improvement may reflect the large number of improvement projects sponsored or completed by MCWD, cities, counties, park boards, and others. Example projects include stream restoration projects, citizen outreach and educational opportunities, and academic research primarily sponsored by MCWD and local governments.

Analysis of macroinvertebrate samples indicated the presence of some organic pollution during the monitored period, possibly significant organic pollution considering that no pollution intolerant species have been collected for the past seven years, and community diversity has been low. All of the M-IBI scores were below the impairment threshold, which suggest that the habitat and water quality of this stream reach were typically unable to sustain all of the needs for aquatic life.

Recommendations

This section presents recommendations for monitoring and assessment of Minnehaha Creek, as well as recommendations for partnerships to implement stream improvements. MCES recognizes that cities, counties, and local water management organizations, like MCWD, are ideally suited to target and implement volume reduction, pollutant removal, and stream restoration projects within the watershed. It is beyond the scope of this document to suggest locations for implementation projects. Instead, MCES encourages the local water management organization to use the results of this report to leverage funding and partnerships to target, prioritize, and implement improvement projects. MCES will repeat its analysis of water quality trends in 10 years, to assess potential changes in water quality.

The following recommendations have been drafted from the results of this report and are intended to assist MCES and its partners in directing future assessment work:

- MCES should work with our partners to analyze the load data from the monitoring stations upstream from our MCES station. This will help identify the origins of potential sources of the chemical loads in Minnehaha Creek. MCWD currently has monitoring stations upstream of the MCES station.

- MCES should validate spatial data for the Minnehaha Creek watershed to ensure the proper watershed boundaries are identified and determine if there are any special circumstances (that is, internal drainages, rerouted flows, or other factors) that alter previously reported boundaries.

- MCES should continue to evaluate the effects of groundwater withdrawal on surface waters, including updating analyses with the best available data and linking results to predictive groundwater modeling and the comprehensive planning process involving local communities.

- MCES should continue to analyze and evaluate the biomonitoring program. Potential additions could include a Stream Habitat Assessment similar to the habitat surveys performed by the MPCA or the addition of data on fish population and algal communities.

- MCES and partners (especially Minnehaha Creek Watershed District, University of Minnesota, and Minneapolis Park and Recreation Board) should create a timeline of past projects and management activities that may have improved or altered stream flow and/or water quality. This information would allow more accurate assessment and interpretation of trends.

- MCES staff should continue to serve on technical advisory committees and other work groups to aid in management of Minnehaha Creek.

- The Minnehaha Creek watershed is relatively developed, and many of the native soils have been disturbed. Published soil surveys may not be representative of actual conditions at specific locations. For installation of infiltration-based stormwater practices (like bioinfiltration basins, rain gardens, and pervious pavers), soil borings should be taken from the exact location of the proposed location to assess level of soil filling or disturbance. Based on the boring results, best management practices designs should be customized and appropriate soil amendments added.

Citations

Brooks, P.D., Grogan, P., Templer, P.H., Groffman, P., Oquist, M.G., Schimel, J. 2011. Carbon and nitrogen cycling in snow-covered environments. Geography Compass 5/9:682-699.

Chirhart, Joel. 2003. Development of a macroinvertebrate index of biological integrity (MIBI) for rivers and streams of the St. Croix River Basin in Minnesota. St. Paul: Minnesota Pollution Control Agency (MPCA).

Emmons & Olivier Resources, Inc. 2003. MCWD H/H and Pollutant Loading Study. Oakdale: Emmons & Olivier Resources, Inc.

Emmons & Olivier Resources, Inc. 2011. MCWD Lakes TMDL – Lake Nokomis, Parley Lake, Lake Virginia, Wassermann Lake. Oakdale: Emmons & Olivier Resources, Inc.

Jennings, C. 2010. Sediment source apportionment to the Lake Pepin TMDL: source characterization. St. Paul: Minnesota Geological Survey.

Metropolitan Council. 2010. Evaluation of groundwater and surface-water interaction: guidance for resource assessment, Twin Cities Metropolitan Area, MN. Prepared by Barr Engineering. St. Paul: Metropolitan Council.

Minneapolis Parks and Recreation Board (MPRB). n.d. Historical Marker at Minnehaha Falls. 4801 South Minnehaha Park Drive, Minneapolis MN 55417.

Minnehaha Creek Watershed District (MCWD). 2007. Minnehaha Creek Watershed District comprehensive water resources management plan 2007-2017. Maple Plain: Wenck Associates, Inc.

Minnehaha Creek Watershed District (MCWD). 2014a. Headwaters control structure management policy and operating procedures. *In* Minnehaha Creek Watershed District, quality of water, quality of life. <http://minnehahacreek.org/projects-capital-projects/past-projects/headwaters-control-structure-management-policy-and-operating> (accessed 05.02.14).

Minnehaha Creek Watershed District (MCWD). 2014b. Minnehaha Creek base flow study. *In* Minnehaha Creek Watershed District, quality of water, quality of life. <http://minnehahacreek.org/project/minnehaha-creek-base-flow-study> (accessed 06.02.14).

Minnehaha Creek Watershed District (MCWD). 2014c. Questions about water levels? *In* Minnehaha Creek Watershed District, quality of water, quality of life. <http://minnehahacreek.org/data-center/water-levels> (accessed 05.03.14).

Minnehaha Creek Watershed District (MCWD). 2014d. Minnehaha Creek urban corridor restoration. *In* Minnehaha Creek Watershed District, quality of water, quality of life. <http://minnehahacreek.org/projects-capital-projects/current-projects/minnehaha-creek-urban-corridor-restoration> (accessed 18.03.14).

Minnesota Climatology Working Group. 2013. Precipitation Grids - an explanation. St. Paul: Minnesota Climatology Working Group. <http://climate.umn.edu/gridded_data/precip/wetland/explain_grids.htm> (accessed 17.01.14).

Minnesota Department of Natural Resources (MnDNR). 2011. Proposed rules relating to Mississippi River Corridor Critical Area. St. Paul: Minnesota Department of Natural Resources. <http://files.dnr.state.mn.us/input/rules/rulemaking/mrcca/draft-rules.pdf> (accessed 17.03.14).

Minnesota Department of Natural Resources (MnDNR). 2014. Lake Finder. *In* Minnesota Department of Natural Resources. St. Paul: Minnesota Department of Natural Resources. < http://www.dnr.state.mn.us/lakefind/index.html> (accessed 11.07.13).

Minnesota Pollution Control Agency (MPCA). 2010. Regionalization of Minnesota's rivers for application of river nutrient criteria. St. Paul: Minnesota Pollution Control Agency. Document wq-s6-18.

Minnesota Pollution Control Agency (MPCA). 2011a. Aquatic life water quality standards draft technical support document for total suspended solids (turbidity). St. Paul: Minnesota Pollution Control Agency. Document wq-s6-11.

Minnesota Pollution Control Agency (MPCA). 2013. Minnesota nutrient criteria development for rivers (Update of November 2010 Report). St. Paul: Minnesota Pollution Control Agency. Document wq-s6-08.

Minnesota Pollution Control Agency (MPCA). 2014a. 2014 Proposed Impaired Waters List. St. Paul: Minnesota Pollution Control Agency. Document wq-iw1-47.

Minnesota Pollution Control Agency (MPCA). 2014b. Pollutants associated with nonpoint sources. *In* Minnesota Stormwater Manual. St. Paul: Minnesota Pollution Control Agency. <http://stormwater.pca.state.mn.us/index.php/Pollutants_associated_with_nonpoint_sources> (accessed 06.02.14).

Minnesota Pollution Control Agency (MPCA). 2014c. Development of a macroinvertebrate-based Index of Biological Integrity for assessment of Minnesota's rivers and streams. Minnesota Pollution Control Agency, Environmental Analysis and Outcomes Division, St. Paul, MN. Document wq-bsm4-01.

Moore, T., Nieber, J.L, Gulliver, J.S., Magner, J., Lahti, L.B. 2013. Minnehaha Creek baseflow and stormwater infiltration interim project report 1. Prepared for the Minnehaha Creek Watershed District. Minneapolis: University of Minnesota.

Nieber, J.L. 2014. Baseflow restoration through stormwater infiltration. Minnehaha Creek Watershed District Office, Minnetonka, MN. 5 February 2014. Oral Presentation.

Novotny, E. and H. Stefan. 2007. Stream flow in Minnesota: indicator of climate change. J. Hydrol. 334, 319-333.

Schottler, S., Ulrich, J., Belmont, P., Moore, R., Lauer, J.W., Engstrom, D., Almendinger, J.E. 2013. Twentieth century agricultural drainage creates more erosive rivers. Hydrol. Process. (2013). doi: 10.1002/hyp.

Tetra Tech, Inc. 2013. Minnehaha Creek/ Lake Hiawatha total maximum daily load – review draft. Cleveland: Tetra Tech, Inc.

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). 2009. National Engineering Handbook, title 210–VI. Part 630, chapter 7. Washington, DC: NRCS. <ftp://ftp.wcc.nrcs.usda.gov/wntsc/H&H/NEHhydrology/ch7.pdf> (accessed 09.04.14).

U.S. Environmental Protection Agency (USEPA). 2007. An approach for using load duration curves in the development of TMDLs. Washington D.C.: U.S. Environmental Protection Agency. EPA 841-B-07-006.

Vecchia, A.V. 2003. Water quality trend analysis and sampling design for streams in North Dakota, 1971-2000. USGS Water Resources Investigations Report 03-4094. <http://nd.water.usgs.gov/pubs/wri/wri034094/index.html> (accessed 15.08.07).

Walker, W.W. 1999. Simplified procedures for eutrophication assessment and prediction: User Manual. US Army Corps of Engineers – Waterways Experiment Station Instruction Report W-96-2.

Wenck and Associates, Inc. 2004. Minnehaha Creek Watershed District Stream Assessment Data Report—Volume 1: Minnehaha Creek. Maple Plain: Wenck and Associates, Inc. <http://www.minnehahacreek.org/project/stream_assessment_2003> (accessed 10.12.14).

Wenck and Associates, Inc. 2013. Minnehaha Creek Watershed District upper watershed nutrient and bacteria TMDL study- DRAFT. Maple Plain: Wenck and Associates, Inc.

Wright, H.E., Jr. 1990. Geologic history of Minnesota rivers. Minnesota Geologic Survey Educational Series 7. St. Paul: Minnesota Geological Society.

390 Robert Street North
St Paul, MN 55101-1805

651.602.1000
TTY 651.291.0904
public.info@metc.state.mn.us
metrocouncil.org