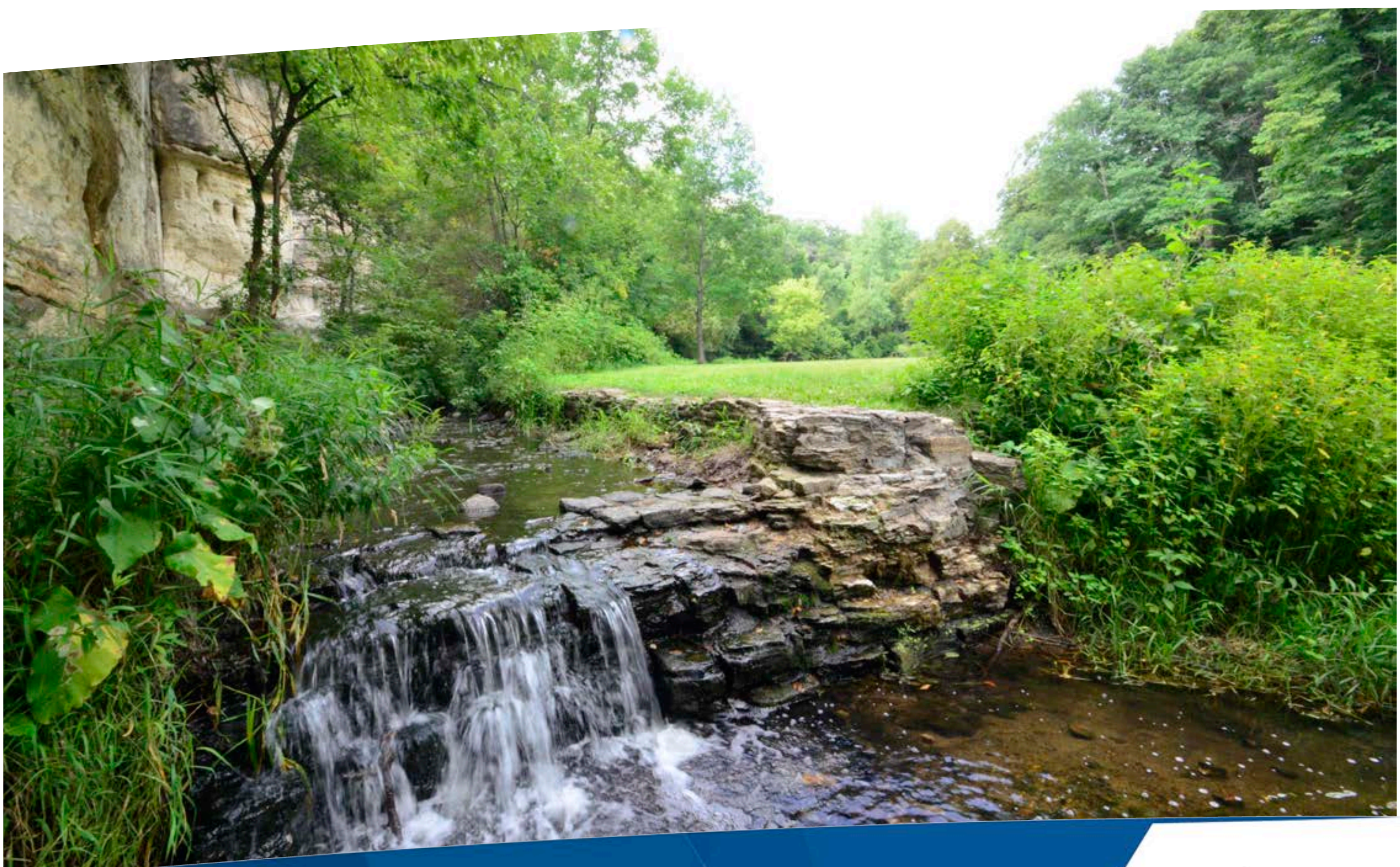
Comprehensive Water Quality Assessment of Select Metropolitan Area Streams

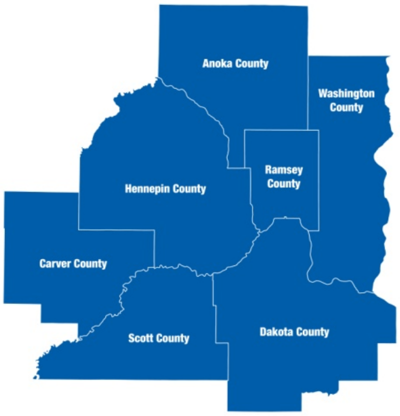
BATTLE CREEK



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 partners 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, *Battle Creek*, is one in a series produced as part of the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams.* Located in Ramsey and Washington counties, Battle 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 Battle Creek.

Cover Photo

The photo on the cover of this section depicts Battle Creek in the Battle Creek Regional Park in St. Paul, MN. It was taken by Metropolitan Council staff.

Recommended Citations

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

Metropolitan Council. 2014. *Battle 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

Battle Creek is located in the central eastern metropolitan area and is a tributary to the Mississippi River, below the Mississippi's confluence with the Minnesota River. It drains approximately 11.2 square miles of mostly urban areas through portions of the cities of Oakdale, Woodbury, Maplewood, St. Paul, and Landfall in Ramsey and Washington Counties.

The goals of this chapter are:

- to document those characteristics of Battle Creek and its watershed most likely to influence flow and water quality.
- to present results of flow, water quality, and biological data assessments.
- to present statistical trend assessments of TSS (total suspended solids); TP (total phosphorus), and NO_3 (nitrate).
- to draw conclusions about landscape features, climatological changes, and human activities possibly affecting flow and water quality.
- to compare Battle Creek flow and water quality with other streams within the metropolitan area monitored by Metropolitan Council Environmental Services (MCES).
- to make general recommendations for future monitoring and assessment activities, watershed management, and other potential remediative actions.

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

Partnerships and Funding

MCES has supported water quality monitoring of Battle Creek since 1996 as part of the Watershed Outlet Monitoring Program (WOMP). MCES partners with the Ramsey Washington Metro Watershed District (RWMWD) to operate the station. MCES funds the monitoring station and laboratory analysis of samples collected.

Monitoring Station Description

The monitoring station is located on Battle Creek in St. Paul, Minnesota, 2.2 miles upstream from the creek confluence with the Mississippi River. The monitoring station is located just west of Highway 61. The monitoring station includes continuous stage monitoring, base flow grab sample collection, and event-based composite sample collection. Stage is measured with a gas-purge bubbler system. Stage is calibrated on site visits with an onsite staff gauge. A continuous discharge record is obtained by relating stage to flow with a rating curve unique to the site. Stage-discharge measurements are made with an acoustic doppler velocimeter several times a year, and the rating curve is adjusted when rating points fall significantly off the existing rating curve, or a change in the station cross-section is observed.

There is no rain gauge at this station; daily precipitation totals from Minnesota Climatology Working Group stations 217377-St. Paul, 218450-University of Minnesota St. Paul, and 217379-St. Paul 3SW 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 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.

The Battle Creek station has been in operation continuously since June 1996, with the first full year of sample collection beginning in 1997. This report will use flow data beginning in June 1996, and water quality sampling data from 1997-2012.

Stream and Watershed Description

Battle Creek is almost 4 miles long and originates as the outlet of Battle Creek Lake in northwest Woodbury. The creek travels west and then southwest through Maplewood and St. Paul before discharging into Pigs Eye Lake and ultimately the Mississippi River.

There are two major lakes in the Battle Creek watershed. The northeastern part of the watershed, 1,732 acres or about 24% of the total watershed, drains to Tanners Lake (surface area 70 acres) in Oakdale and Landfall (RWMWD, 2007). Tanners Lake then discharges to Battle Creek Lake in Woodbury. The Battle Creek Lake (surface area 103 acres) direct watershed encompasses all of the southeast part of the watershed, 2,593 acres, or about 36% of the total watershed. Battle Creek Lake then forms the headwaters of Battle Creek. The western part of the watershed downstream of Battle Creek Lake - 2,921 acres or about 40% of the total watershed - does not first drain to one of these major lakes and discharges through a series of smaller lakes, wetlands, and storm sewer directly to the creek. Water quality in Battle Creek is partially driven by water quality in Battle Creek Lake, which tempers creek flashiness and evens out peaks in pollutant concentration.

The Battle Creek watershed has a total of 7,143 acres, with the entire watershed upstream of the monitoring station (Figure BA-1; Table BA-1). The watershed is heavily urbanized, with 4,482 acres/62.7% developed urban land, including 1,594 (22.3%) acres with 76-100% impervious and only 22 acres/0.3% of agricultural land. Other primary land covers in the watershed are forest, grasses/herbaceous, and wetlands. The watershed encompasses portions of the cities of Woodbury, Oakdale, Maplewood, and St. Paul, and all of Landfall. The entirety of the Battle Creek watershed is within the Metropolitan Council's jurisdiction (Council Districts of 11, 12, and 13). The watershed is most heavily urbanized along the I-94 corridor in St. Paul and along the I-494/I-694 corridor in Oakdale and Woodbury. The Battle Creek watershed is contained with the RWMWD, an independent governmental unit responsible for protecting the water resources of the watershed.

Table BA-1: Battle Creek Land Cover Classes[1]

Land Cover Class	Monitored	
	Acres	**Percent**
5-10% Impervious	397	5.6%
11-25% Impervious	227	3.2%
26-50% Impervious	1,749	24.5%
51-75% Impervious	516	7.2%
76-100% Impervious	1,594	22.3%
Agricultural Land	22	0.3%
Forest (all types)	692	9.7%
Open Water	210	2.9%
Barren Land	0	0.0%
Shrubland	33	0.5%
Grasses/Herbaceous	906	12.7%
Wetlands (all types)	798	11.2%
Total	**7,143**	**100.0%**

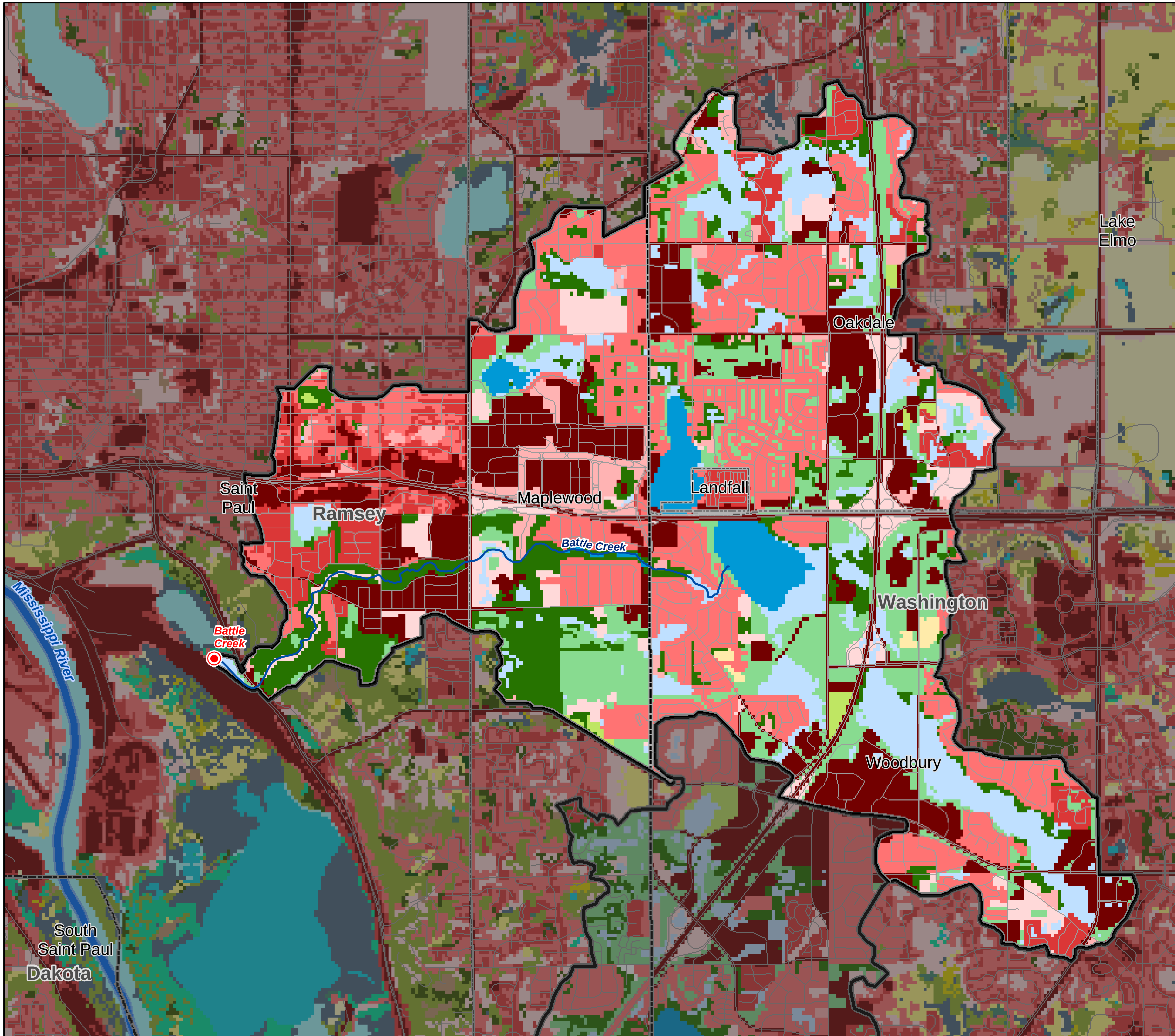
[1] Land cover spatial data file provided by MnDNR. The data is a composite of the 2008 MLCCS (Minnesota Land Cover Classification System), which covered primarily the 7-county metro area; and the 2001 NLCD (National Land Cover Data), which covered the outstate areas not included in the 2008 MLCCS.

Figure BA-1

METROPOLITAN COUNCIL

MLCCS-NLCD Hybrid Land Cover

Battle Creek



- MCES Stream Monitoring Sites
- USGS Flow Stations
- Mainstems (Monitored and Unmonitored)
- Major Mainstem Tributaries
- Monitored Watershed Boundaries
- Unmonitored Portion of Watersheds
- NCompass Street Centerlines, 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						
Battle Creek						
	Monitored		**Unmonitored**		**Total**	
Land Cover Class	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
5-10% Impervious	397	5.6%				
11-25% Impervious	227	3.2%				
26-50% Impervious	1,749	24.5%				
51-75% Impervious	516	7.2%				
76-100% Impervious	1,594	22.3%				
Agricultural Land	22	0.3%		Not Available		
Forest (all types)	692	9.7%				
Open Water	210	2.9%				
Barren Land	0	0.0%				
Shrubland	33	0.5%				
Grasses/Herbaceous	906	12.7%				
Wetlands (all types)	798	11.2%				
Total	**7,143**	**100.0%**				

0 0.5 1 1.5
Miles

According to the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) STATSGO soils data, all native soils in the Battle Creek watershed are type B soils, which have moderately low runoff potential (USDA, 2009). Because the Battle Creek watershed is heavily urbanized, many of the native soils have been disturbed, and the STATSGO database 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.

The majority of the watershed is sandy, hummocky till, with flatter areas of glacial lake sediments and outwash in the center and northern parts of the watershed (Meyer, 2007). Battle Creek discharges to the Mississippi River floodplain on an alluvial fan. A tunnel valley cuts through the watershed from north to south, containing Battle Creek and Tanners Lakes. The maximum watershed elevation is 1104.3 MSL (mean sea level) and the minimum elevation is 699.1 (Figure BA-2). The watershed is highest in the northeast and along its south border, and lowest in the west, where the creek enters the Mississippi River floodplain. Slopes in the watershed are generally gradual: 4% of slopes within the monitored area are considered steep, and an additional 1% are considered very steep. Steep slopes are those between 12-18%, and very steep slopes are those 18% or greater (MnDNR, 2011). For most of its length the creek travels through a steep ravine that cuts down through the Mississippi River bluffs, and this ravine makes up the majority of steep areas in the watershed.

There are few point sources within the Battle Creek Watershed (Figure BA-3). The watershed contains one individual wastewater facility holding an NPDES discharge permit, an alum injection system in a pond upstream of Tanner's Lake, built by RWMWD to remove phosphorus from stormwater runoff. The watershed also includes two facilities holding industrial stormwater permits. Some of these facilities have multiple discharge points shown on Figure BA-3. There are no domestic wastewater facilities in the watershed and no feedlots.

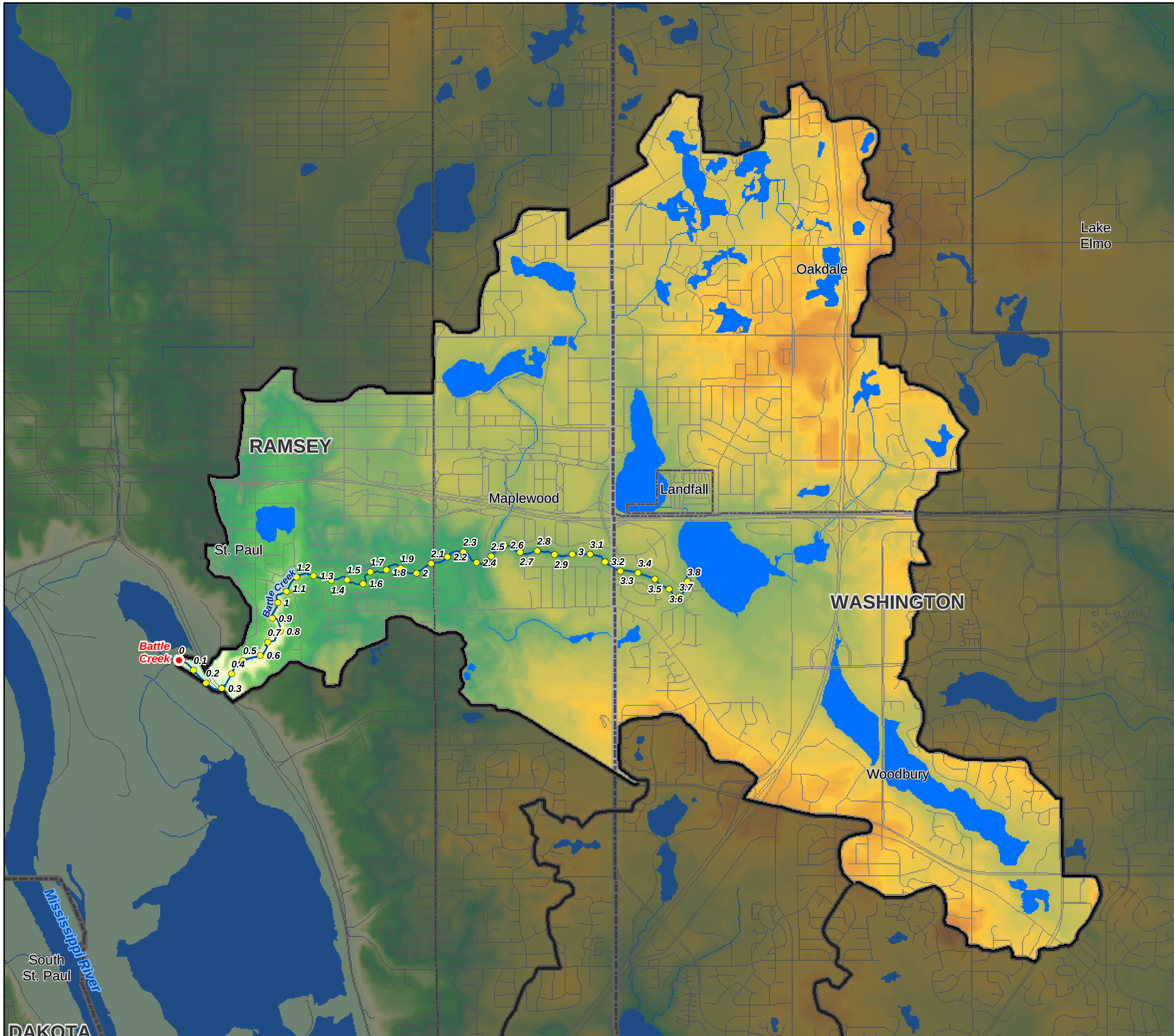
RWMWD and the cities within its borders have engaged in several capital improvement projects in the Battle Creek watershed to address water quality since the installation of the MCES monitoring station. From 1997-1998, the watershed engaged in a series of improvements to improve water quality in Tanners Lake. The projects included constructing an alum treatment facility upstream of Tanners Lake, upgrading a degraded wetland upstream of Tanners Lake to a multi-celled treatment system, constructing a pond upstream of the lake to intercept stormwater runoff from two schools, and constructing a berm around part of the lake to reroute direct stormwater discharge into an existing treatment pond (RWMWD, n.d.a). From 1999-2000, two small dry ponds with a polymer filtration system were installed in residential neighborhoods upstream of the Tamarack Swamp (RWMWD, n.d.b) to provide treatment to a previously untreated area and protect the wetland. Tamarack Swamp is a high quality wetland with a diverse habitat and sensitive ecosystem (RWMWD, 2007). From 2002-2003 the Fortis Pond upstream of Battle Creek Lake was expanded and a multi-stage outlet added to improve performance of the pond (RWMWD, n.d.c). Also from 2002-2003, a project along Valley Creek Road diverted runoff away from the Tamarack Swamp, into a series of infiltration basins with check dams, a flow splitter with an infiltration basin, and an extended detention pond and filtration system (RWMWD, n.d.d). The goal of this project was to remove phosphorus from runoff prior to discharging to Tamarack Swamp. From 2002-2004 a water quality treatment pond was constructed just north of I-94 to treat runoff that formerly discharged directly into Battle Creek Lake (RWMWD, n.d.e). From 2011-2012 the city of Maplewood reconstructed 2 miles of residential streets in the northwest corner of the Battle Creek watershed as "living streets", in part with a grant from RWMWD. The area was reconstructed with raingardens, a large regional stormwater basin, additional boulevard trees, and reduced impervious surfaces. The project significantly decreased the amount of stormwater running untreated into the stormwater system (RWMWD n.d.f.).

Figure BA-2

METROPOLITAN COUNCIL

Watershed Topography

Battle Creek



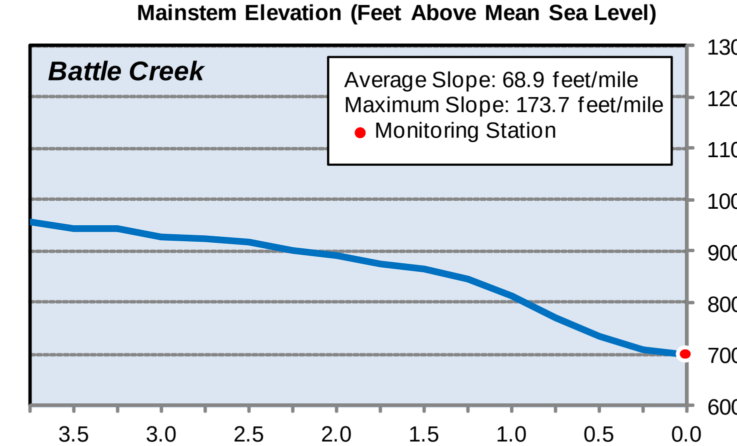
- MCES Stream Monitoring Sites
- USGS Flow Stations
- Stream Mile Markers
- Mainstems (Monitored and Unmonitored)
- Monitored Watershed Boundaries
- Public Waters Inventory
- Other Rivers and Streams
- City and Township Boundaries
- County Boundary
- NCompass Street Centerlines, 2012

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)



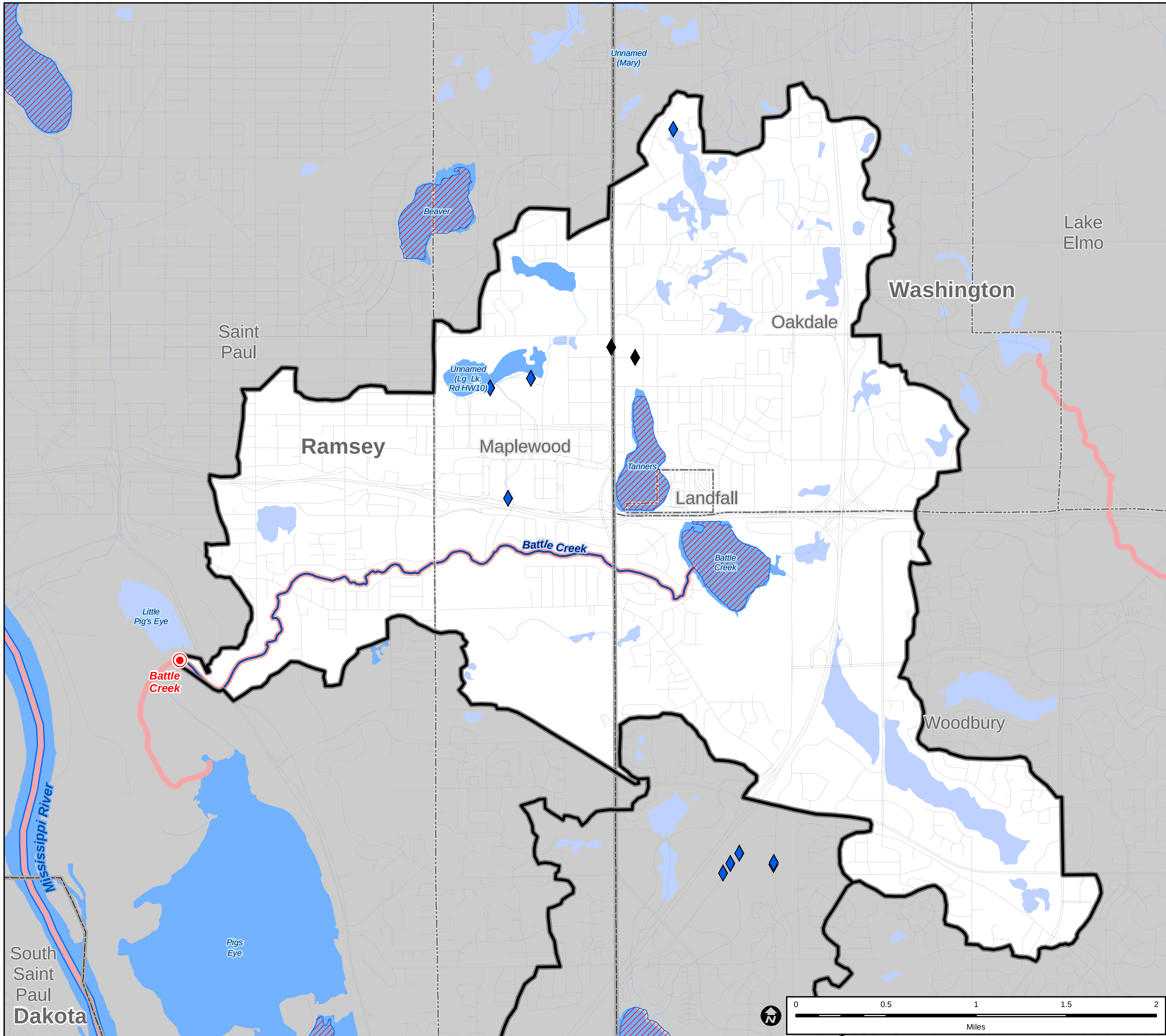
0 0.5 1 1.5
Miles

Figure BA-3

METROPOLITAN COUNCIL

Public and Impaired Waters and Potential Pollution Sources

Battle 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

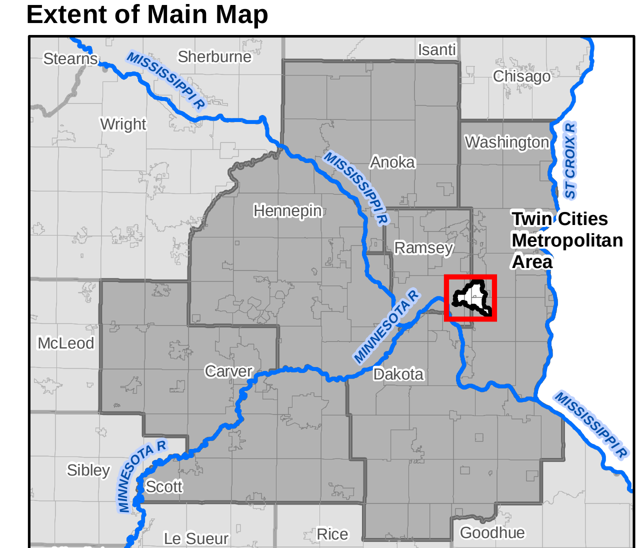
Feedlots with 100 or more animal units **

- 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 Battle Creek watershed contains one stream reach and two lakes that are included on the MPCA 2014 Impaired Waters List (Figure BA-3; Tables BA-2 and BA-3). The entire length of Battle Creek from Battle Creek Lake to the Mississippi River (Pigs Eye Lake) is impaired for aquatic life due to stressors affecting the fish and macroinvertebrate communities and for excess chloride.

Battle Creek and Tanners Lakes are both impaired for aquatic consumption based on mercury and are covered by the statewide mercury TMDL, and are also both impaired for aquatic life based on excess chloride. Battle Creek Lake was previously impaired for aquatic recreation based on excess nutrient levels; however, based on additional monitoring, Battle Creek Lake was delisted for excess nutrients on the 2014 list.

Table BA-2: Battle Creek Impaired Stream Reaches as Identified on the MPCA 2014 Impaired Waters List

Reach Name	Reach Description	ID	Affected Use(s)[1]	Approved Plan	Needs Plan[2]
Battle Creek	Battle Creek Lk to Pigs Eye Lk	07010206-592	AQL	--	Cl, F-IBI, M-IBI

[1] AQL = Aquatic Life;

[2] Cl = Chloride; F-IBI = Fisheries Bioassessments; M-IBI = Aquatic Macroinvertebrates Bioassessments;

Table BA-3: Battle Creek Watershed Impaired Lakes as Identified on the MPCA 2014 Impaired Waters List

Lake Name	Lake ID	Affected Use(s)[1]	Approved Plan[2]	Needs Plan[2]
Battle Creek	82-0091-00	AQC, AQL	HgF, Nutrients (delisted for Nutrients in 2014)	Cl
Tanners	82-0115-00	AQC, AQL	HgF	Cl

[1] AQC = Aquatic Consumption; AQL = Aquatic Life;

[2] HgF = Mercury in Fish Tissue; Cl = Chloride;

Hydrology

MCES has monitored flow on Battle Creek since June of 1996. Flow measurements are collected at 10-minute increments and aggregated to daily averages. The monitoring equipment on Battle Creek is removed each fall to ensure equipment doesn't freeze, and then reinstalled in the spring. Daily averages during this winter period are estimated using gauge readings taken throughout the winter. The hydrograph of Battle Creek, which displays daily average flow, daily precipitation, and the flow associated with grab and composite samples, indicates the variation in both intra-annual and inter-annual flow rates (Figure BA-4), and the responsiveness of flow to precipitation events.

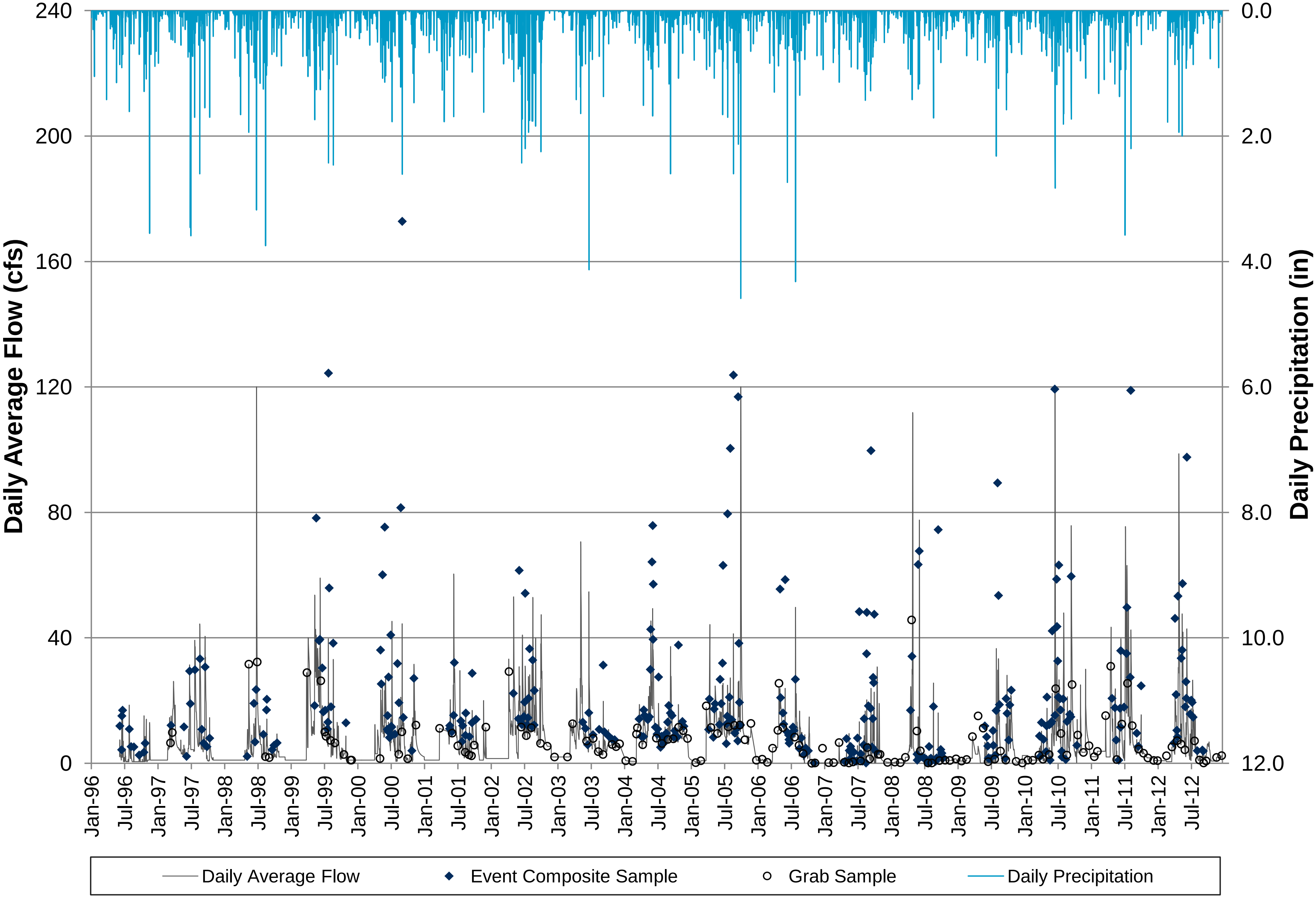
The MCES sampling program specifies collection of baseflow grab samples between events and event-based composites. The hydrograph indicates samples were collected during most events and that baseflow was also adequately sampled.

The MnDNR monitors water levels on Battle Creek Lake. Using the MnDNR water levels (MnDNR, 2013) and a RWMWD rating curve determined from survey information and HEC-RAS modeling (J. Koehler, Barr Engineering, personal communication, July 25, 2013), Battle Creek Lake discharge was estimated. The median percentage that Battle Creek Lake discharge makes up of Battle Creek flow is 52%. During winter periods when Battle Creek Lake is frozen, there was little or no discharge from the lake. However, Battle Creek Lake has an important influence on Battle Creek's hydrology during ice-free periods.

Flow duration analysis of daily average flows indicates the upper 10th percentile flows for period 1996-2012 ranged between approximately 15-120 cfs, while the lowest 10th percentile flows ranged from 0-0.5 cfs (See Figure BA-11 in the ***Flow and Load Duration Curves*** section of this report).

Additional annual flow and volume metrics are shown on Figures BA-5 to BA-8, along with the annual pollutant load parameters. The first graph on each sheet illustrates an annual flow metric: average annual flow (a measure of annual flow volume); areal-weighted flow; and fraction of annual precipitation converted to flow. Figure BA-5 indicates the highest average annual flow (and thus the highest volume of flow) during 1997-2012 occurred during 2005(approximately 10.1 cfs average annual flow); the lowest in 2007 (approximately 2.2 cfs average annual flow).

Figure BA-4: Battle Creek Daily Average Flow, Sample Flow, and Precipitation, 1996-2012*



*Precipitation record was acquired from NWS COOP stations: 217377-St. Paul, 218450-Univ of Minn St. Paul, and 217379-St. Paul 3SW

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 Battle Creek to groundwater withdrawals, MCES staff examined spatial datasets of vulnerable stream segments and basins created as part of the 2010 regional groundwater analysis. The entire length of Battle Creek is considered vulnerable, with the estimated creek surface elevation below the water table. Tanners and Battle Creek Lakes are also considered vulnerable, with the water table modeled above the elevation of each lake. Both lakes also have large littoral areas, which makes them especially susceptible to impacts from changes in lake stage. A number of other unnamed wetlands, primarily in the north and south central parts of the watershed, are also identified as potentially vulnerable.

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.

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 TSS, TP, TDP, NO_3, NH_3, and Cl for each full year of monitored data in Battle Creek (1997-2012). Flow monitoring and sampling began in June 1996, but loads are calculated beginning in 1997, the first complete year of data collection. Figures BA-5 through BA-8 illustrate annual loads expressed as mass, as flow-weighted mean (FWM) concentration, as mass-per-unit area (lb/ac), and as mass-per-unit area-per inch of precipitation (lb/ac/in), as well as three hydrological metrics (annual average flow rate, depth of flow (annual flow per unit area) and precipitation depth, and runoff ratio). A later section in this report (***Comparison with Other Metro Area Streams***) offers graphical comparison of the Battle Creek loads and FWM concentrations with the other MCES-monitored metropolitan area tributaries.

The flow metrics indicate year-to-year variation in annual flow rate likely driven by variation in annual precipitation amount as well as by variation in frequency of intense storm events. The fraction of annual precipitation delivered as flow was relatively stable from 1997 through 2006, before dipping substantially in 2007-2009 before coming back up during 2010-2011. Year-to-year variability is likely influenced by drought periods, by low soil moisture during antecedent dry periods, by increase capacity in upland storage areas during drought periods, etc. Because the creek originates at Battle Creek Lake, drought effects can be prolonged. A drop in Battle Creek Lake water level can take several years to recover, causing low creek flows to persist even through wet years.

The annual mass loads for all parameters exhibited significant year-to-year variation, indicating the influence of precipitation and flow on the transport of pollutants within the watershed and the stream.

The annual FWM concentrations for all parameters also fluctuated from year-to-year and were likely influenced by annual precipitation and flow. Changes in TSS, TP, TDP, and Cl between years generally track well with variations in flow. NO_3 concentrations slowly decreased from 2001 to 2011 before increasing slightly in 2012. At the same time as NO_3 was decreasing, NH_3 increased fairly steadily from 2001 to 2008. There may have been watershed or in-stream processes that shifted nitrogen species from NO_3 to NH_3.

Figures BA-7 and BA-8 present the areal and precipitation-weighted loads, respectively. These graphics are presented to assist local partners and watershed managers, and will generally not be discussed here.

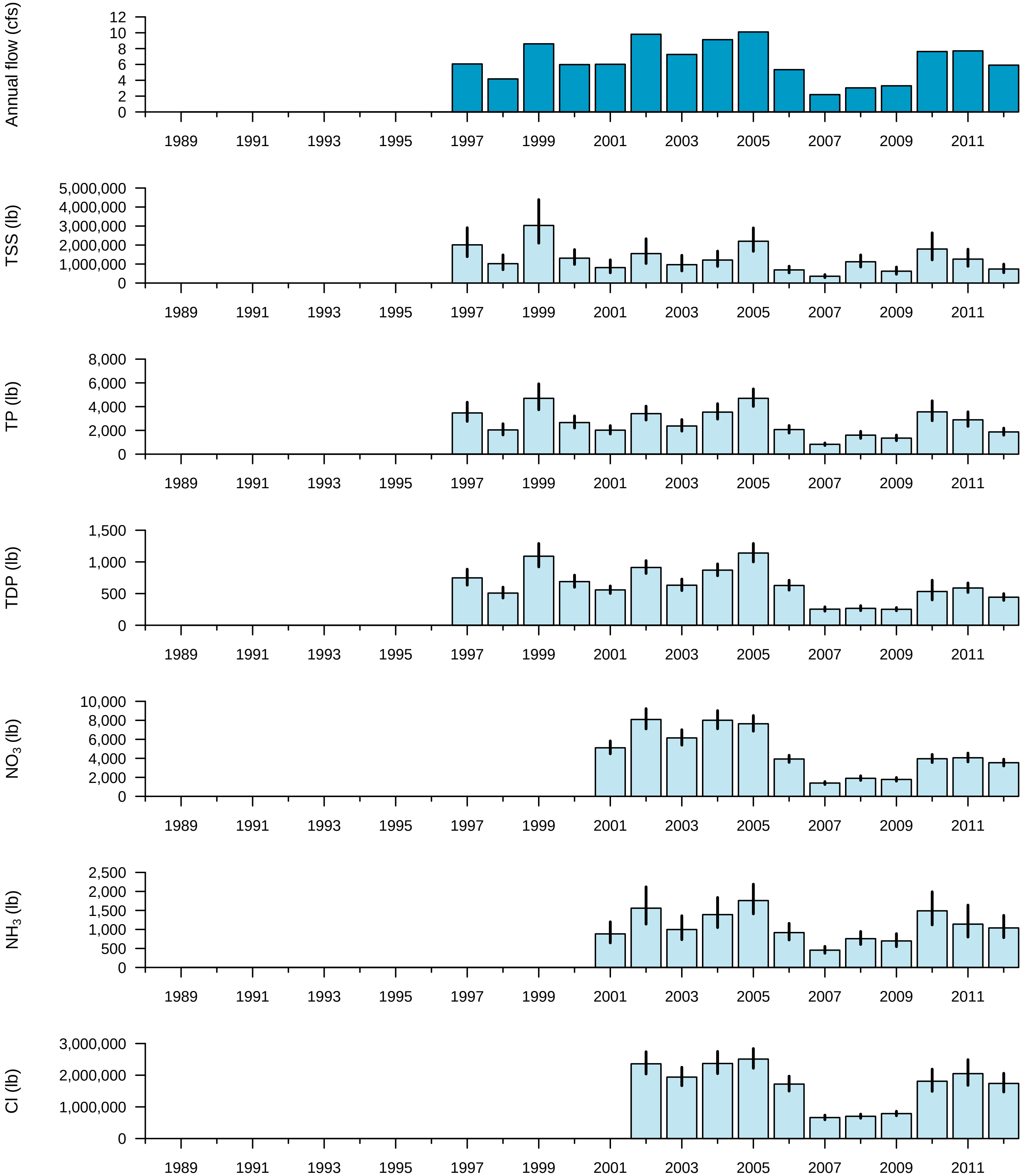
The Flux32 loads and FWM concentrations were also compiled by month to allow analysis of temporal patterns in the loads in Battle Creek (Figure BA-9 and BA-10). The results for each month are expressed in two ways: the monthly results for the most recent year of data (2012 for Battle Creek) and the monthly average for 2003-2012 (with a bar indicating the maximum and minimum value for that month).

For most constituents in Battle Creek, the mass load was low in the months of January and February and then increased in March and April, likely due to effects of snow melt and spring rains. Mass load usually peaked in May before decreasing slightly through the summer months and then peaking again in September and October. This secondary load pulse is likely due to fall precipitation occurring after tree leaf fall and vegetation die-off. Loads fell off in November and December as lakes froze and snowpack began to build.

The FWM concentration showed less month-to-month variability than the loads. TSS and TP concentrations were highest in spring and fall, corresponding to high flow periods. TDP concentrations were fairly stable, but a little lower in the winter as compared to the rest of the year. NO_3 concentrations were also pretty stable but a little higher in the winter than the rest of the year. Cl concentrations were highest in November-February, likely reflecting the impact of road de-icers during winter months.

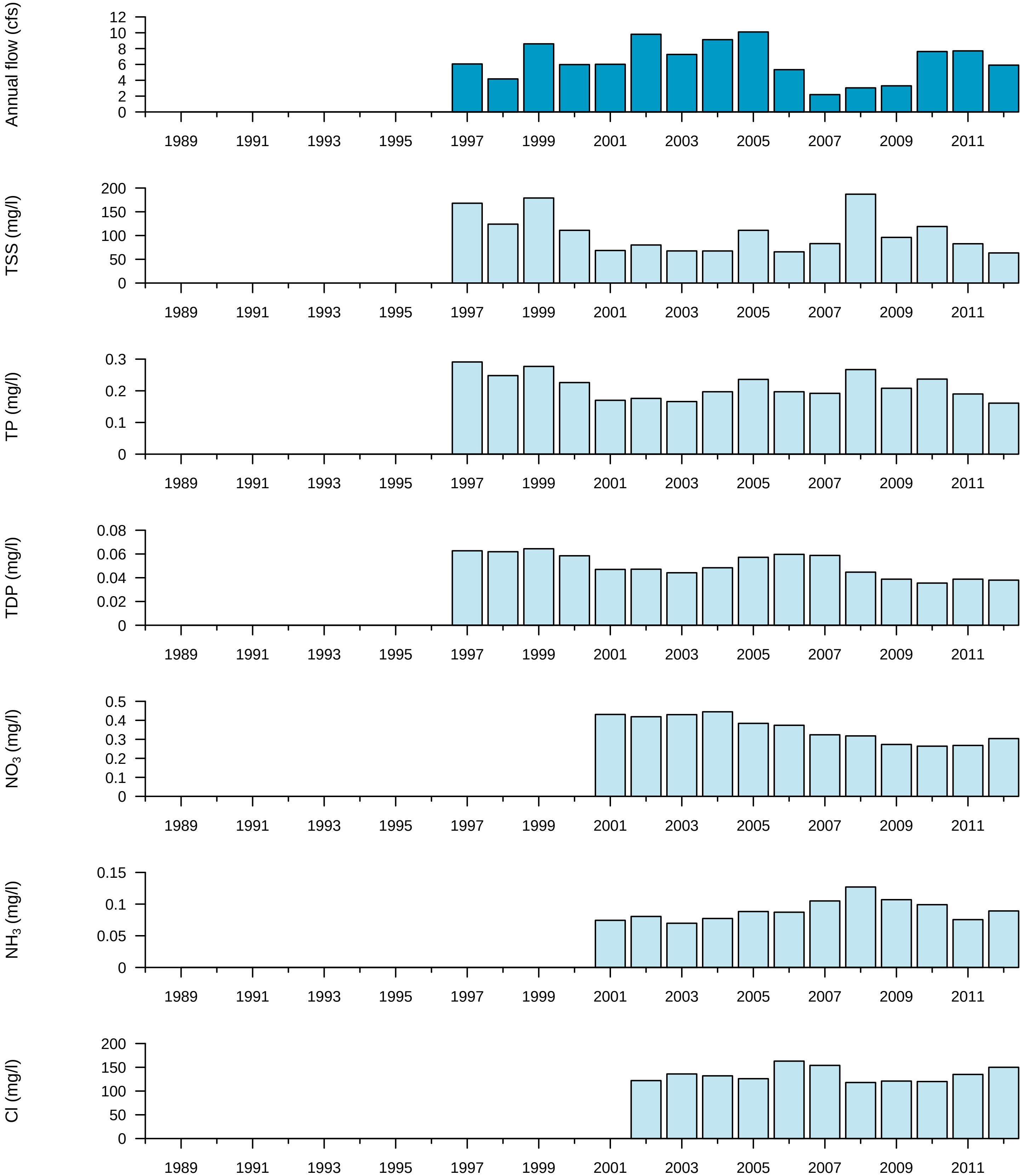
NH_3 concentration patterns were significantly different than the other pollutants. Ammonia concentrations were highest in January-March, peaked in February, and then dropped off steeply in April. There is a large variation in concentrations between years, especially in February. The high ammonia concentrations may have been caused by lower rates of nitrification due to lower temperatures, and limited algal assimilation because of low temperature and light limitation caused by snow cover (Lee *et al.*, 2012). There may also have been increased nitrogen mineralization of decaying organisms in the reducing environment of stream bottom sediments when the creek was frozen or partially frozen.

Figure BA−5: Battle Creek*
Annual Mass Load



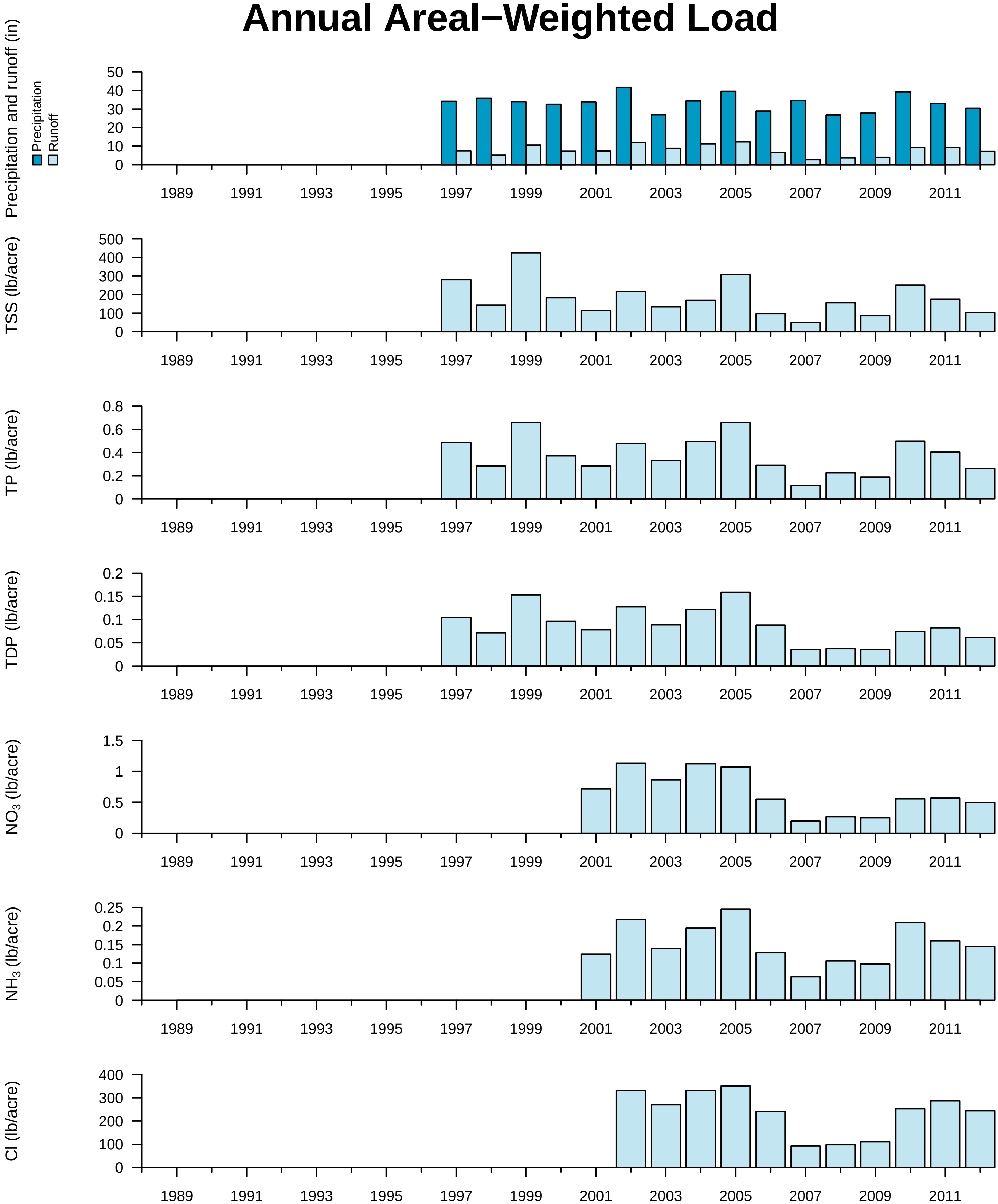
*First full year of sampling for TSS, TP, and TDP began in 1997, NO3 and NH3 began in 2001, and Cl began in 2002. Bars represent 95% confidence intervals as calculated in Flux32.

Figure BA−6: Battle Creek*
Annual Flow−Weighted Mean Concentration



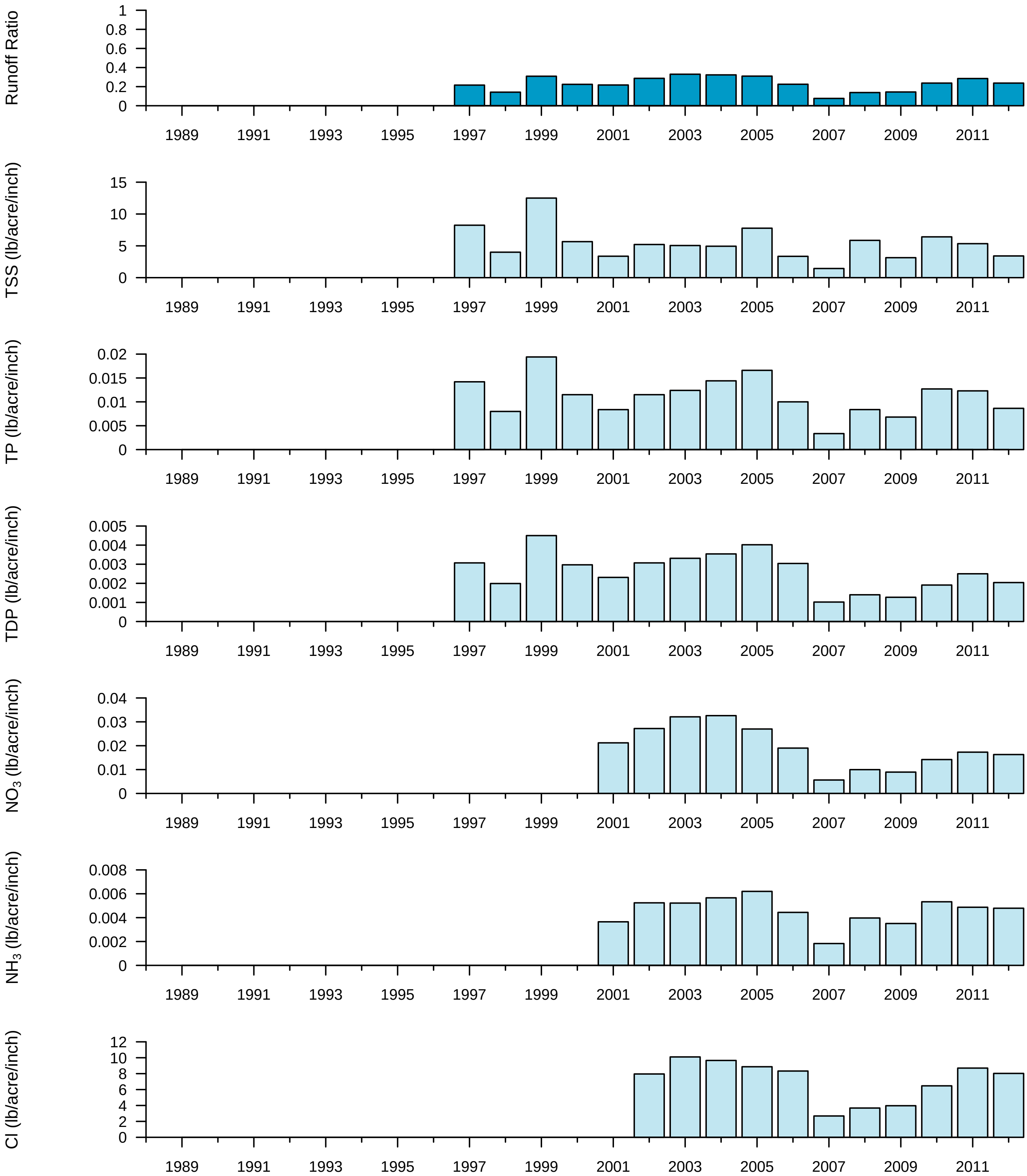
*First full year of sampling for TSS, TP, and TDP began in 1997, NO3 and NH3 began in 2001, and Cl began in 2002.

Figure BA−7: Battle Creek*
Annual Areal−Weighted Load



*First full year of sampling for TSS, TP, and TDP began in 1997, NO3 and NH3 began in 2001, and Cl began in 2002.

Figure BA−8: Battle Creek*
Annual Precipitation−Weighted Areal Load



*First full year of sampling for TSS, TP, and TDP began in 1997, NO3 and NH3 began in 2001, and Cl began in 2002.

Figure BA−9: Battle Creek
Mass Load by Month

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

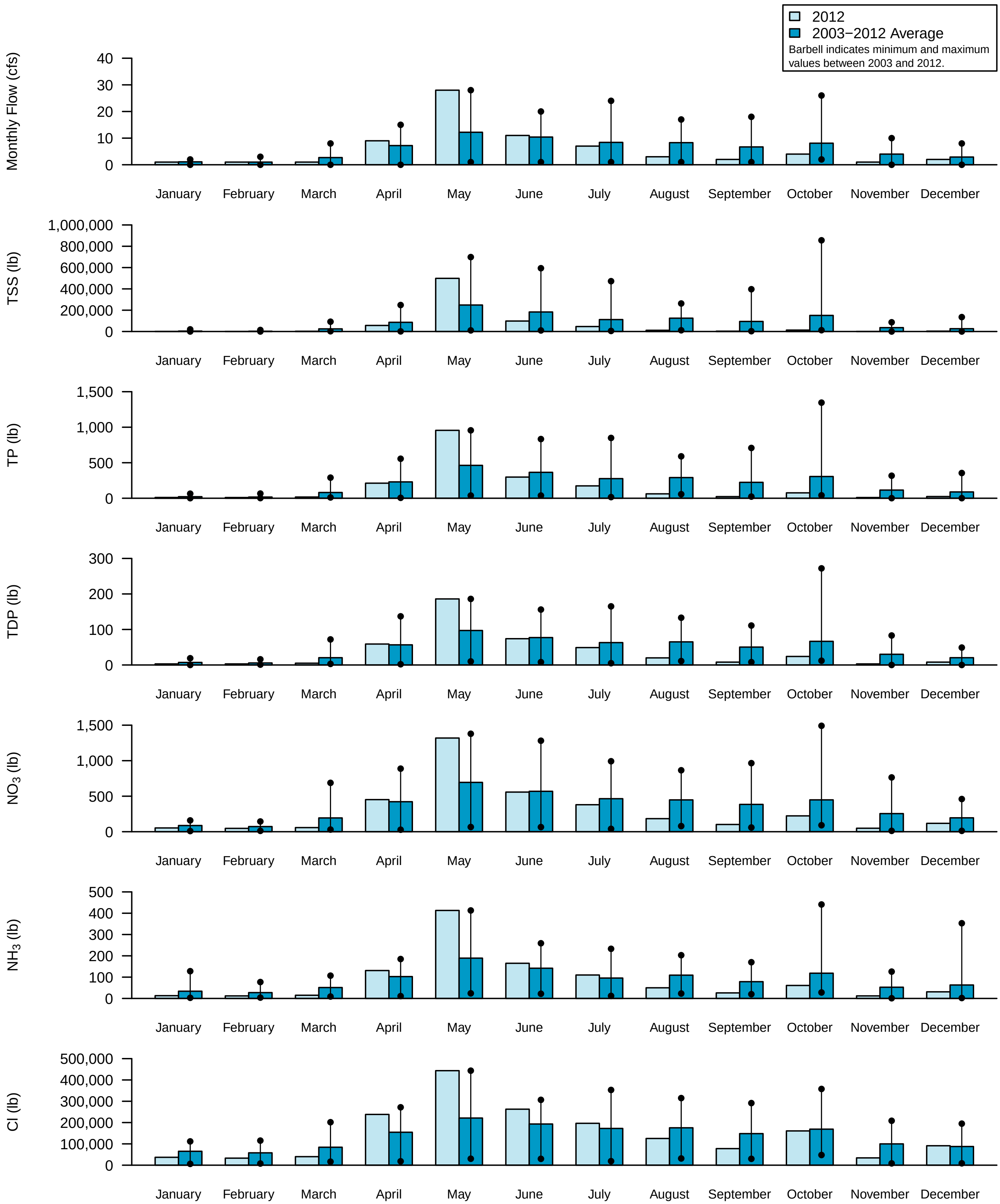
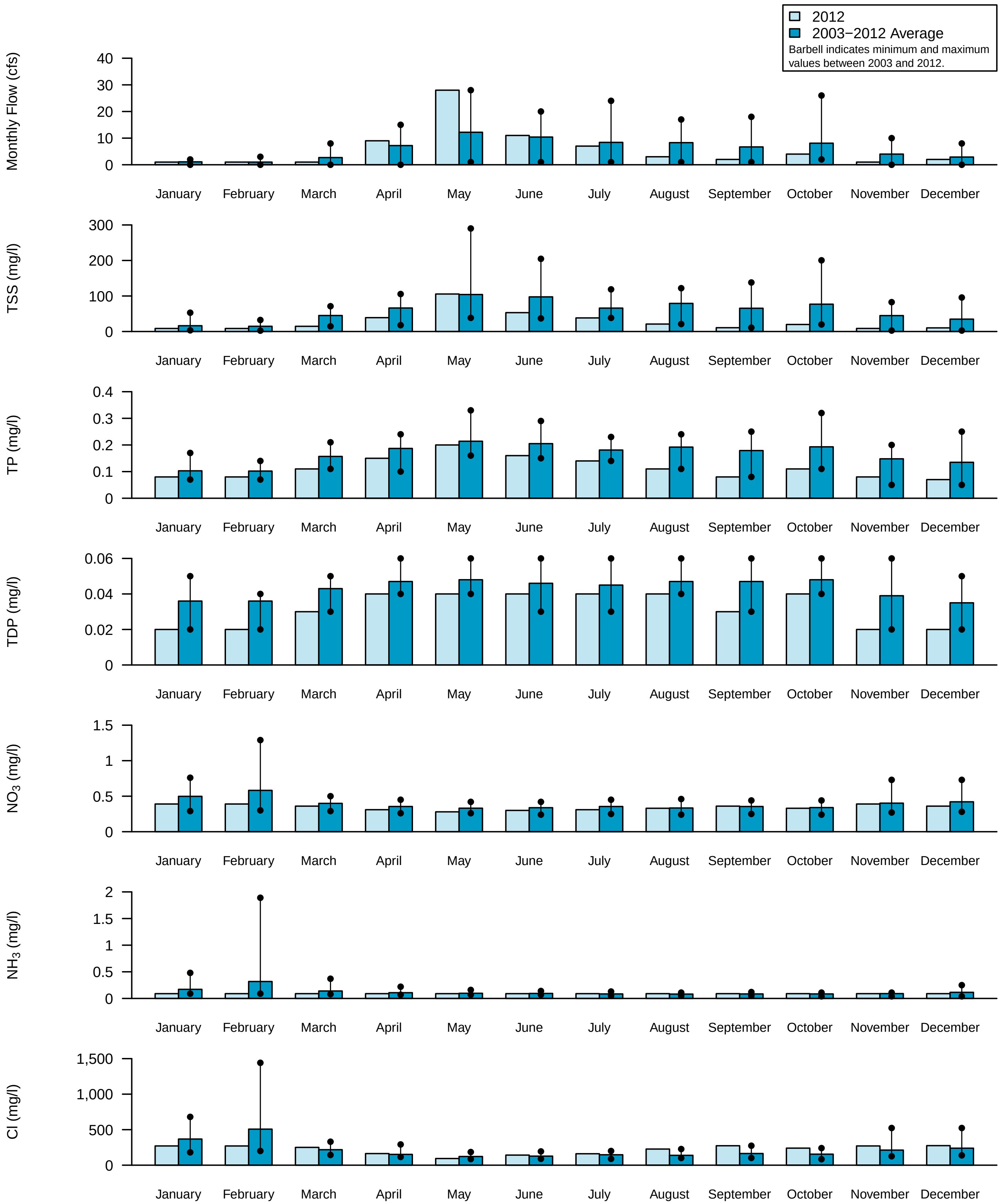


Figure BA−10: Battle Creek
Flow−Weighted Mean Concentation by Month

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. 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 locations using USEPA recommendations, including:

- Develop flow duration curves using average daily flow values for 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 Battle Creek monitoring station daily average flows and sample data, along with the most appropriate MPCA draft numerical standard as listed in Table BA-4. No draft standard has been set for nitrate, 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 standard, the water body must exceed the causative variable (TP concentration), as well as one or more response variables: sestonic chlorophyll, BOD_5, DO flux, and/or pH (MPCA, 2013a). 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 1996–2012 flow duration curve and load duration curves for TSS, TP, NO_3, and Cl for the Battle Creek monitoring station is shown in Figure BA-11. TSS concentrations have mostly remained below the draft standard at low flow and dry conditions; during mid-range and moist conditions about half of the samples exceed the standard; and during high flow most samples collected exceed the draft standard. TP concentrations consistently exceeded the draft nutrient standard at all flows. The largest number of elevated concentrations was again in the mid-range to high flows. These responses are consistent with other streams that discharge down the Mississippi River bluffs, where high flows lead to streambank, bluff, and ravine erosion.

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 NO_3 concentrations in the Battle Creek watershed will need to be reevaluated at that time.

Cl concentrations in Battle Creek exceeded the standard in a few samples at both high and low flows, indicating that Cl concentrations in the stream were more likely to be seasonally-driven by winter and spring runoff containing dissolved road salt, rather than flow driven.

Table BA-4: Battle Creek Beneficial Use and River Nutrient Region 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	Chloride Draft Stnd[3] (mg/l)	TSS Draft Stnd[4] (mg/l)	TP Draft Stnd[5] (ug/l)	Nitrate DW Stnd[6] (mg/l)
Battle Creek below Hwy 61 (BA2.2)	2B	Central	230	30	100	10

[1] Minn. Rules 7050.0470 and 7050.0430

[2] MPCA, 2010.

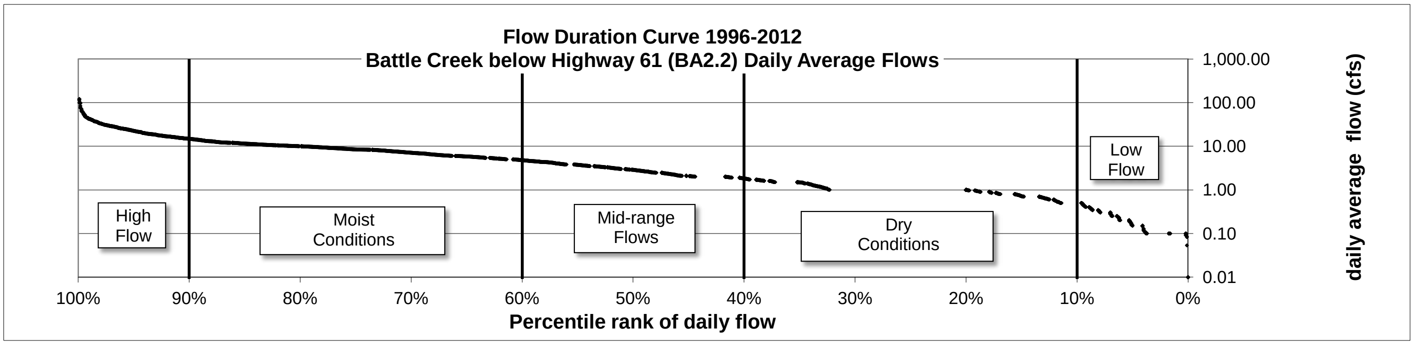
[3] Mark Tomasek, MPCA, personal communication, March 2013. MCES used 230 mg/l as the draft chloride standard pending results of EPA toxicity tests.

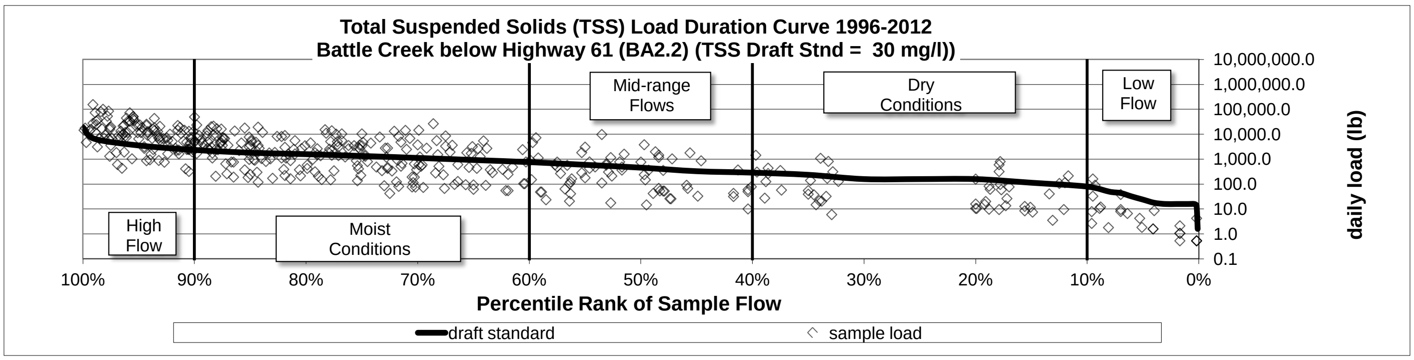
[4] MPCA, 2011. Draft standard states TSS standard concentration for Class 2A and 2B water must not be exceeded more than 10% of the time over a multiyear data window, with an assessment period of April through September.

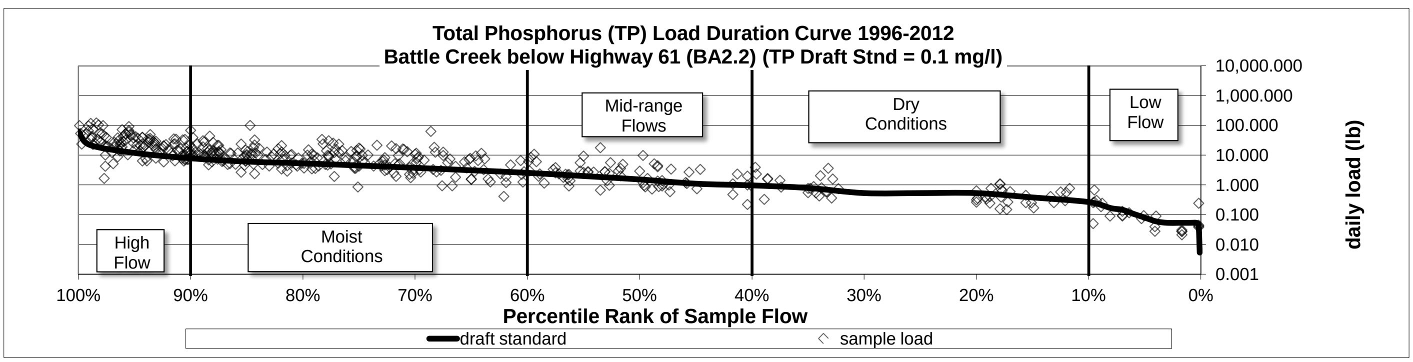
[5] MPCA, 2013a. To violate standard, concentration of causative variable (TP) must be exceeded, as well as one or more response variables: sestonic chlorophyll, BOD_5, DO flux, and/or pH.

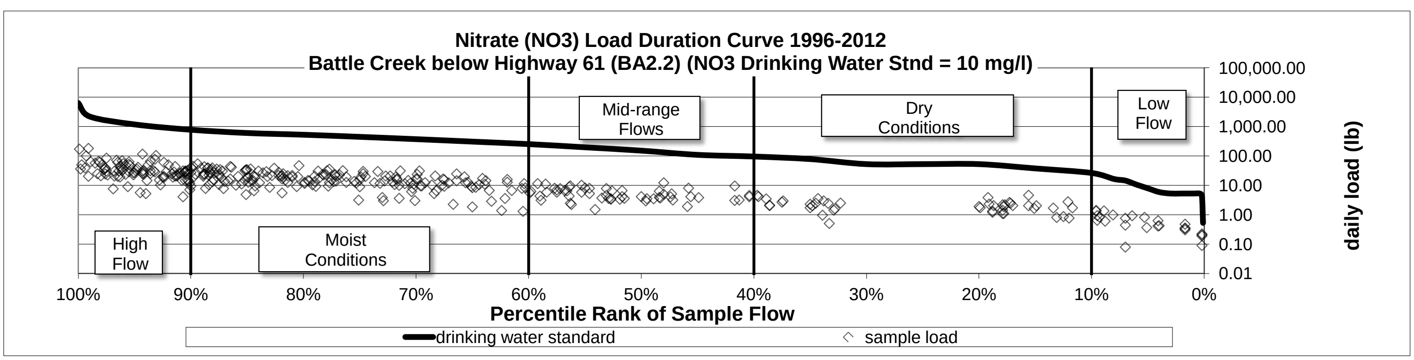
[6] MCES used the nitrate drinking water standard of 10 mg/l pending results of EPA toxicity tests and establishment of a draft nitrate standard for rivers and streams.

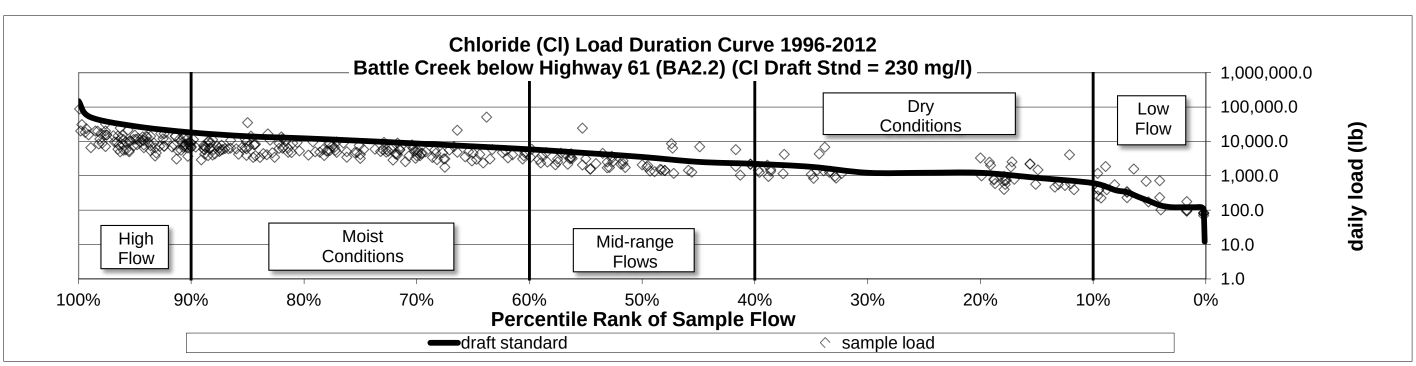
Figure BA-11: Flow and Load Duration Curves, 1996-2012











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.

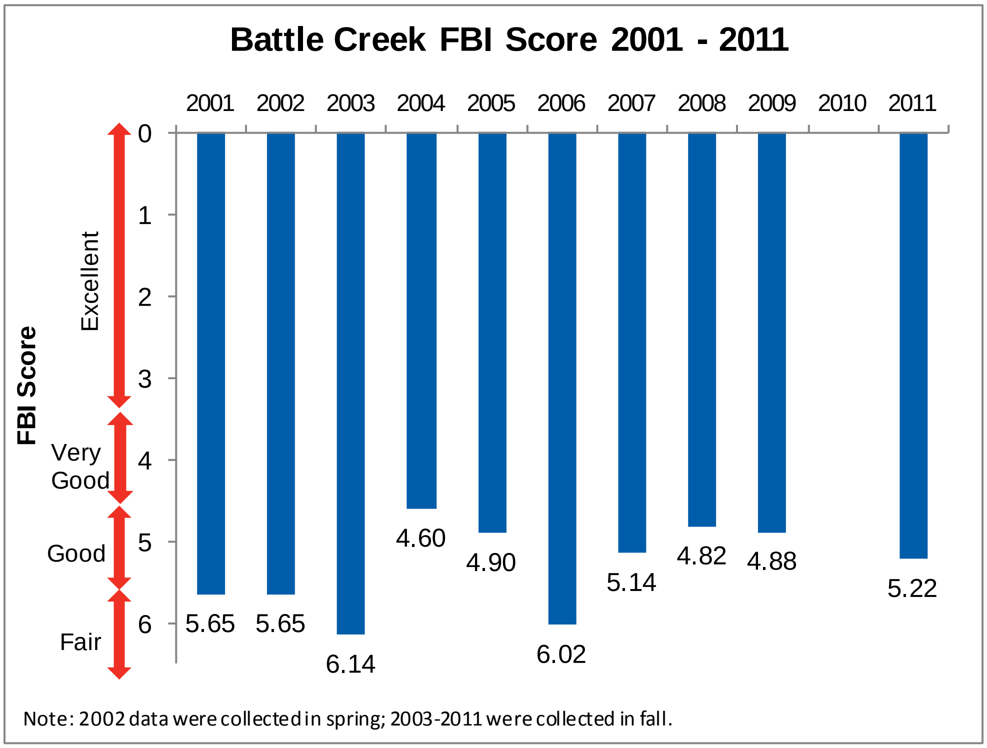
Each metric is independently important and clarifies one aspect of the ecosystem health: species richness, community diversity, water quality, and other factors. The results may have conflicting conclusions when comparing the single metric results. However, integrating the individual metrics into a multi-metric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

MCES has been sampling macroinvertebrates in Battle Creek since 2001. 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 common 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, ten is quite tolerant of pollution. The tolerance values are used to calculate a weighted average tolerance value for the sample; allowing for inter-annual comparison. The Battle Creek FBI scores show good (2004, 2005, 2007-2009, 2011) to fair (2001, 2002, 2003, 2006) water quality, indicating the presence of some organic pollution during most years (Figure BA-12).

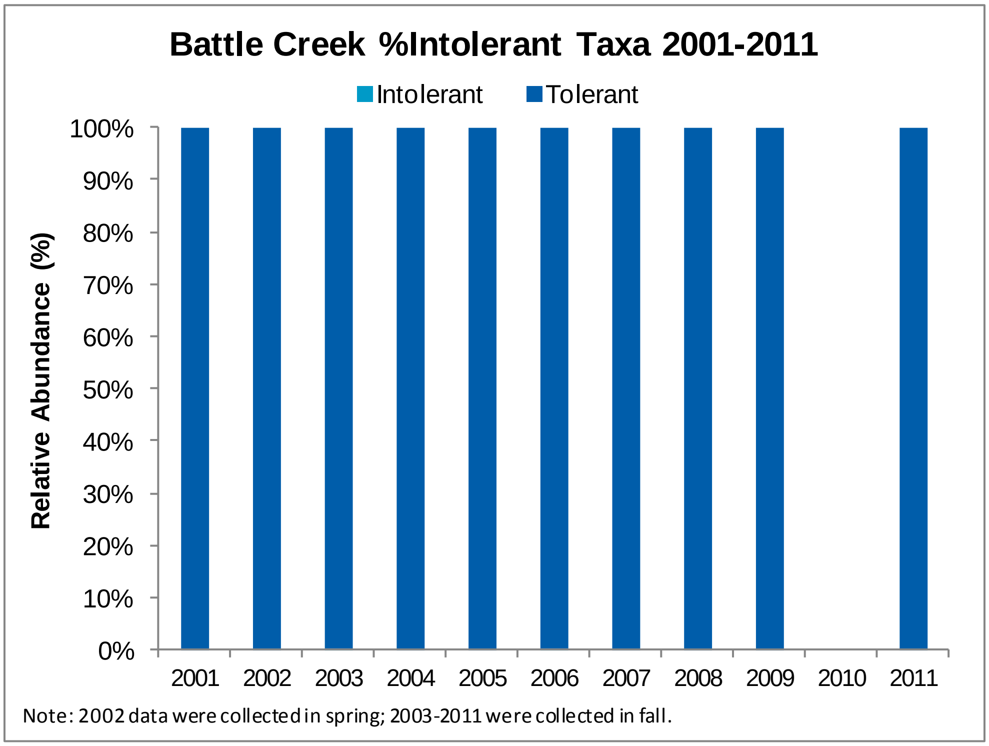
Figure BA-12: Battle Creek Annual Family Biotic Index (FBI) Scores, 2001-2011



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 BA-13). The presence of moderate numbers of intolerant taxa is an indicator of good aquatic health (Chirhart, 2003). There are no intolerant taxa present in any sample from Battle Creek in the period of record. The lack of these macroinvertebrates strongly suggests that the pollution load is consistently high enough to influence the macroinvertebrate community at this stream reach.

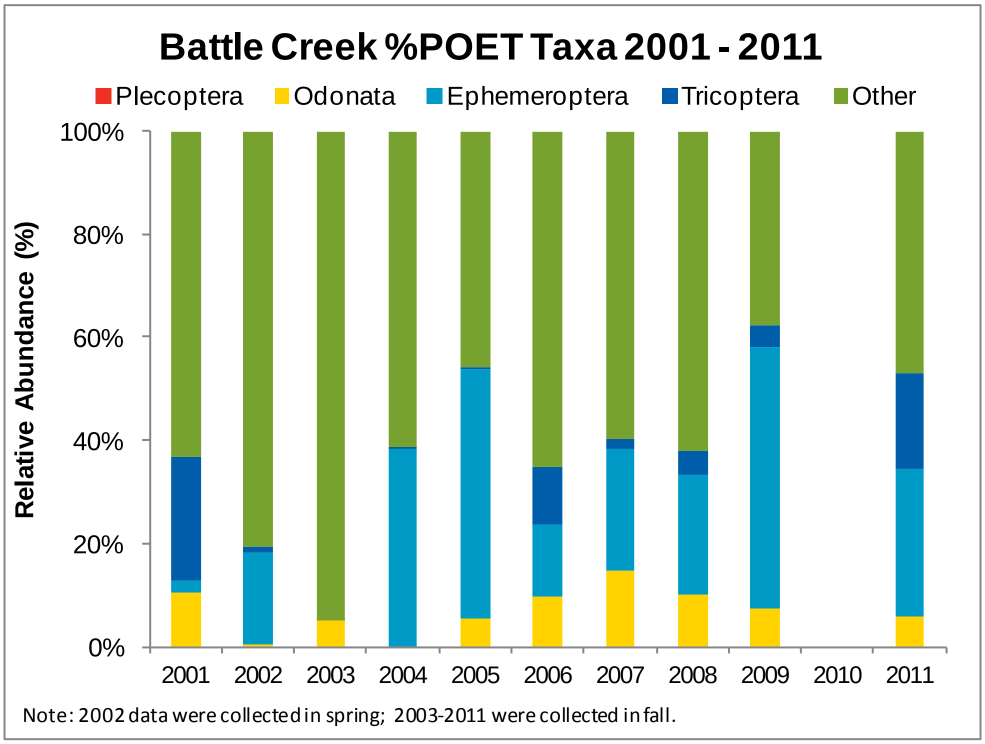
Figure BA-13: Battle Creek Percent Abundance of Pollution Intolerant, 2001-2011



Percent POET Taxa

The taxonomic richness metric, Percent POET Taxa (Figure BA-14), is the percent of individuals in the sample which 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 had the greatest value in 2009 at 62%, and lowest in 2003 at 5%. The Odonata taxa tend to be more dominant in slow moving water, and Plecoptera tend to be present in fast moving waters. Biological sampling at Battle Creek has generally occurred in low to moist conditions based on the average daily flow record and flow duration curve (Figure BA-11) which may partly explain the dearth of Plecoptera.

Figure BA-14: Battle Creek Percent Abundance of POET Taxa, 2001-2011



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.

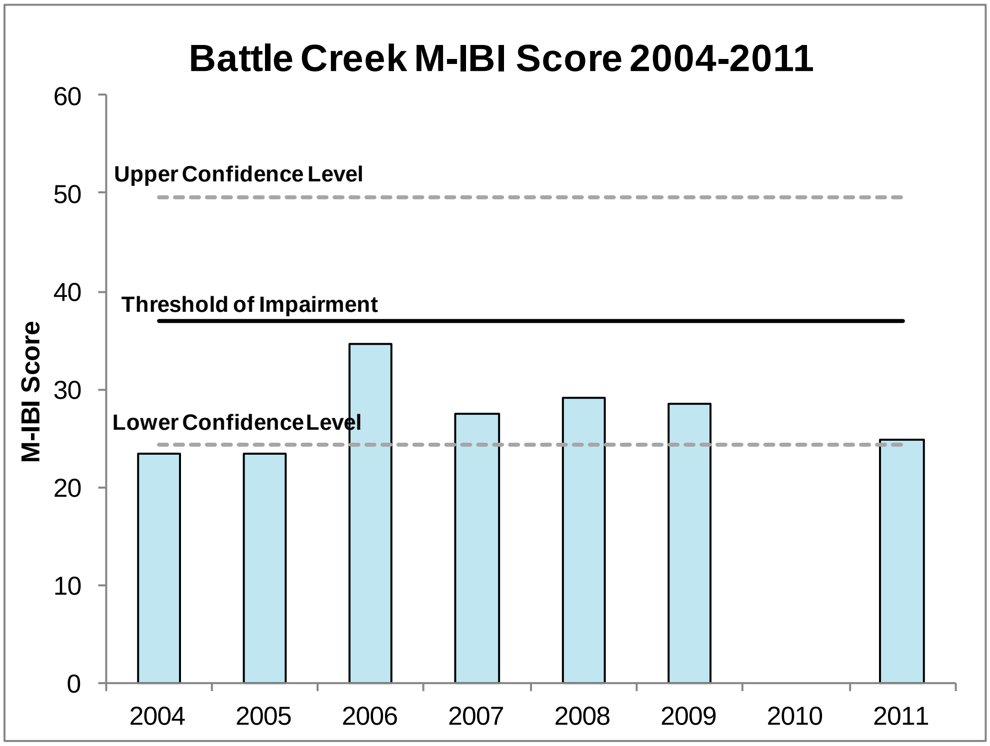
All seven years of monitoring Battle Creek included in the M-IBI assessment resulted in M-IBI scores between the impairment threshold and the lower confidence level (Figure BA-15). When this situation occurs it is difficult to confidently assess the water quality by biological assessment alone, and it is necessary to incorporate other monitoring information, such as hydrology, water chemistry, or land use change (MPCA, 2014b).

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 falling between the confidence levels, these scores may be assigned more or less weight in the final evaluation.

Battle Creek is a highly impervious watershed. The stream hydrology is flashy; storm runoff quickly flows into the stream, the storm hydrograph peaks rapidly and flow recedes quickly after a storm. This flow regime likely flushes macroinvertebrates downstream and alters community composition. Additionally, storm runoff carries a higher pollutant load which can reduce the number of pollution intolerant individuals (Carlisle *et al.*, 2013).

The most recent three data points, 2008, 2009 and 2011, exhibit a decreasing trend in M-IBI scores. This suggests that stressors are negatively affecting the macroinvertebrates, and demonstrating a potential inability to sustain the needs of the aquatic community. MCES is planning additional future analysis to fully investigate our biological monitoring data.

Figure BA-15: Battle 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 U.S. Geological Survey (USGS) program QWTREND (Vecchia, 2003). QWTREND removes the variability of annual flow and seasonality from the statistical analysis, so 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 periods of from 90 to 10 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 likely have also 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 1996-2012 on Battle Creek for TP, NO_3, and TSS. The results are presented below.

Total Suspended Solids (TSS)

Three trends were identified for TSS flow-adjusted concentrations in Battle Creek during the assessment period from 1996 to 2012 (Figure BA-16, top chart). Based on a run without the precedent 5-year flow, the p value was 1.53x10-6, indicating the trends identified are statistically significant.

- From 1996 to 2001, flow-adjusted TSS decreased 79%, from 43.4 mg/l to 9.2 mg/l, at a rate of -5.7 mg/l/yr.
- From 2002 to 2009, flow-adjusted TSS increased 124%, from 9.2 mg/l to 20.7 mg/l, at a rate of 1.4 mg/l/yr.
- From 2010 to 2012, flow-adjusted TSS decreased 80%, from 20.7 mg/l to 4.2 mg/l, at a rate of -5.5 mg/l/yr.

In order to compare the TSS trends in Battle Creek with other MCES-monitored streams in report section ***Comparison with Other Metro Area Streams***, the five year trend for period 2008-2012 was calculated. From 2008 to 2012, average flow-adjusted TSS decreased 77%, from 18.1 mg/l to 4.2 mg/l, at a rate of -2.8 mg/l/yr.

Total Phosphorus (TP)

Three trends were identified for TP flow-adjusted concentrations in Battle Creek during the assessment period from 1996 to 2012 (Figure BA-16, middle chart). Based on a run without the precedent 5-year flow, the p value was 2.05x10-6, indicating the trends identified are statistically significant.

- From 1996 to 2001, TP flow-adjusted concentrations decreased 57%, from 0.20 mg/l to 0.09 mg/l, at a rate of -0.019 mg/l/yr.
- From 2002 to 2007, TP flow-adjusted concentrations increased 88%, from 0.09 mg/l to 0.16 mg/l, at a rate of 0.013 mg/l/yr.
- From 2008 to 2012, TP flow-adjusted concentrations decreased 56%, from 0.16 mg/l to 0.07 mg/l, at a rate of -0.018 mg/l/yr.

In order to compare the TP trends in Battle Creek with other MCES-monitored streams in report section ***Comparison with Other Metro Area Streams***, the five year trend for period 2008-2012 was calculated. From 2008 to 2012, TP flow-adjusted concentration decreased 56%, from 0.16 mg/l to 0.07 mg/l, at a rate of -0.018 mg/l/yr.

Nitrate (NO_3)

Three trends were identified for NO_3 flow-adjusted concentrations in Battle Creek during the assessment period from 2000 to 2012 (Figure BA-16, bottom chart). Based on a run without the precedent 5-year flow, the p value was 0.0034, indicating the trends identified are statistically significant.

- From 2000 to 2004, NO_3 flow-adjusted concentrations increased 10%, from 0.35 mg/l to 0.39 mg/l, at a rate of 0.0068 mg/l/yr.
- From 2004 to 2010, NO_3 flow-adjusted concentrations decreased 32%, from 0.39 mg/l to 0.26 mg/l, at a rate of -0.02 mg/l/yr.
- From 2011 to 2012, NO_3 flow-adjusted concentrations increased 53%, from 0.26 mg/l to 0.41 mg/l, at a rate of 0.071 mg/l/yr.

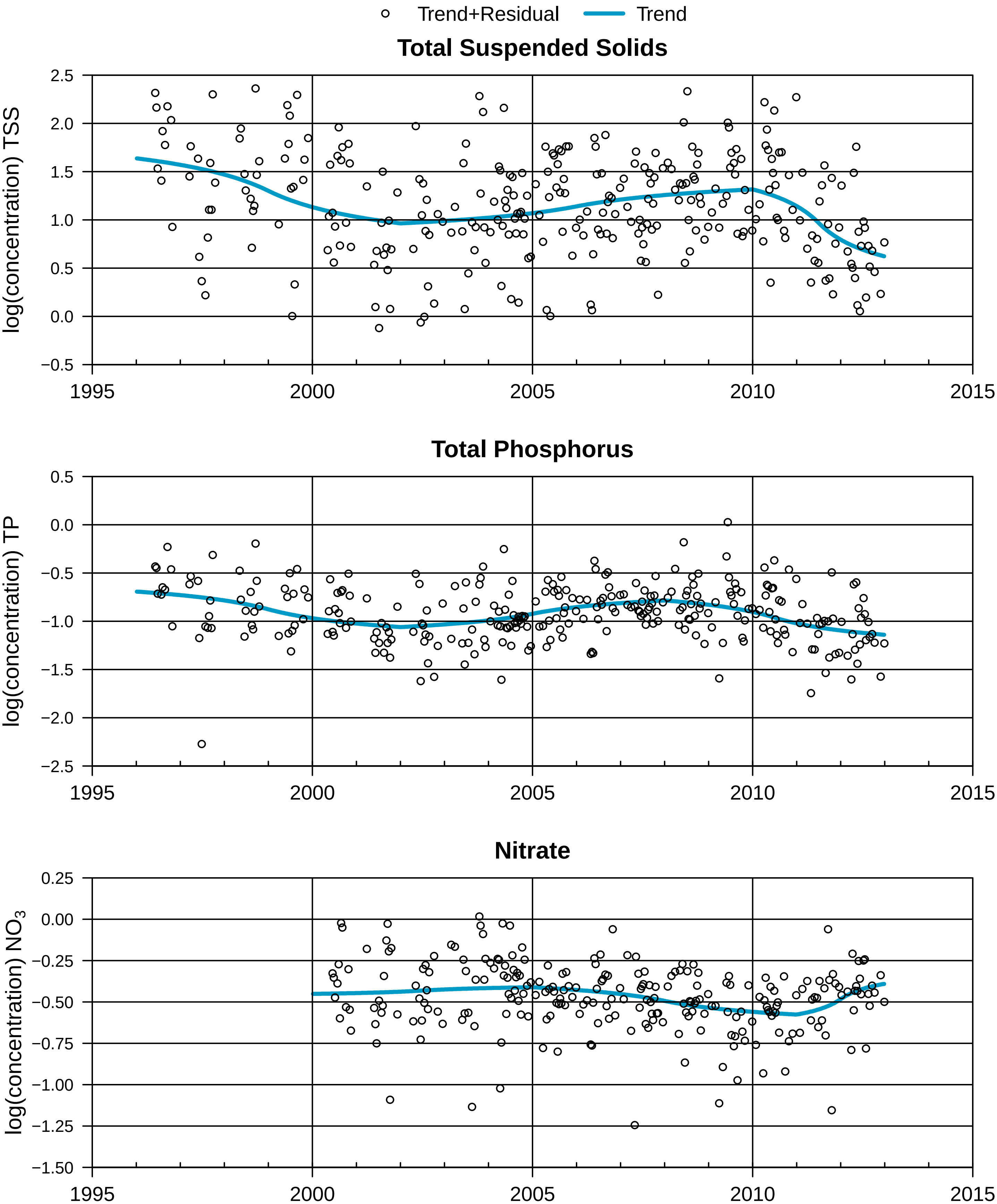
In order to compare the NO_3 trends in Battle Creek with other MCES-monitored streams in report section ***Comparison with Other Metro Area Streams***, the five year trend for period 2008-2012 was calculated. From 2008 to 2012, NO_3 flow-adjusted concentrations increased 27%, from 0.32 mg/l to 0.41 mg/l, at a rate of 0.017 mg/l/yr.

While MCES staff have assessed monitoring data and trend analysis statistics, more work is needed to assign causative actions to the trend analysis results. TSS and TP chemistry, delivery, transport and remediation are complicated, although fairly well-understood. Identifying contributing events, implementation practices, and other causative actions is expected to be somewhat straightforward for these two parameters.

NO_3 chemistry and transport dynamics within the natural environmental are significantly more complicated. The NO_3 trends for most of 21 streams assessed in this study showed periods of both rising and falling flow-adjusted concentrations. NO_3 concentrations may be affected by periods of saturated and unsaturated soil conditions related to precipitation patterns, by agricultural crop rotations, by changing levels of fertilizer applications, or other unidentified causative variables, rather than true long-term improvement in concentrations based on intentional implementation of best management practices.

MCES staff will repeat the trend analysis in 5 years, and the meantime will continue to investigate the NO_3, TSS, and TP dynamics in streams entering the metropolitan area with local partners and state agency staff.

Figure BA−16: Battle Creek Trends for TSS, TP and NO_3



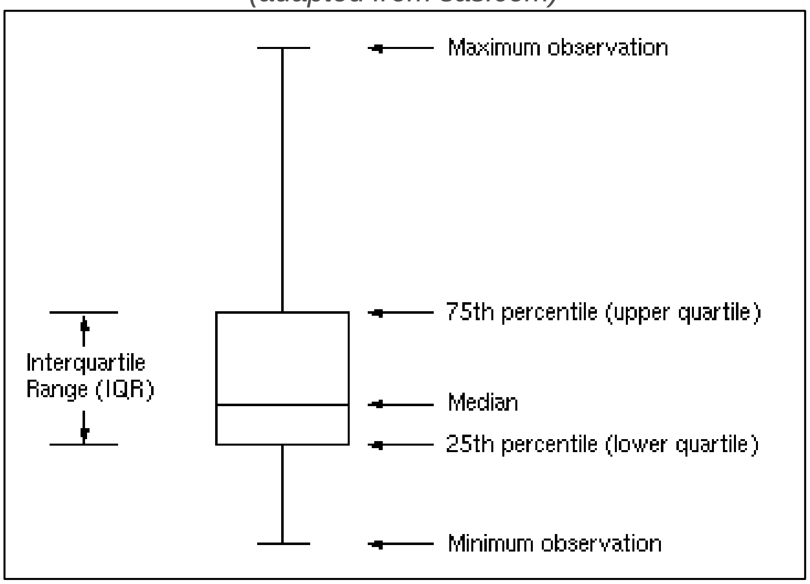
Comparison with Other Metro Area Streams

Chemistry

Box-and-whisker plots were used to summarize the comparison of the historical flow, TSS, TP, and NO_3, and Cl data for Battle Creek with those of the other metropolitan area streams monitored by MCES, and with the major receiving water (in this case the Mississippi River below the confluence with the Minnesota River). The comparisons are shown in Figures BA-18 to BA-21; Table BA-5.

The legend for the format of box-and-whisker plots used in this report is shown in Figure BA-17. 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 extents of the whiskers designate the maximum and minimum values.

Figure BA-17: General Schematic of a Box-and-Whisker Plot
(adapted from sas.com)



Comparisons for each chemical parameter for 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 should be identical on each of the four parameter pages), total annual load, and annual areal yield), 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.

Flow. Median annual runoff ratio for Battle Creek is in the middle of the metropolitan area urban streams: higher than Willow and Nine Mile Creeks, slightly lower than Bassett and Fish Creeks. For streams that are highly influenced by wetlands, lakes, or other impoundments on the stream channel, one would expect a relatively lower runoff ratio (for example, Minnehaha Creek or Carnelian-Marine); if the flow was highly influenced by shallow groundwater inflow, one would expect a relatively higher runoff ratio (for example, Eagle Creek or Valley Creek). Battle Creek flow is highly impacted by Battle Creek Lake water levels, but the runoff ratio is quite a bit higher than Minnehaha Creek or Carnelian Marine. This may be because the downstream part of the

Battle Creek watershed is highly impervious and has high runoff potential, or because of inflow of shallow groundwater.

Total Suspended Solids. The median annual FWM concentration for TSS in Battle Creek is higher than that in the Mississippi River (as measured at Mississippi River at St. Paul; 83 mg/l vs. 58 mg/l, respectively), indicating that Battle Creek contributes to a higher TSS concentration in the Mississippi River (Figure BA-18). The median annual FWM concentration for TSS in Battle Creek is higher than the other highly urbanized watersheds (Fish, Bassett, Nine Mile, Willow), but is lower than many of the agricultural watersheds. The higher concentrations in Battle Creek may be due to erosion along the steep slopes in the downstream portion of the watershed.

Total Phosphorus. As with TSS, the FWM TP concentration in Battle Creek is higher than the Mississippi River (0.20 mg/l vs. 0.15 mg/l, respectively) and thus may serve to increase the river concentration (Figure BA-19). Battle Creek's FWM TP concentration is in the middle of those of the other highly urban watersheds: slightly below Nine Mile Creek, about the same as Fish Creek, and slightly higher than Willow and Bassett Creeks. All of the highly urbanized streams have significantly lower FWM TP concentrations than the more agricultural watersheds monitored by MCES.

Nitrate. NO_3 FWM concentration in Battle Creek is significantly lower than in the Mississippi River (0.3 mg/l vs. 3 mg/l, respectively) and thus dilutes the river concentration downstream (Figure BA-20). All urban watersheds have very low nitrate concentrations. The areal load and annual yield of NO_3 in Battle Creek are also low and similar to the streams with more urban watersheds, which are dwarfed by the streams with primarily agricultural watersheds, such as the Crow River, Vermillion River, and Cannon River.

Chloride. Cl FWM concentration in Battle Creek is significantly higher than in the Mississippi River (134 mg/l vs. 22 mg/l) and thus may serve to increase the Cl concentration in the Mississippi River (Figure BA-21). Battle Creek's Cl concentration is the second highest of any stream monitored by MCES, right below Bassett Creek. The two most prevalent sources of Cl to streams are road surfaces (from Cl application as a winter de-icer) and WWTP effluent (from domestic water softeners). Battle Creek does not have any domestic WWTPs, but has a dense network of roads and highways that are de-iced in the winter. The Battle Creek watershed includes portions of I-94, I-494, and I-694, which may contribute to the high Cl concentration.

Because of its relatively small size, the annual load of TSS, TP, NO_3, and Cl from the Battle Creek watershed is small relative to the larger watersheds, especially the Crow River, Crow River South Branch, and Cannon River watersheds. This is true for parameters where the Battle Creek concentration is high relative to most other watersheds (Cl) or low (NO_3).

Macroinvertebrates

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

The M-IBI scores for Battle Creek all fall below the MPCA impairment threshold (Figure BA-22). This suggests that in this stream reach habitat and water quality typically may not have been able to sustain the needs for aquatic life.

These results are similar to other highly urban watersheds in the Minnesota and Mississippi River basins, including Fish and Nine Mile Creeks, and lower than primarily agricultural watersheds. This suggests the urban stream macroinvertebrate communities are more stressed than the agricultural stream macroinvertebrates in the metropolitan area.

Figure BA−18: Total Suspended Solids for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

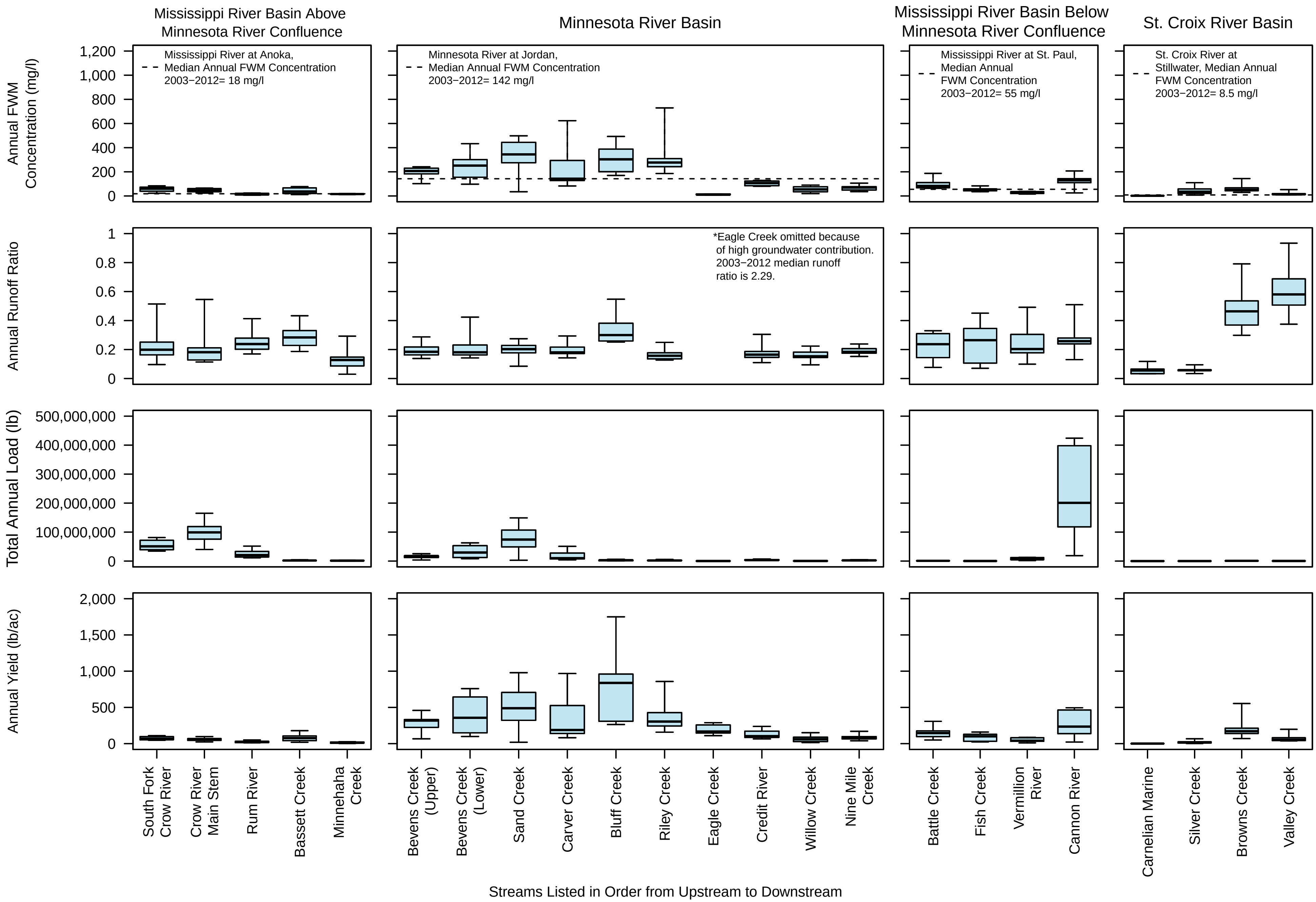


Figure BA−19: Total Phosphorus for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

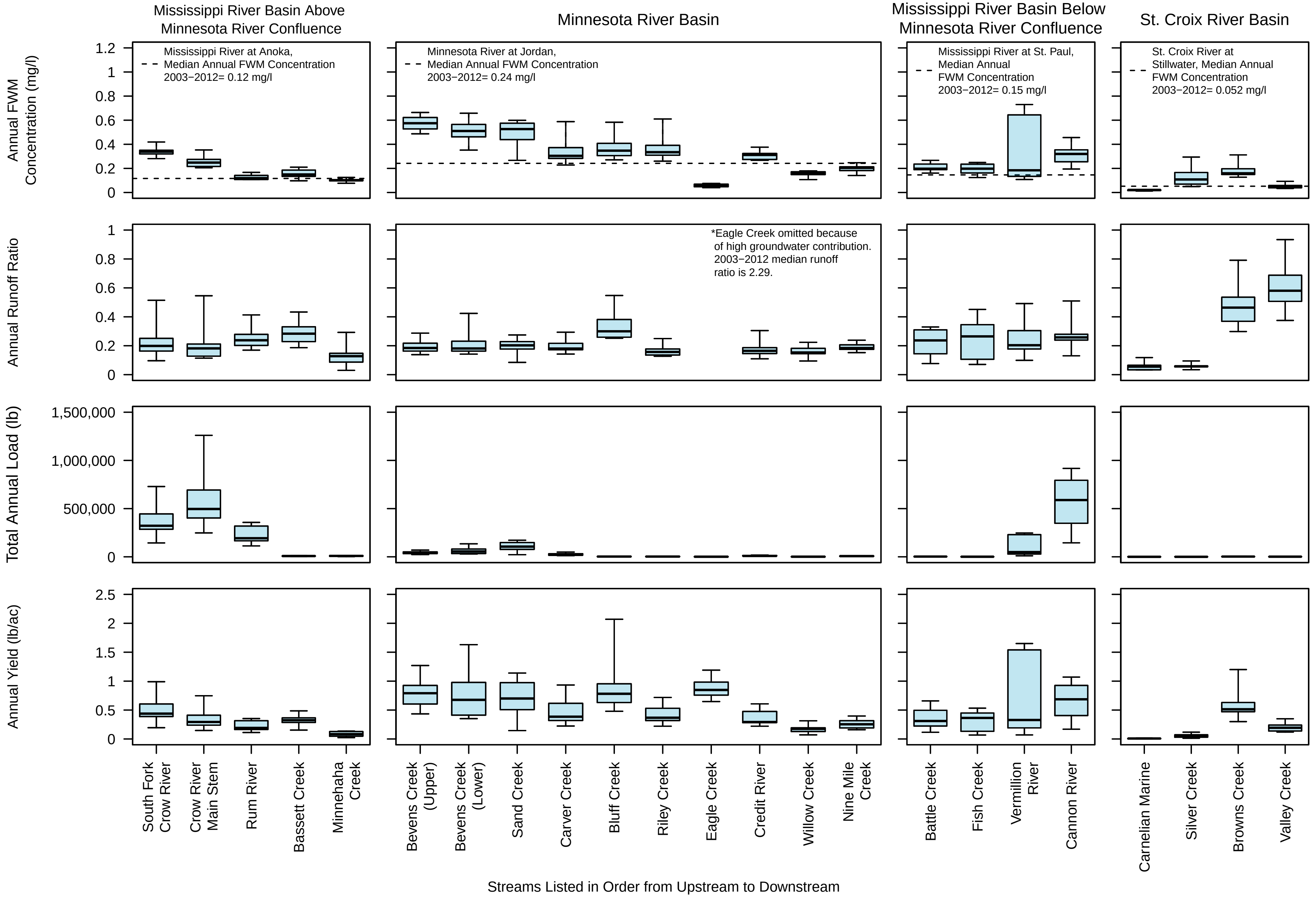


Figure BA−20: Nitrate for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

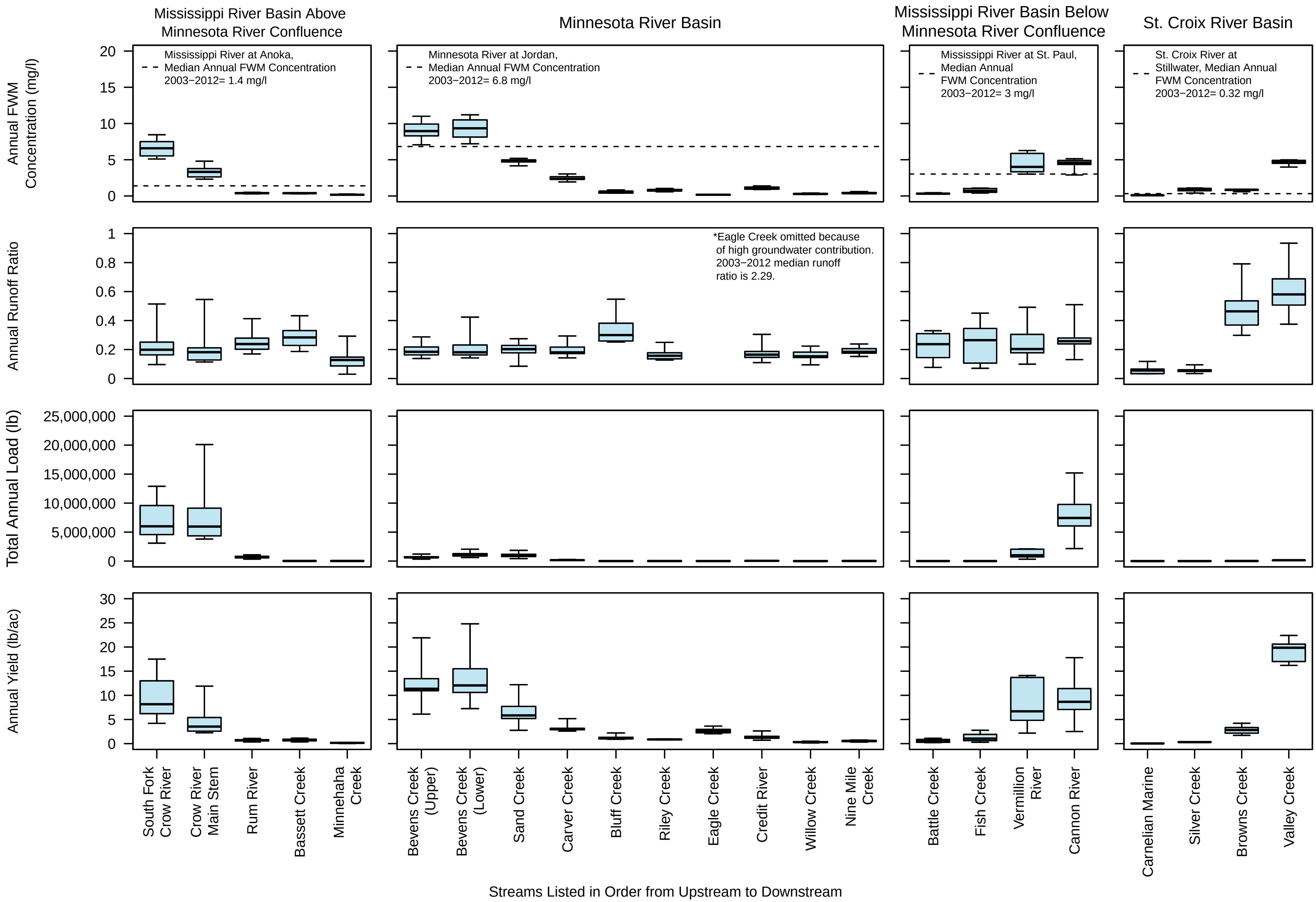


Figure BA−21: Chloride for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

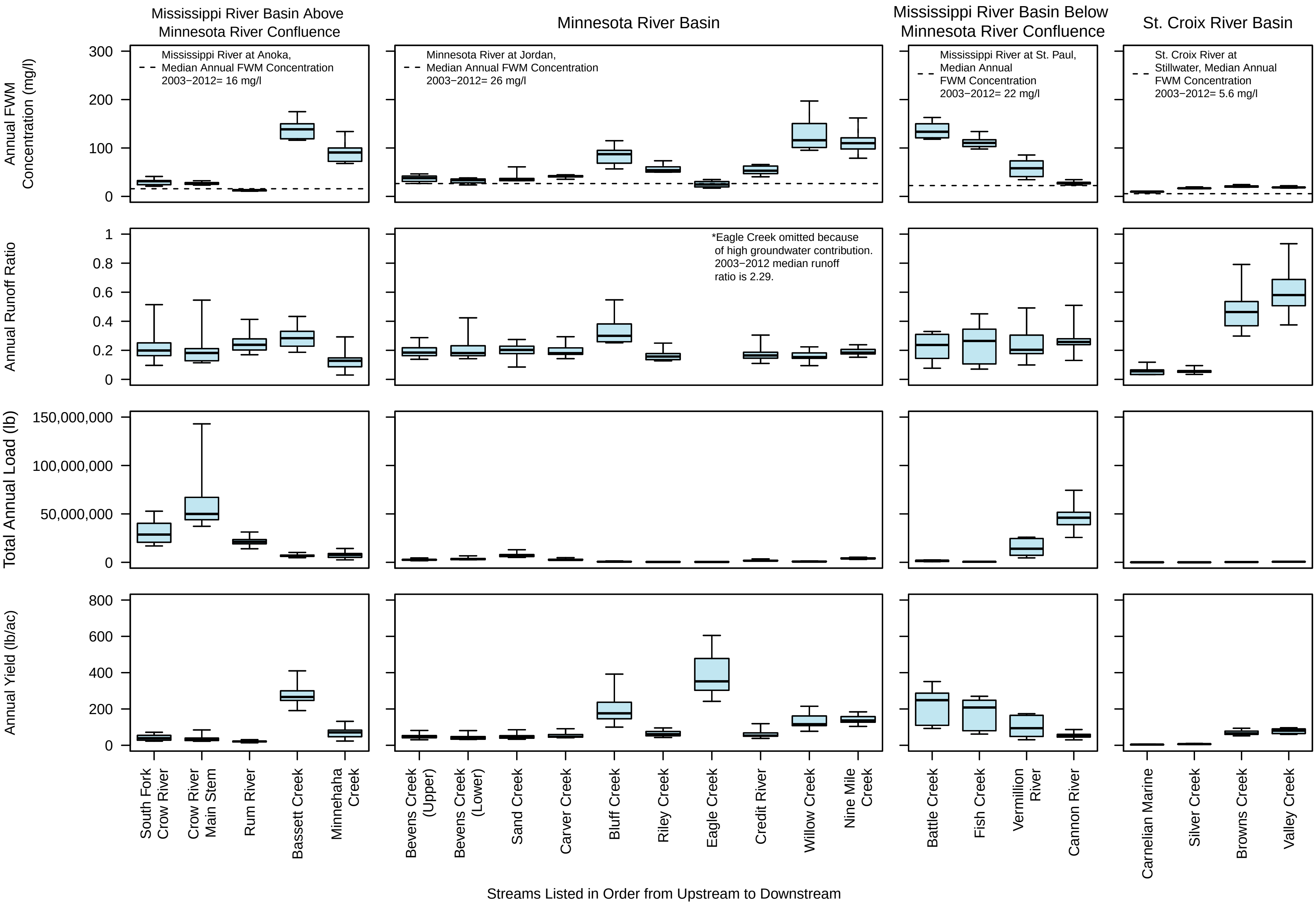


Table BA-5: Annual Median Concentrations, Loads, and Yields for MCES-Monitored Streams, 2003-2012

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)

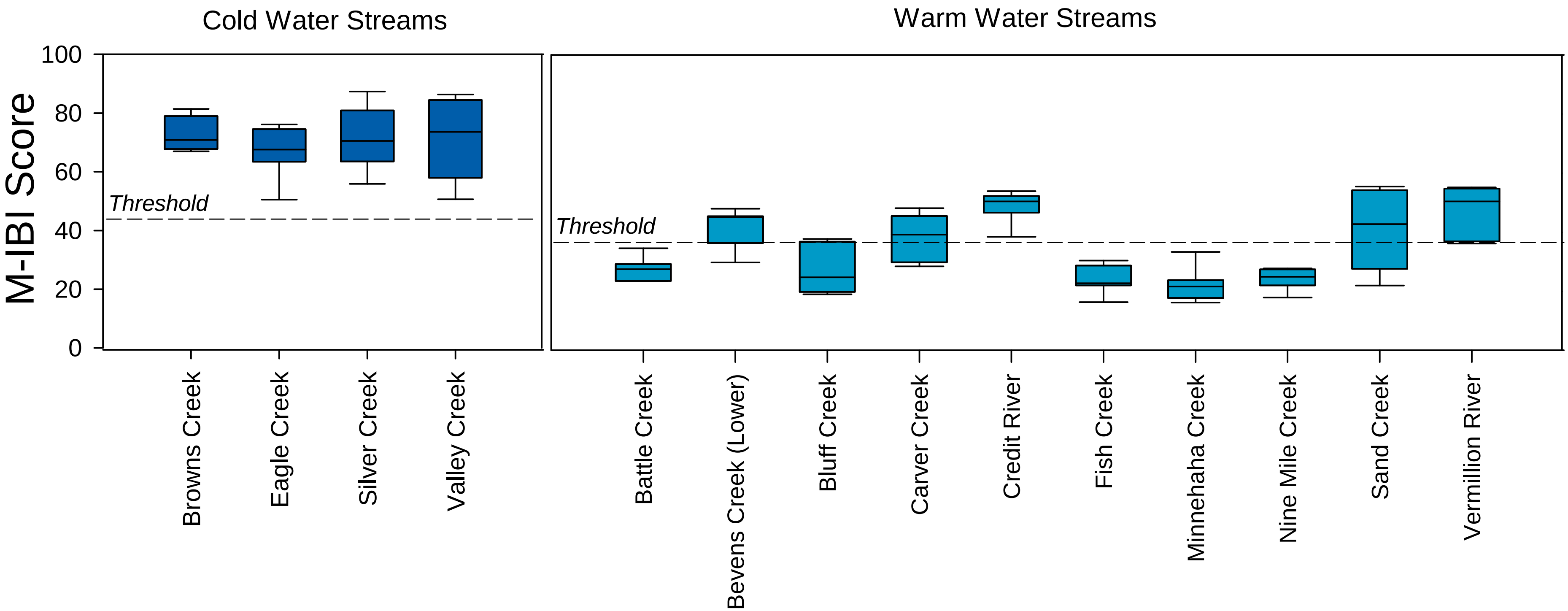
[2] FWM conc = annual flow-weighted mean concentration estimated using Flux32 (Walker, 1999).

[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 BA-22: 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 Trends 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: tabulated results with directional arrows indicating increasing (blue upward arrow) and decreasing (red downward arrow) water quality paired with percent change in concentration estimated for 2008-2012 (Figure BA-23); and by three seven-county metropolitan area maps (one each for TSS, TP, and NO_3 trends) colored to represent improving and declining water quality (Figure BA-24). In both figures no trend was reported for those QWTREND analyses with poor quality of statistical metrics (e.g. $p>0.05$).

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 declining 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 monitored tributaries to the Mississippi River below the confluence with the Minnesota River generally contribute waters higher in concentration of TSS and TP than the Mississippi River itself. The trend analysis results indicate decreasing flow-adjusted concentrations in TSS and TP for each of these sites, which could ultimately lead to cleaner water quality in the Mississippi River. Of the monitored tributaries to the Mississippi below the confluence with the Minnesota, both Battle Creek and the Cannon River had increasing NO_3 flow-adjusted concentrations.

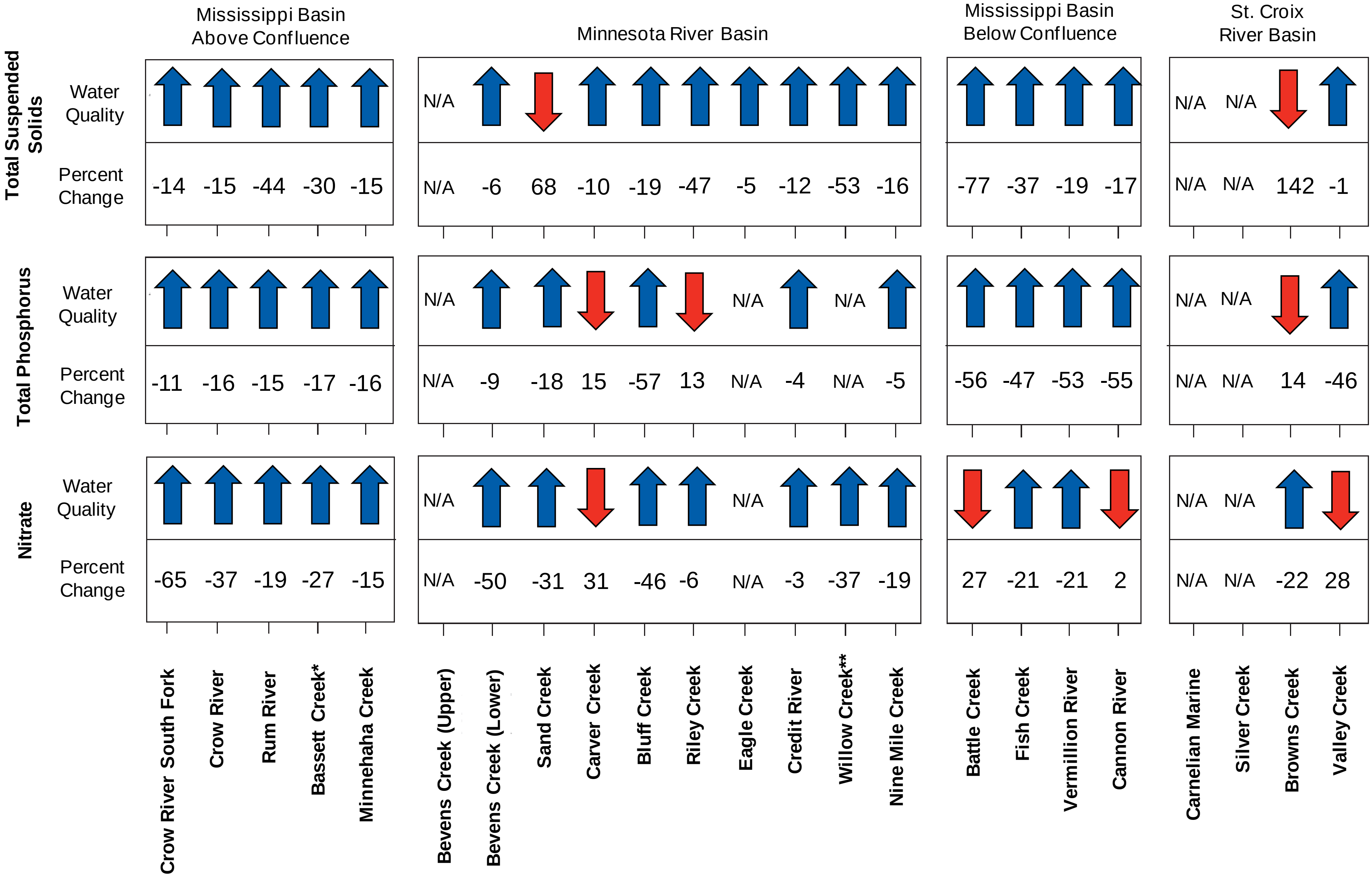
While MCES staff have assessed monitoring data and trend analysis statistics, more work is needed to assign causative actions to the trend analysis results. TSS and TP chemistry, delivery, transport and remediation are complicated, although fairly well-understood. Identifying contributing events, implementation practices, and other causative actions is expected to be somewhat straightforward for these two parameters.

NO_3 chemistry and transport dynamics within the natural environmental are significantly more complicated. The NO_3 trends for most of 21 streams assessed in this study showed periods of both rising and falling flow-adjusted concentrations. NO_3 concentrations may be affected by periods of saturated and unsaturated soil conditions related to precipitation patterns, by agricultural crop rotations, by changing levels of fertilizer applications, or other unidentified causative variables, rather than true long-term improvement in concentrations based on intentional implementation of best management practices.

MCES staff will repeat the trend analysis in 5 years, and the meantime will continue to investigate the $NO_{3,}$ TSS, and TP dynamics in streams entering the metropolitan area with local partners and state agency staff.

Figure BA-23: 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)



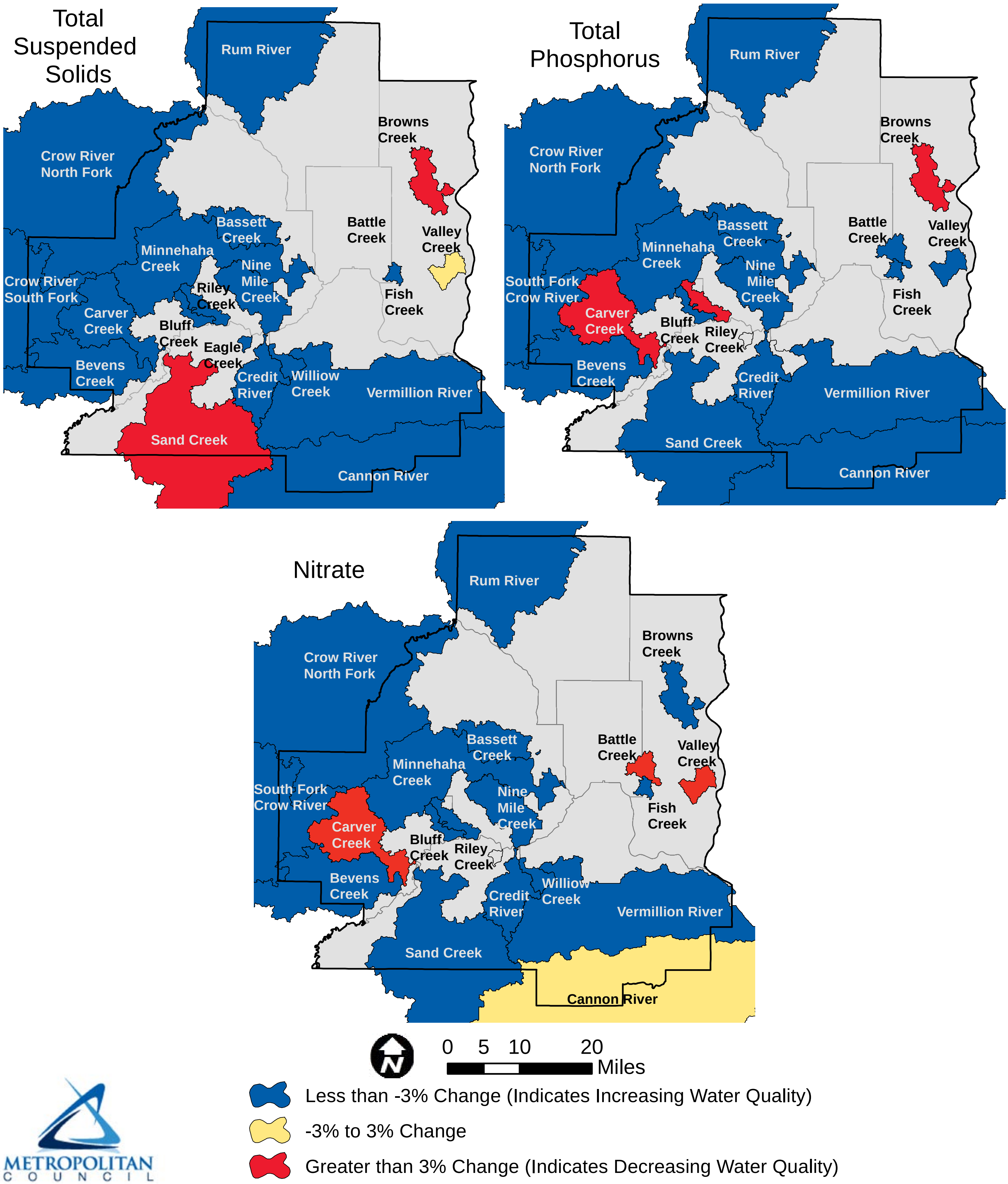
Blue arrows indicate improved water quality; Red arrows indicate declining water quality.

"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 BA-24: Regional Maps of Estimated Trends in Flow-Adjusted Stream Concentrations of TSS, TP, and NO3, 2008-2012

(As estimated by QWTrend)



METROPOLITAN COUNCIL

Conclusions

Battle Creek is a tributary to the Mississippi River and drains portions of the cities of Woodbury, Oakdale, Maplewood and St. Paul and Landfall, within Ramsey and Washington Counties. The watershed is entirely developed as urban area. There are no major point sources in the watershed. The upper part of the watershed is relatively flat, while the topography steepens at the transition from the Mississippi River bluff to the river floodplain. The majority of the watershed drains to one of two lakes, either Tanners or Battle Creek Lake. Battle Creek originates at Battle Creek Lake. The monitoring station is located in St. Paul just west of Highway 61 in the Mississippi River floodplain. Downstream of the monitoring station, Battle Creek continues through the floodplain before discharging to Pigs Eye Lake, a backwater area of the Mississippi River. 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 Battle Creek is clearly affected by urban runoff, including reasonably high TSS and TP concentrations and very high Cl concentrations. Battle Creek is affected by several factors: highly urbanized areas with increased runoff and high deicing application, erosion along streambanks, and discharge from impaired lakes. TSS and TP in the stream are both slightly higher in concentration than the Mississippi River, and are comparable to and in the middle of other highly urbanized streams monitored by MCES. NO_3 concentrations in the Battle Creek watershed remain very low and are significantly below the Mississippi River median concentration. The Cl concentrations in Battle Creek were the second highest of the watersheds monitored by MCES, reflecting the high level of development and road density (especially highways) in the watershed. All of the pollutant loads from the Battle Creek watershed were very small compared to loads from the very large watersheds monitored by MCES (Cannon, Crow, and Vermillion River watersheds).

Trend analysis indicated both upward and downward trends in TSS and TP flow-adjusted concentrations since 1996. The most recent trends are of decreasing TSS and TP flow-adjusted concentration and thus improving water quality. Trend analysis indicated both upward and downward trends in NO_3 flow-adjusted concentration since 1996; the most recent trend is of increasing NO_3 flow-adjusted concentration and thus declining water quality. MCES staff believe NO_3 trends may be affected by periods of saturated and unsaturated soil conditions related to periods of high and low precipitation, rather than response to intentional implementation practices. MCES staff plan to repeat the trend analysis for all parameters, including Cl, in 5 years, and in the mean time will continue to investigate NO_3 dynamics with local and state agency partners.

Analysis of macroinvertebrate samples indicated the influence of pollution during the monitored period, as 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 suggests that this stream reach habitat and water quality were typically unable to sustain all of the needs for aquatic life.

Recommendations

This section presents recommendations for monitoring and assessment of Battle Creek, as well as recommendations for partnerships to implement stream improvements. MCES recognizes that cities, counties, and local water management organizations, like the RWMWD, 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 organizations 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 five years, to assess potential changes in water quality in Battle Creek.

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 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.
- MCES should continue to analyze and evaluate the biomonitoring program. Potential additions should include a Stream Habitat Assessment similar to the MSHA surveys performed by the MPCA.
- RWMWD routinely monitors Battle Creek and Tanners Lakes as part of its Lake Monitoring Program. MCES should collaborate with RWMWD to increase the suite of parameters monitored to aid in understanding sources and trends of pollutants in Battle Creek, especially nitrate and ammonia.
- MCES staff should continue to serve on technical advisory committees and other work groups to support management of Battle Creek.
- MCES and partners (especially RWMWD) 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, which MCES plan to repeat in 5 years.
- Local surface water management plans should acknowledge the heightened potential for surface waters to be impacted by groundwater changes in the Battle Creek watershed.

Citations

Carlisle, D.M., Meador, M.R., Short, T.M., Tate, C.M., Gurtz, M.E., Bryant, W.L., Falcone, J.A., and Woodside, M.D., 2013, The quality of our Nation's waters—Ecological health in the Nation's streams, 1993–2005: U.S. Geological Survey Circular 1391, 120 p., http://pubs.usgs.gov/circ/1391/.

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).

Lee, K.E., Lorenz, D.L., Petersen, J.C., Greene, J.B. 2012, Seasonal patterns in nutrients, carbon, and algal responses in wadeable streams within three geographically distinct areas of the United States, 2007–08: U.S. Geological Survey Scientific Investigations Report 2012–5086, 55 p.

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.

Meyer, G., 2007. Surficial geology of the Twin Cities Metropolitan Area, Minnesota,: St. Paul: Minnesota Geological Survey. Miscellaneous Map Series M-178.

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). 2013. Lake Finder Battle Creek Lake Water Level Report. *In* Minnesota Department of Natural Resources. St. Paul: Minnesota Department of Natural Resources. <http://www.dnr.state.mn.us/lakefind/showlevel.html?id=82009100> (accessed 26.07.13).

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). 2011. 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). 2013a. 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). 2013b. Nitrogen in Minnesota surface waters: conditions, trends, sources, and reductions. St. Paul: Minnesota Pollution Control Agency. Document wq-s6-26a.

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

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

Ramsey-Washington Metro Watershed District (RWMWD). 2007. 2006-2016 Ramsey-Washington Metro Watershed District watershed management plan. St. Paul: Ramsey-Washington Metro Watershed District. <http://www.rwmwd.org/index.asp?Type=B_BASIC&SEC={54D1FD5A-6EE7-452C-A8EB-B43A14ED8998}> (accessed 21.03.14).

Ramsey-Washington Metro Watershed District (RWMWD) n.d.a. Tanners Lake WQ Improvements. *In* Our Projects. St. Paul: Ramsey-Washington Metro Watershed District. <http://www.rwmwd.org/index.asp?Type=B_BASIC&SEC={EEC70BBA-B1F8-47CA-9151-1470539D285C}> (accessed 21.03.14).

Ramsey-Washington Metro Watershed District (RWMWD) n.d.b. East Tamarack WQ Treatment System. *In* Our Projects. St. Paul: Ramsey-Washington Metro Watershed District. <http://www.rwmwd.org/index.asp?Type=B_BASIC&SEC={B10768F7-3919-48C3-9E9A-4A67D190C37E}> (accessed 21.03.14).

Ramsey-Washington Metro Watershed District (RWMWD) n.d.c. Fortis Pond Enhancements. *In* Our Projects. St. Paul: Ramsey-Washington Metro Watershed District. <http://www.rwmwd.org/index.asp?Type=B_BASIC&SEC={EC6C4CE9-EC7A-4248-829B-FEB8F8BCFC2E}> (accessed 21.03.14).

Ramsey-Washington Metro Watershed District (RWMWD) n.d.d. Valley Creek Road Storm Water Treatment System. *In* Our Projects. St. Paul: Ramsey-Washington Metro Watershed District. <http://www.rwmwd.org/index.asp?Type=B_BASIC&SEC={E29A50A2-B1FD-48ED-B516-B927E2D1EB97}> (accessed 21.03.14).

Ramsey-Washington Metro Watershed District (RWMWD) n.d.e. Apostolic Bible Institute (ABI) Water Quality Pond. *In* Our Projects. St. Paul: Ramsey-Washington Metro Watershed District. <http://www.rwmwd.org/index.asp?Type=B_BASIC&SEC={D27C0383-E6E9-46D8-B15E-F39DD193F842}> (accessed 21.03.14).

Ramsey-Washington Metro Watershed District (RWMWD) n.d.f. Living Streets Demonstration. *In* Our Projects. St. Paul: Ramsey-Washington Metro Watershed District. <http://www.rwmwd.org/index.asp?Type=B_BASIC&SEC={FD1328AC-CEEF-455E-A806-BCEF42A2A1B6}> (accessed 21.03.14).

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.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA). 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.

METROPOLITAN
COUNCIL

390 Robert Street North
St Paul, MN 55101-1805

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