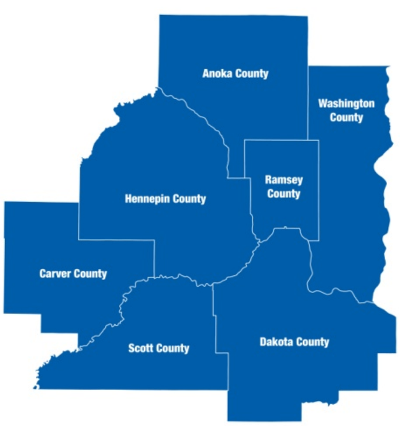
Comprehensive Water Quality Assessment of Select Metropolitan Area Streams

BROWNS CREEK

December 2014

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

Metropolitan Council Members



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.

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, *Browns Creek*, is one in a series produced as part of the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams.* Located entirely in Washington County, Browns Creek is one of the four St. Croix River tributaries examined. This section discusses a wide range of factors that have affected the condition and water quality of Browns Creek.

Cover Photo

The photo on the cover of this section depicts Browns Creek trout habitat and vegetation restoration in the Oak Glen Golf Course, Stillwater, Minnesota.

Recommended Citations

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

Metropolitan Council. 2014. *Browns 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.

Contents

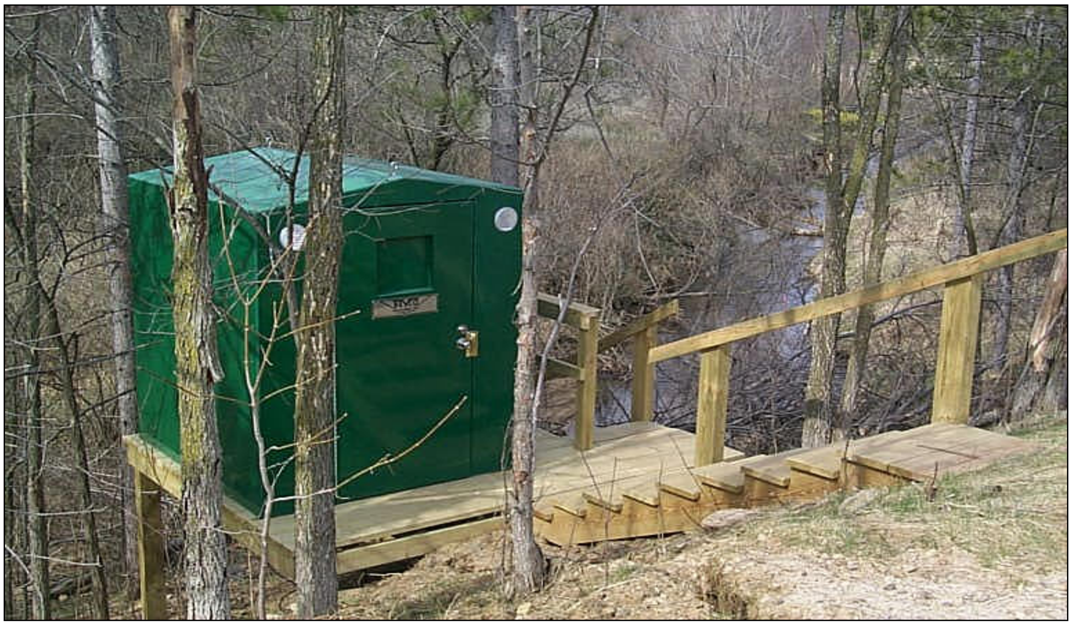
Figures

Tables

Introduction

Browns Creek is located in the eastern metropolitan area and is a tributary to the St. Croix River (Figure BR-1). It drains approximately 28.5 square miles of urban areas, grass lands, forest lands, and mixed agricultural lands. The watershed lies entirely in Washington County and includes portions of the cities of Stillwater, Oak Park Heights, Lake Elmo, Grant, Hugo, and May and Stillwater townships.

Figure BR-1: Browns Creek at Dellwood Road



This report:

- documents those characteristics of Browns 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 Browns Creek flow and water quality with other streams within the metropolitan area monitored by Metropolitan Council Environmental Services (MCES).
- makes general recommendations for future assessment activities, watershed management, partnerships, and other potential actions to remediate water quality or flow concerns.

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

Partnerships and Funding

The Browns Creek monitoring site is supported by a collaboration of many agencies and organizations. MCES has performed water quality monitoring of Browns Creek since 1998 as part of its Watershed Outlet Monitoring Program (WOMP). Both MCES and the Browns Creek Watershed District (BCWD) have provided the operational funds. Additionally, the Minnesota Department of Natural Resources (MnDNR) established a rating curve (used to estimate flow rates from water depth measurements) for this location between 1998 and 2001. The Washington Conservation District (WCD) currently collects water samples, maintains the rating curve, and operates the monitoring station.

Monitoring Station Description

The monitoring station is located on Browns Creek in Stillwater, Minnesota, approximately 0.3 mile upstream from the creek's confluence with the St. Croix River.

The monitoring equipment was updated at this station in 2000. The monitoring station includes a tipping bucket rain gauge (Texas Electronics), continuous flow monitoring (Design Analysis H350/H355 Bubbler), base-flow grab-sample collection, event-based composite sample collection (Hach Sigma Sampler), and continuous water temperature (Campbell Scientific Inc.) and dissolved oxygen (YSI) monitoring. Browns Creek has been monitored for continuous dissolved oxygen data since 2008. The probe is deployed late in April and removed for the winter by early October.

The rain gauge at this monitoring station collects rainfall data; however, the data record is not complete, so supplemental winter precipitation data are obtained from the Minnesota Climatology Working Group, and the National Weather Service Cooperative Observer Program sites: Stillwater 1 SE Station Number 218037, Stillwater 2 SW Station Number 218039, and New Richmond Station Number 475948.

Daily precipitation totals from the National Weather Service stations 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 represent the variability of rainfall within the watersheds (Minnesota Climatology Working Group, 2013). These data are 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

Browns Creek begins in May Township and flows through the city of Grant, Stillwater Township, and the city of Stillwater before discharging into the St. Croix River. The Browns Creek watershed is within Metropolitan Council's jurisdiction (Council Districts 11 and 12). The BCWD administers water quality and stream flow management within the watershed and funds and manages water resources improvement projects. The North and Main Branches of Browns Creek are designated as trout streams by the MnDNR, and fall within the Minnesota Pollution Control Agency's (MPCA) Class 2A Water Regulations for Aquatic Life and Recreation.

The Browns Creek watershed lies entirely in Washington County and has a drainage area of approximately 28.5 square miles (18,154 acres). Browns Creek has two headwater branches, the North and South Branches of Brown Creek. The North Branch of Browns Creek originates from headwater wetlands in the southwest part of May Township and generally flows south with a channel length of 5.75 miles. The South Branch of Browns Creek originates from the outlet of Long Lake and the Jackson Wildlife Management Area, and flows north through Creekside Park in Stillwater, where it converges with the North Branch to form the main branch of Browns Creek 2.2 miles upstream of the monitoring station. The main branch of Browns Creek continues to flow east for 0.3 miles, and discharges into the St. Croix River.

The watershed is a total of 18,154 acres; however, the majority of the watershed is isolated from the stream (that is, landlocked, partially landlocked, and/or hydrologically diverted) and currently only 4,577 acres (25.2%) of the watershed contributes surface flow to Browns Creek upstream of the monitoring station (Table BR-1, Figure BR-2). A greater portion of the watershed likely contributes shallow groundwater flow to the stream.

The entire watershed is 14.8% agricultural land (12.5% within the contributing monitored area), 35.4% developed urban land (31.4% within the contributing monitored area), including portions of the cities of Grant, Hugo, Lake Elmo, Oak Park Heights, and Stillwater. Based on the U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) 2009 Cropland Data Layer, of the agricultural land, 21% (35% of the contributing monitored area) is planted in corn and 16% (3% of the contributing monitored area) in soybeans. According to a statewide estimate of potentially draintiled fields by University of Minnesota researchers (D. Mulla, University of Minnesota, personal communication, 2012), 1% of the agricultural land in the watershed is potentially draintiled. Other primary land covers in the watershed are forest, grasses/herbaceous, and wetlands.

In addition to Browns Creek, there are many other open water bodies within the landlocked northwest and western portions of the watershed. Fingers Pond (7 acres), Plaisted Lake (30 acres), North and South School Section Lakes (30 and 124 acres, respectively), Lynch Lake (20 acres), and Goggins Lake (24 acres) are to the north of Browns Creek. July Lake (11 acres), Benz Lake (32 acres), Pat Lake (13 acres), Kismet Lake (8 acres), Bass Lake West (22 acres), Masterman Lake (31 acres), and Woodpile Lake (11 acres) are west of Browns Creek.

State and local agencies have completed many large-scale water improvement projects with the goal of improving water quality in the Browns Creek watershed, mostly with the intent of preserving the trout habitat in Browns Creek itself. In 1955, MnDNR fisheries managers decided to reroute Browns Creek from Lake McKusick to relieve temperature stress on the trout population. Subsequent projects continued to target stream temperature reduction. In 1999, BCWD rerouted the creek along the Minnesota Zephyr Rail Line and through the Oak Glen Golf Course. This reduced the water temperature by shortening the stream length and reducing the water residence and solar exposure times.

BCWD continued to modify the watershed with the Trout Habitat Preservation Project (THPP) that was completed in 2000. This project involved building three infiltration basins at the outlet of Goggins Lake to promote groundwater recharge and decrease water temperatures in the North Branch of Browns Creek. To increase recharge rates, an infiltration trench was added to the basins over the years 2005-2006. The THPP projects created partially landlocked areas that are hydrologically connected to the stream system only during extreme precipitation events.

In 2003, the City of Stillwater built a major diversion structure that rerouted the warm urban runoff and altered the hydrologic connectedness of the area. The diversion pipe channels the runoff from storms with a magnitude of three inch rainfall or less into Lake McKusick instead of Browns Creek.

The flows from larger storm events are evenly split between the lake and the creek. Additionally, Stillwater constructed an earthen berm along the northern side of the lake to prevent any overflows from entering the creek. These two structures protect Browns Creek from urban runoff that has a higher temperature which would impact the trout population. Another effect of these structures is the effective hydrologic separation of the South Branch of Browns Creek from the main branch of Browns Creek, resulting in lower flows from 2003 to the present day (Emmons & Olivier Resources, 2012).

Smaller-scale projects have also been implemented; for example, the 2010 Stillwater Country Club Water Quality Improvement Project. This project installed rain gardens and other stormwater management features to reduce the amount of sedimentation in the creek. Many other projects have been implemented but are not listed above. For a complete list of projects and plans, please see BCWD’s website.

Table BR-1: Browns Creek Land Cover Classes[1]

Land Cover Class	Monitored[2]		Stillwater Diversion		Partially Landlocked		Landlocked		Unmonitored[3]		Total	
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
5-10% Impervious	685	15.0%	222	5.9%	601	14.0%	1,009	18.3%	<0.1	<0.1%	2,518	13.9%
11-25% Impervious	413	9.0%	381	10.2%	249	5.8%	730	13.2%	3	17.0%	1,776	9.8%
26-50% Impervious	194	4.2%	270	7.2%	58	1.4%	159	2.9%	<0.1	<0.1%	681	3.7%
51-75% Impervious	21	0.5%	582	15.5%	29	0.7%	24	0.4%	4	19.3%	660	3.6%
76-100% Impervious	124	2.7%	545	14.6%	41	1.0%	79	1.4%	5	25.0%	794	4.4%
Agricultural Land	570	12.5%	518	13.8%	937	21.8%	668	12.1%	<0.1	<0.1%	2,693	14.8%
Forest (all types)	597	13.0%	345	9.2%	744	17.3%	887	16.1%	8	38.6%	2,580	14.2%
Open Water	4	0.1%	138	3.7%	549	12.7%	144	2.6%	<0.1	<0.1%	834	4.6%
Barren Land	<0.1	<0.1%	<0.1	<0.1%	<0.1	<0.1%	<0.1	<0.1%	<0.1	<0.1%	<0.1	<0.1%
Shrubland	3	0.1%	7	0.2%	17	0.4%	3	0.1%	<0.1	<0.1%	31	0.2%
Grasses/Herbaceous	1,098	24.0%	563	15.0%	691	16.1%	1,154	20.9%	<0.1	<0.1%	3,506	19.3%
Wetlands (all types)	867	18.9%	171	4.6%	390	9.1%	653	11.8%	<0.1	<0.1%	2,081	11.5%
Total	**4,577**	**100%**	**3,742**	**100%**	**4,307**	**100%**	**5,508**	**100%**	**20**	**100%**	**18,154**	**100%**

[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 seven-county metro area; and the 2001 NLCD (National Land Cover Data), which covered the outstate areas not included in the 2008 MLCCS.

[2]Monitored areas determined using surface topography and assessment of diverted and landlocked areas. Does not include potential discharge from landlocked or diversion areas to the stream via shallow groundwater flow.

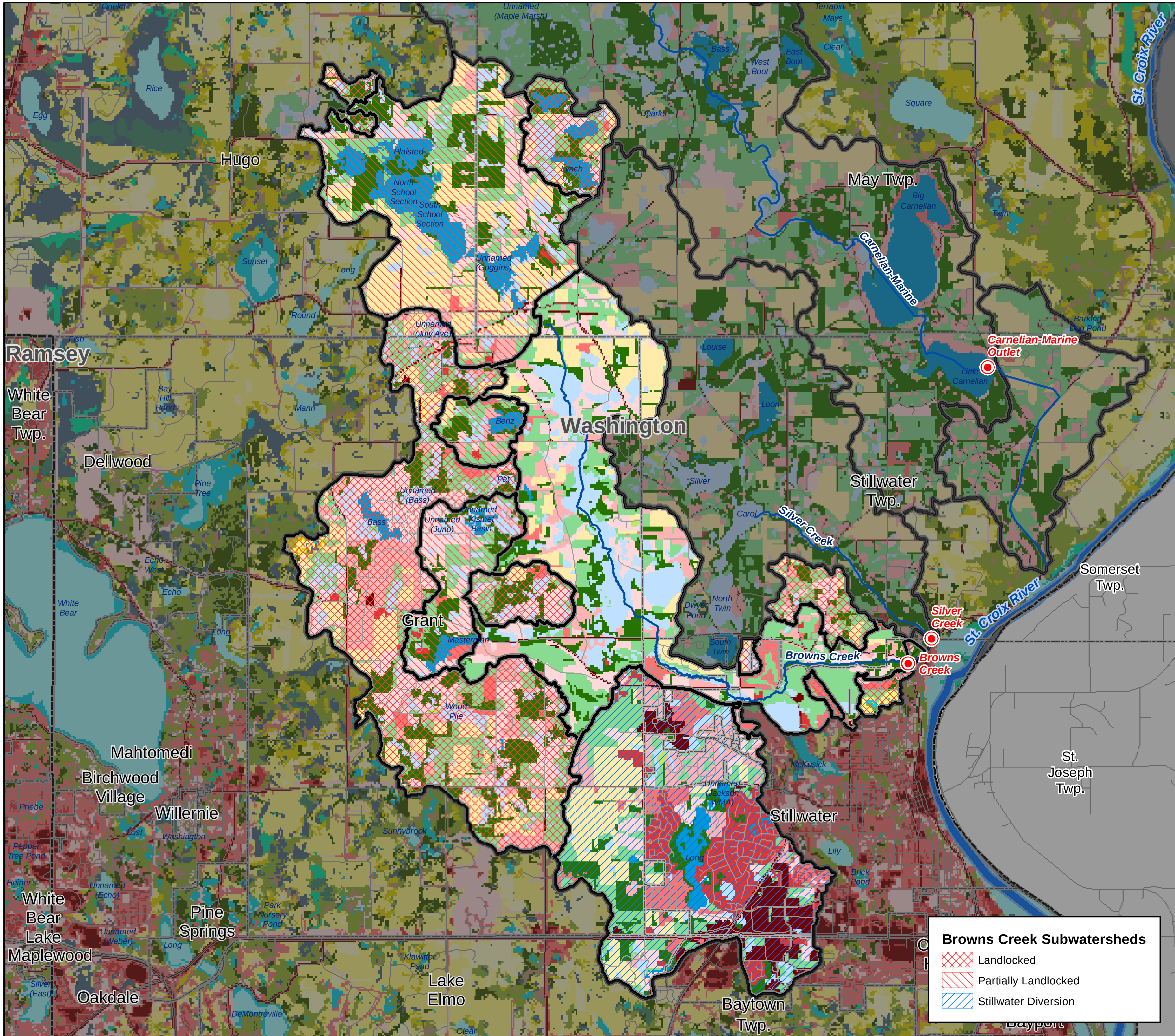
[3]Unmonitored area is that portion of the watershed discharging to the stream downstream of the monitoring station.

Figure BR-2

METROPOLITAN COUNCIL

MLCCS-NLCD Hybrid Land Cover

Browns 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 Browns Creek						
	Monitored		Stillwater Diversion		Landlocked	
Land Cover Class	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
5-10% Impervious	685	15.0%	222	5.9%	1,009	18.3%
11-25% Impervious	413	9.0%	381	10.2%	730	13.2%
26-50% Impervious	194	4.2%	270	7.2%	159	2.9%
51-75% Impervious	21	0.5%	582	15.5%	24	0.4%
76-100% Impervious	124	2.7%	545	14.6%	79	1.4%
Agricultural Land	570	12.5%	518	13.8%	668	12.1%
Forest (all types)	597	13.0%	345	9.2%	887	16.1%
Open Water	4	0.1%	138	3.7%	144	2.6%
Barren Land	0	0.0%	0	0.0%	0	0.0%
Shrubland	3	0.1%	7	0.2%	3	0.1%
Grasses/Herbaceous	1,098	24.0%	563	15.0%	1,154	20.9%
Wetlands (all types)	867	18.9%	171	4.6%	653	11.8%
Total	**4,577**	**100.0%**	**3,742**	**100.0%**	**5,508**	**100.0%**
	Partially Landlocked		Unmonitored		Total	
Land Cover Class	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
5-10% Impervious	601	14.0%	0	0.0%	2,518	13.9%
11-25% Impervious	249	5.8%	3	17.0%	1,776	9.8%
26-50% Impervious	58	1.4%	0	0.0%	681	3.8%
51-75% Impervious	29	0.7%	4	19.3%	660	3.6%
76-100% Impervious	41	1.0%	5	25.0%	794	4.4%
Agricultural Land	937	21.8%	0	0.0%	2,693	14.8%
Forest (all types)	744	17.3%	8	38.6%	2,580	14.2%
Open Water	549	12.7%	0	0.0%	834	4.6%
Barren Land	0	0.0%	0	0.0%	0	0.0%
Shrubland	17	0.4%	0	0.0%	31	0.2%
Grasses/Herbaceous	691	16.1%	0	0.0%	3,506	19.3%
Wetlands (all types)	390	9.1%	0	0.0%	2,081	11.5%
Total	**4,307**	**100.0%**	**20**	**100.0%**	**18,154**	**100.0%**

0 0.5 1 1.5 2 2.5 3
Miles

The geologic history of a watershed dictates many soil and hydrologic properties and surface topography. The Browns Creek watershed was last glaciated during the Wisconsin Glaciation (approximately 20,000 years ago). As the glaciers retreated, they exposed the limestone, dolomite, sandstone, and shale bedrock. Additionally, they deposited till that created the St. Croix moraine most notable near Long Lake and in the northern portion of the watershed near Lake Plasited and the School Sections lakes. Browns Creek watershed also contains a high proportion of organic deposits from glacial lakes that once covered the area (Pitt et al., 2003).

According to the USDA's, Natural Resources Conservation Service (NRCS) STATSGO (State Soil Geographic Database) soils data, nearly all of the soils in the monitored portion of the Browns Creek watershed are glacier outwash associated loamy sands or silty loams. These soils are characterized as Type B soils that have moderate to high infiltration capacities. The Type B soils are primarily found in the lowest elevations of the watershed. The stream channel is primarily Type D soils that have a high clay content and low infiltration capacities. The STATSGO soil survey may not be representative of actual conditions, especially in areas where human disturbance has occurred. For installation of infiltration-based water quality practices (for example, raingardens or bioinfiltration basins) soil borings should be taken from the exact location of the proposed site location to assess level of soil filling or disturbance.

The topography is mostly hilly end moraine, with flatter areas distributed throughout the watershed, culminating with a steep drop into the St. Croix River (Figure BR-3). The maximum contributing watershed elevation is 1048.9 above mean sea level (MSL) and the minimum elevation is 689 MSL within the monitored area. Within the monitored area, 3% of the slopes are considered steep, and an additional 2% are considered very steep. Steep slopes are those between 12-18%, and very steep slopes are those 18% or greater (MnDNR, 2011).The gradient of the creek channel averages 33 feet/mile, with a maximum gradient of 272 feet/mile.

The Browns Creek watershed is relatively undeveloped in the northern portion, with agricultural lands, hobby farms, and rural-residential developments. The southern portion of the watershed is significantly urbanized with a high level of impervious surfaces. Despite the development, there are no MPCA-permitted point source discharges within the Browns Creek watershed. As of 2010, the watershed does have eight registered feedlots with a total of 778 animal units (AUs), all within the monitored portion of the watershed. Only one feedlot has over 100 AUs, with 477 AUs. This feedlot is located in the northern, landlocked portion of the watershed and does not influence the water quality of Browns Creek (Figure BR-4).

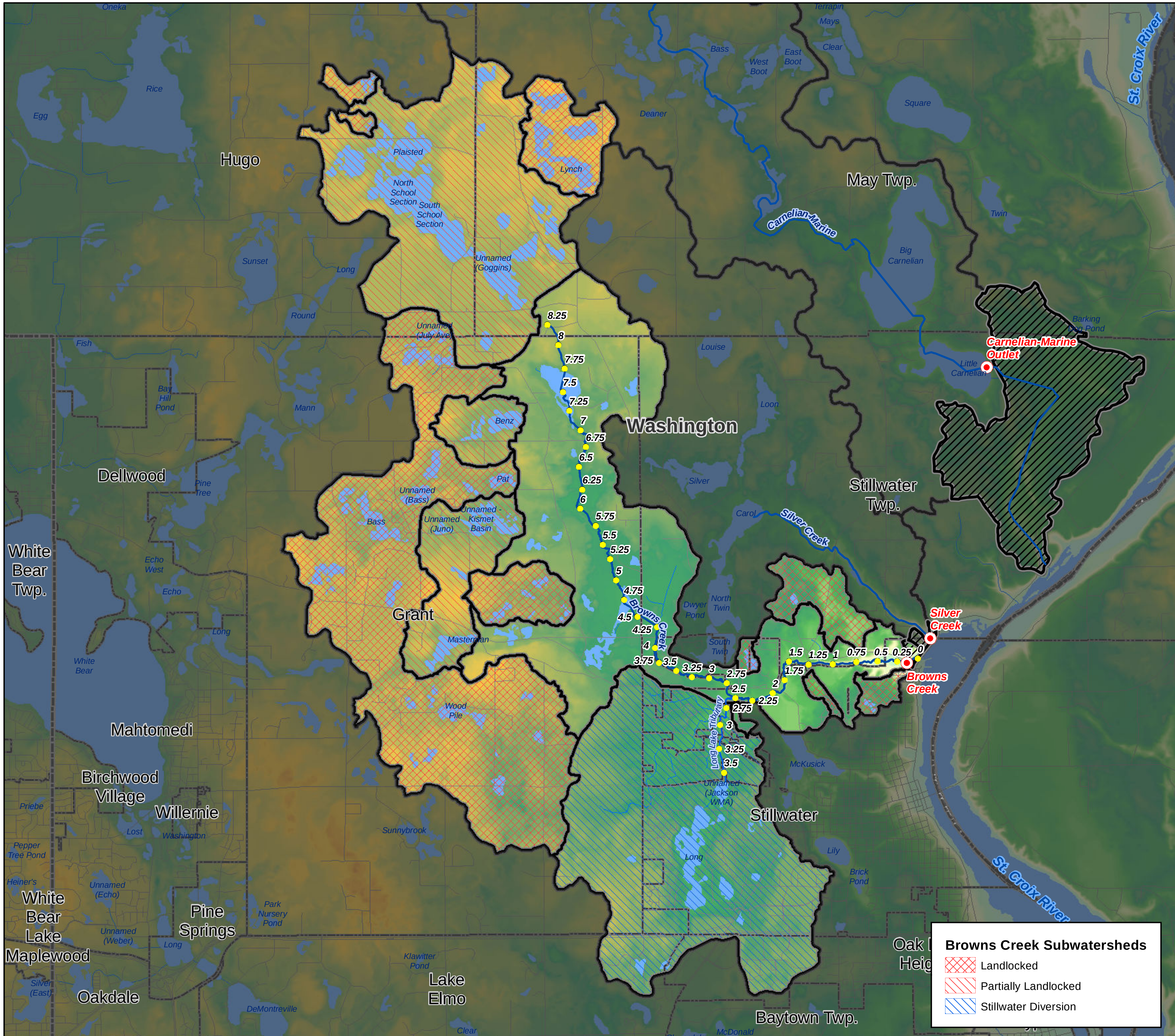


Figure BR-3

METROPOLITAN COUNCIL

Watershed Topography

Browns Creek

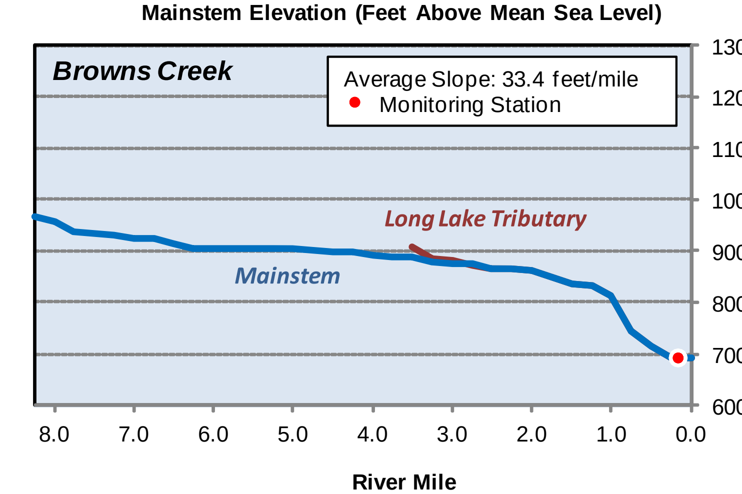
- MCES Stream Monitoring Sites
- USGS Flow Stations
- Stream Mile Markers
- Mainstems (Monitored and Unmonitored)
- Unmonitored Watershed Areas
- Monitored Watershed Boundaries
- Public Waters Inventory
- Other Rivers and Streams
- City and Township Boundaries
- County Boundary
- NCompass Street Centerlines,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



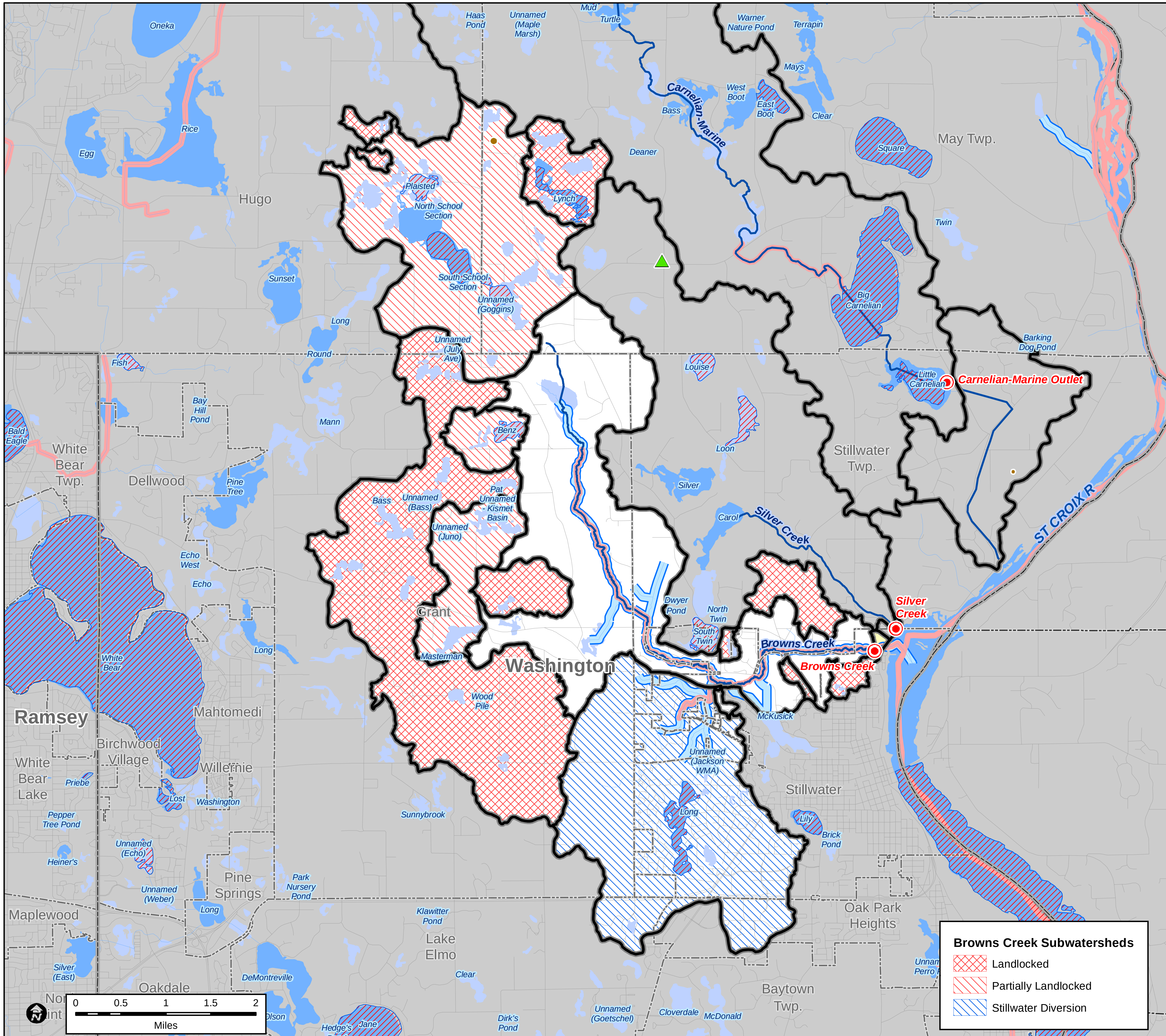
0 0.5 1 1.5 2 2.5 3
Miles

Figure BR-4

METROPOLITAN COUNCIL

Public and Impaired Waters and Potential Pollution Sources

Browns 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

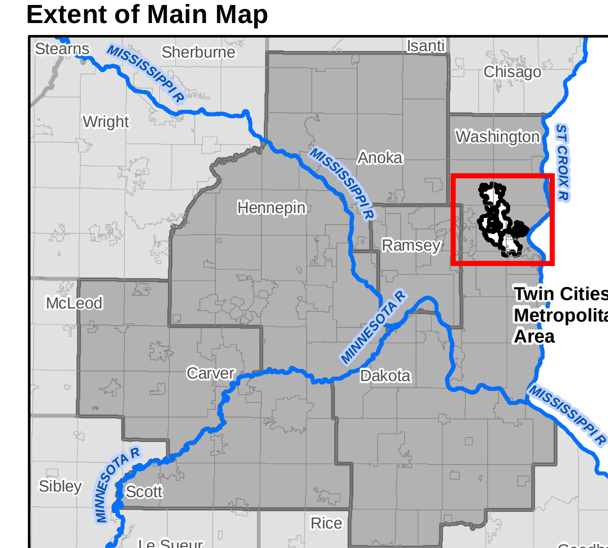
Feedlots with 100 or more animal units **

- 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, 2012
- County Boundary
- City and Township Boundaries

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

Extent of Main Map



Water Quality Impairments

The Browns Creek watershed contains three stream reaches and six lakes that are included on the MPCA 2014 303d (Impaired Waters) list (Figure BR-4, Tables BR-2 and BR-3) (MPCA, 2014a). Both reaches of Browns Creek, the North Branch (T30 R21W S12, north line, to T30 R21W S13, east line) and Main Branch (T30 R20W S18, west line to the St. Croix River) are impaired for aquatic recreation and aquatic life due to low levels of dissolved oxygen, the lack of a cold water fish assemblage, and high levels of *E. coli* (*Escherichia coli*) bacteria.

Table BR-2: Impaired Reaches of Browns Creek Watershed as Identified on the MPCA 2014 Impaired Waters List

Reach Name	Reach Description	Reach ID	Affected Use[1]	Approved Plan[2]	Needs Plan[2]
Browns Creek	T30 R21W S12, north line to T30 R21W S13, east line	07030005-587	AQR, AQL	--	M-IBI, E.coli, LCWA, DO
Browns Creek	T30 R20W S18, west line to St Croix R	07030005-520	AQR, AQL	LCWA, T	E.coli, DO
Unnamed Creek	T30 R20W S19, south line to underground diversion	07030005-767	AQR	--	E.coli

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

[2] T = turbidity; DO = dissolved oxygen; M-IBI = aquatic macroinvertebrates bioassessments; LCWA = lack of cold water assemblage;

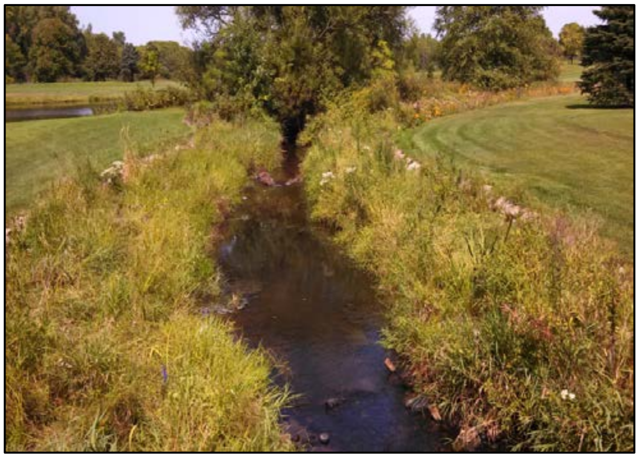
The North Branch is also impaired due to a low score of the Minnesota Macroinvertebrate Index of Biological Integrity (M-IBI). The Main Branch is impaired due to temperature. Benz Lake, Long Lake, Lynch Lake, Plaisted Lake, South School Section Lake, and Goggins Lake are all impaired for aquatic recreation due to high levels of nutrients.

Table BR-3: Impaired Lakes of Browns Creek Watershed as Identified on the MPCA 2014 Impaired Waters List

Lake Name	Lake ID	Water Quality Impairment[1]	Approved Plan	Needs Plan
Benz	82-0120-00	AQR	--	Nutrients
Long	82-0021-00	AQR	--	Nutrients
Lynch	82-0042-00	AQR	--	Nutrients
Plaisted	82-0148-00	AQR	--	Nutrients
South School Section	82-0151-00	AQR	--	Nutrients
Unnamed (Goggins)	82-0077-00	AQR	--	Nutrients

[1] AQR = aquatic recreation

Figure BR-5: Browns Creek Stream Restoration



The BCWD completed a Total Maximum Daily Load (TMDL) Implementation Plan in 2012 to address the TSS and temperature impairments in Browns Creek. These parameters were identified as the major stressors on the in-stream biota. The MPCA, MnDNR, and BCWD anticipate that by improving the stream habitat the macroinvertebrate community will thrive and that trout population will reproduce naturally and not need the annual restocking required since 1958 (Emmons & Olivier Resources, 2012). Part of this plan includes the Browns Creek Thermal Load Reduction, a partnership between BCWD, the Minnesota Board of Water and Soil Resources (BWSR), and the Oak Glen Golf Course. With the help of funding from the Clean Water, Land, and Legacy Amendment Fund, the partnership plans on restoring 1,300 linear feet of the creek, including the planting of native riparian vegetation along the stream banks (Figure BR-5). This project will reduce the stream temperature, making it tolerable for the trout population (Legislative Coordinating Commission, 2013).

Hydrology

MCES has measured flow on Browns Creek at the monitoring station near Dellwood Road in Stillwater, Minnesota since 1998. Flow measurements are collected at 15-minute intervals and converted to daily averages. The hydrograph of Browns Creek, which displays daily average flow, daily precipitation, and the flow associated with grab and composite samples, indicates the variation in flow rates from season to season and from year to year (Figure BR-6), and the effect of precipitation events on flow.

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

The Browns Creek hydrograph is characteristic of a small, responsive groundwater-fed stream system (Figure BR-6). Generally, the storm event daily average flows were less than 90 cubic feet per second (cfs); three spring rains or snowmelt driven events exceeded this level in 2000 and 2001. Of those events, the highest recorded daily average flow in Browns Creek, approximately 109 cfs, occurred in 2001. After the Stillwater diversion structures were installed in 2003, the storm event response was reduced, with the storm event daily average flows rarely exceeding 30 cfs. The mean average daily flow is much lower, 7.8 cfs, which is close to the median average daily flow of 6.6 cfs. Due to the upwelling of groundwater, Browns Creek maintains a baseflow during the winter months or prolonged periods with little precipitation. The lowest recorded average daily flow was 2.0 cfs.

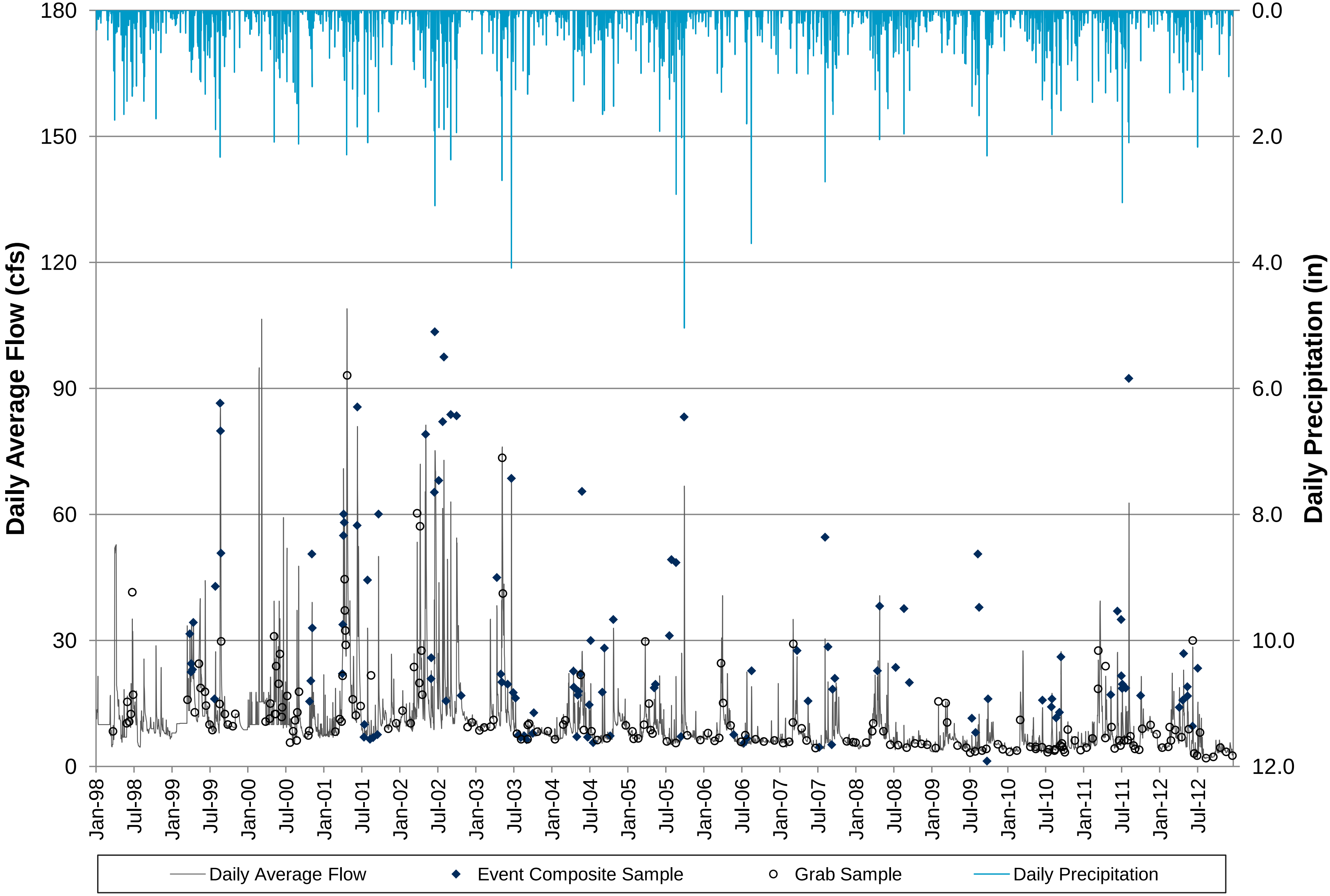
Analysis of the duration of daily average flows indicates the upper 10th percentile flows for the period 1999-2012 ranged between approximately 16 -109 cfs, while the lowest 10th percentile flows ranged from 2.0 - 4.5 cfs (See Figure BR-14 in the ***Flow and Load Duration Curves*** section of this report).

The variations in flow were likely driven by annual precipitation amounts as well as by variation in frequency of intense storm events. However, well over half of the precipitation most likely did not affect the stream as stormwater runoff or overland flows. During the years 1999-2012, the average runoff ratio (annual precipitation total divided by annual runoff volume) was 0.44, indicating an average of 54% of the precipitation either infiltrated the soils, evaporated off of the surface, was evaportranspirated by vegetation, or was stored in watershed wetlands, lakes, and ponds (watershed area was adjusted year-by-year as watershed improvement projects reduced contributing area throughout the study period). As mentioned in the stream and watershed description, the Browns Creek soil types (Type B) facilitate moderately high infiltration. Given this characteristic, the infiltrated precipitation recharges the groundwater aquifers that eventually discharge into Browns Creek.

In the years 1998-1999, the Science Museum of Minnesota's St. Croix Watershed Research Station (SCWRS) performed an extensive hydrological study to determine the source of Browns Creek stream flow and identify the degree and importance of the surface-groundwater interaction. The isotopic and piezometeric analysis confirmed the flows in the North and Main branches primarily originated from the surficial quaternary aquifers (Almendinger, 2003). The groundwater discharged along the length of both channels and was not localized at a single point (for example, headwater springs). These sources can moderate the water temperatures in the both reaches of the stream to maintain suitability for trout habitat.

Both the stream and groundwater discharge tends to be young, about 50 years old, which indicates a short residence time in the aquifer that can be measured in decades, not centuries. The isotopic analysis proved the water in the South Branch was primarily derived from the surface outflows of Long Lake and the Jackson Wildlife Management Area and did not have a groundwater source. Due to the 2003 Stillwater diversion structures installed on this branch, these waters rarely flow into Browns Creek.

Figure BR-6: Browns Creek Daily Average Flow, Sample Flow, and Precipitation, 1998-2012*



*Precipitation record was acquired from NWS COOP stations: 218037-Stillwater 1 SE, 475948-New Richmond, and 218039-Stillwater 2SW

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 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 Browns 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 the greater Browns Creek watershed, the entirety of Browns Creek was identified as potentially vulnerable, as was the St. Croix River proper. Several basins within the watershed were identified as vulnerable to groundwater withdrawals, including North and South School Section, Goggins Lake, Benz Lake, Pat Lake, Long Lake, Lake McKusick, plus a number of surrounding smaller unnamed wetlands.

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 Browns Creek (1999-2012).

Figures BR-7-BR-10 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 three hydrological metrics (annual average flow rate, depth of flow (annual flow per unit area) and precipitation depth coupled with runoff ratio). A later section in this report (***Comparison with Other Metro Area Streams***) offers graphical comparison of the Browns Creek loads and FWM concentrations with the other MCES-monitored metropolitan area tributaries.

The first charts in Figures BR-7 and BR-8 plot the annual flows from 1999-2012. The highest average annual flow, and thus the highest volume of flow, occurred during 2002 (approximately 18.7 cfs average annual flow); the lowest average annual flow, and lowest volume of flow, occurred in 2009 (approximately 5.5 cfs average annual flow). For the full record of data, the mean average annual flow was 9.98 cfs, which is close to the median average annual flow of 8.93 cfs, suggesting the annual flows were evenly distributed around the mean annual flow. The flow metrics indicate a gradual decrease in flows from 2002 to 2010. The diversion structure modified the flows in the creek from 2003 to present by diverting the South Branch flows into a different drainage system. This potentially explains the immediate drop in flows from 2002 to 2003. Additionally, the WCD (2010) attributed some decrease in flows during the period 2003-2009 to minimal snowfall and dry summers in the catchment and a series of newly constructed beaver dams in 2010. The flows increased in 2011, presumably because the beavers were relocated.

The annual mass loads for all analytes exhibit some year-to-year variation, but generally mirrored the pattern in annual flows (Figure BR-7). Every graph shows the highest load occurred in 2002. Similarly, almost every graph shows the lowest loads occurred in 2009, with the exception of NH_3 and NO_3, which occurred in 2012. This strongly suggests that loads in Browns Creek are driven by changes in both water source and flow conditions.

The annual FWM concentrations provide greater insight to the loading dynamics in Browns Creek (Figure BR-8). The FWM concentrations from 1999-2002 were the product of two different water sources, near-channel overland flow, and in-stream nutrient exchanges. The two different water sources were the rural, spring-fed North Branch and the urban, surface-water sourced South Branch of Browns Creek. At the monitoring station the branches combined to create the flows in the Main Branch. During this time the FWM TSS and TP concentrations consistently increased to their second highest average annual concentration in 2002, (126 and 0.27 mg/l, respectively). The FWM NO_3 concentrations declined over this period, while FWM TDP, NH_3, and Cl concentrations maintained a relatively steady concentration.

From 2003 and forward, the FWM concentrations were only a product of the one rural-residential, spring-fed water source (North Branch), near-channel overland flow, and in-stream chemical cycling. As stated previously, the precipitation inputs were limited during the years 2003-2009, reducing the influence of flushed terrestrial pollutants on the concentration. Therefore, the variations in FWM concentrations during that period were most likely from natural variations in the groundwater source and in-stream nutrient exchanges.

The TSS and TP concentrations declined from the 1999-2002 levels and remained relatively steady. The NO_3 FWM concentrations increased from the 1999-2002 levels, and also remained relatively steady. In 2011, the stream flows increased from heightened precipitation, which most likely diluted the groundwater-sourced NO_3. The TDP, NH_3, and Cl FWM concentrations did not demonstrate a noticeable change in annual concentrations with the change in water source.

Figures BR-9 and BR-10 present the areal- and precipitation-weighted loads, respectively. The Browns Creek watershed area was adjusted year-by-year as watershed improvement projects reduced contributing area throughout the study period. 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 Browns Creek (Figure BR-11 and BR-12). The results for each month are expressed on each graph in two ways: the monthly results for the most recent year of data (2012 for Browns Creek) and the monthly average for 2003-2012 (with a bar indicating the maximum and minimum value for that month).

The 2012 Browns Creek monthly mass loads were not noticeably different than the 10-year average. The Browns Creek 10-year average monthly loads of TSS, TP, TDP did not clearly demonstrate a peak month load (Figure BR-11). They did show the lowest loads during the winter months (November-February). The remaining monthly loads were variable and did not exhibit a clear seasonal trend.

The highest 10-year average monthly NH_3 load occurred in March. A possible explanation for this load could be the flushing of NH_3 in the near-stream watershed produced by microbial activity. It is widely accepted that soil microbes are highly active under insulating snows, accumulating large stores of NH_3 in the soils (Brooks et al., 2011). Snowmelt events produced a large volume of water to flow over the thawed soils that likely flushed and transported NH_3 into the stream. The remainder of the year was characterized by lower loads of NH_3.

The 10-year Cl average monthly mass loads appeared slightly elevated during the spring, and then relatively consistent throughout the year. This could be due to the flushing of urban road deicers during snowmelt.

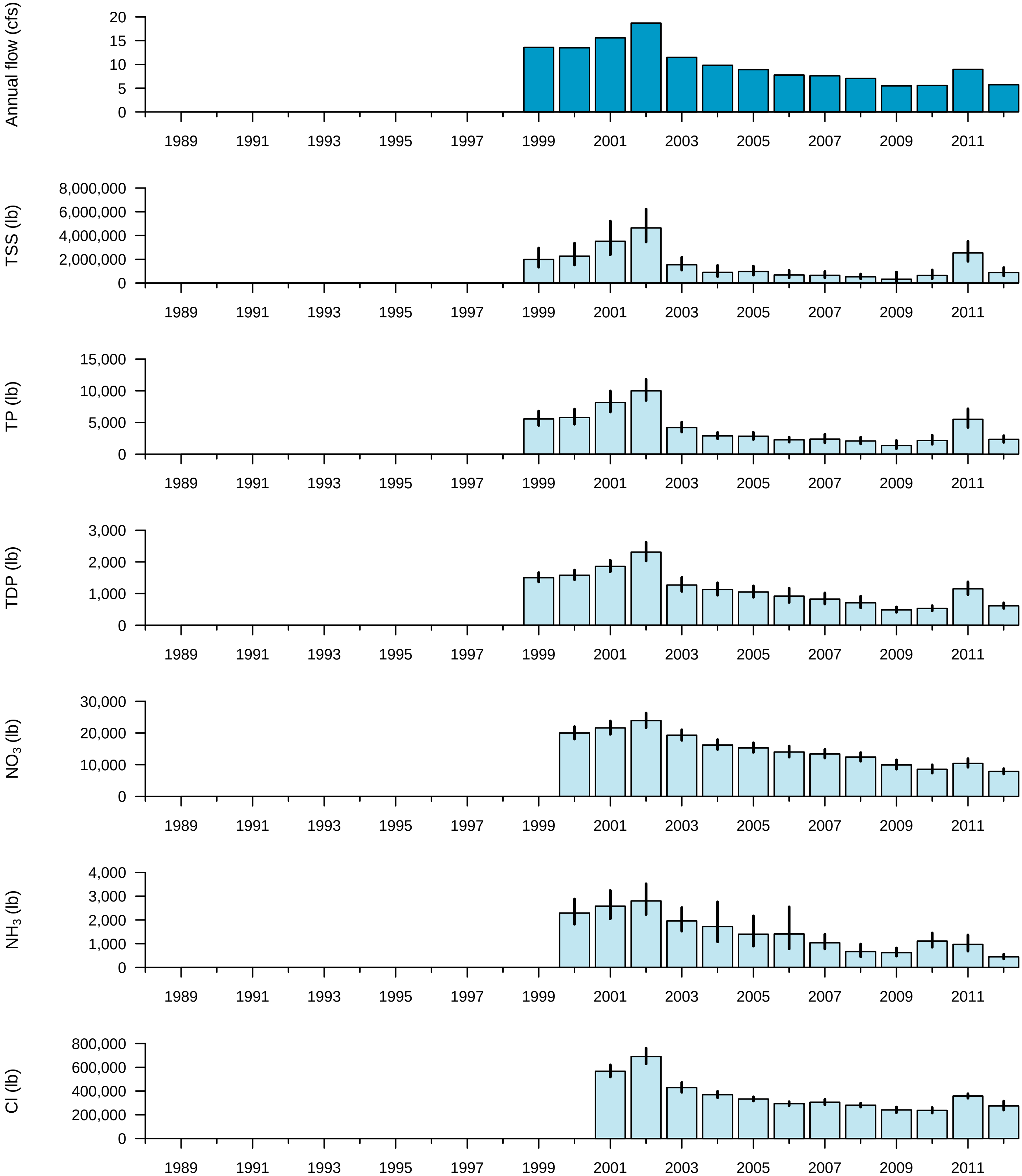
Generally, the 10-year average and the 2012 Browns Creek FWM concentrations support the same patterns shown in the monthly mass loads (Figure BR-12). The TSS and TP FWM concentrations were lower in the winter months and had no discernible concentration pattern for the remainder of the year. The NH_3 FWM concentrations were highest in March. Although NO_3 FWM concentrations did exhibit a very slight reduction during March through June, most likely attributable to dilution from snowmelt and spring biological uptake, comparatively both Cl and NO_3 showed little monthly variation.

The consistency in Cl and NO_3 monthly average FWM concentrations is strongly suggestive of contaminated groundwater. Cl concentrations in urbanized streams tend to noticeably increase during spring snowmelt due to the flushing of road de-icers. The Browns Creek Cl concentration did increase slightly, but not the degree of other urbanized watersheds in the metro area. The Stillwater diversion structure diverted the stormwater contributions from a large urban section of the watershed, but the watershed still retained surfaces that require de-icer treatment (primarily roads, sidewalks, and parking lots). Yet, the spring months do not show a snowmelt Cl signal. This suggests that the groundwater is more concentrated with Cl than the spring runoff. Similarly, the NO_3 signal should increase during the spring/summer months as agricultural field and lawn fertilizers are applied to promote crop or grass growth and are potentially flushed into the stream. However, during this period the Browns Creek NO_3 signal decreases. This is suggestive of a dilution in the NO_3 laden groundwater-fed base flow with less concentrated spring runoff.

Given these data, it is impossible to attribute Cl or NO_3 contamination to any specific source in the watershed. However, there are plausible mechanisms that could cause the elevated levels of NO_3 and Cl in the groundwater. For example, the application of nitrogen and potash (KCl) fertilizers on agricultural lands could raise groundwater concentrations. While NH_3 is the most common form of nitrogen applied to fields, it readily converts to NO_3, the most mobile form of nitrogen (Böhlke, 2002). Potassium is a macronutrient for plants, and the most common potassium source in Minnesota is KCl fertilizer (Rehm and Schmitt, 1997). The combination of high to moderately high infiltration capacity of the soils and the need for fertilizer application may result in a direct application of NO_3 and Cl into the groundwater aquifer when soil waters drain downwards.

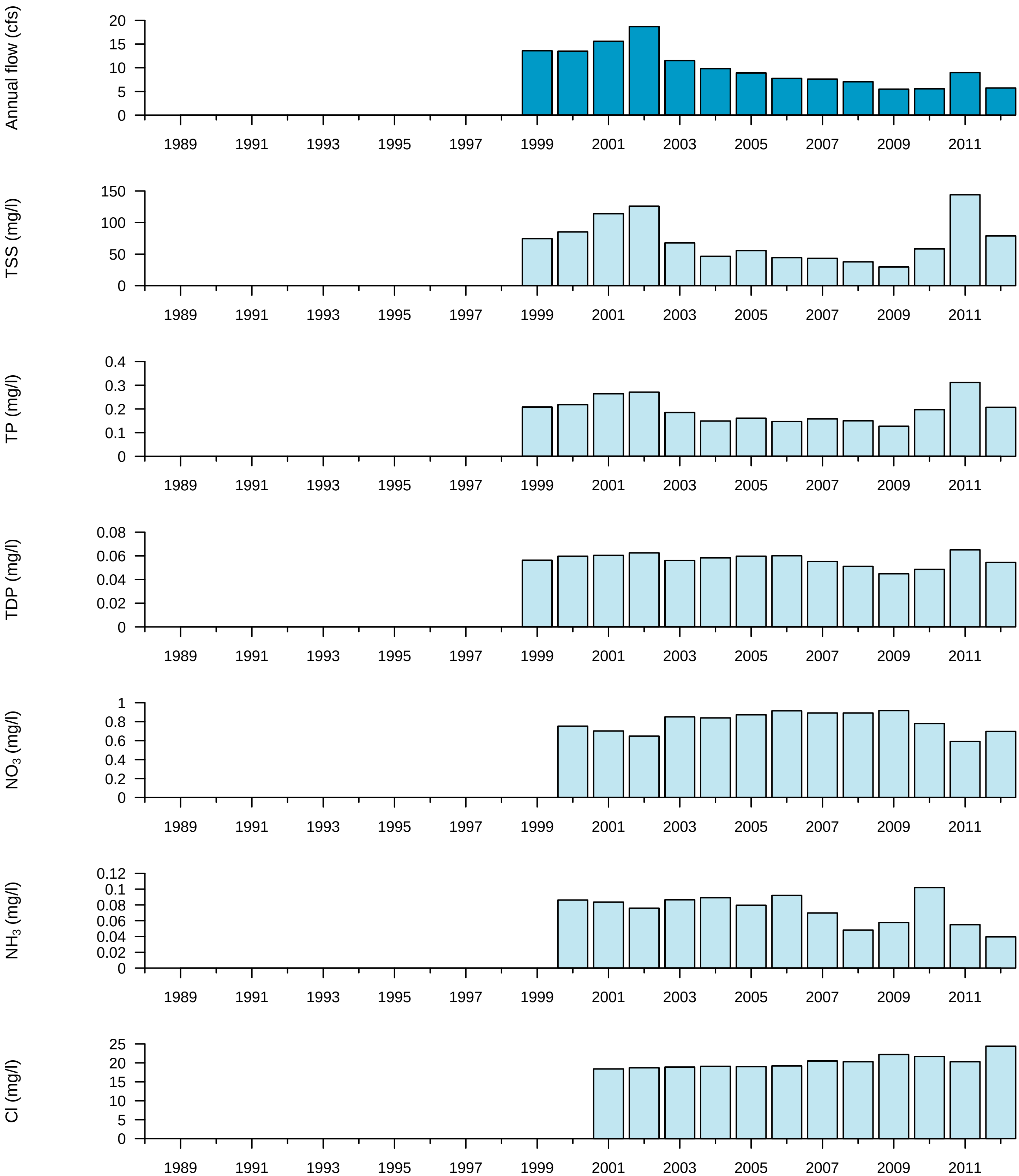
Another potential source of Cl could be related to sewage and water treatment. The lack of access to the central sewer system (discharging to the St. Croix Valley wastewater treatment plant) in portions of the Browns Creek watershed means landowners are forced to use on-site septic systems to manage wastewater, which provides another plausible avenue for Cl contamination. Untreated domestic wastewater typically contains 30-90 mg/l of Cl (Metcalf and Eddy, 2003). Further, water softening can increase this Cl load, as the softening chemicals used to remove minerals from water are primarily salt resins (Sander et al., 2008). During the recharging process these resins are rinsed, creating a brine backwash. If released into a drain field, both the wastewater and the brine would infiltrate the soils and contaminate the groundwater.

Figure BR−7: Browns Creek*
Annual Mass Load



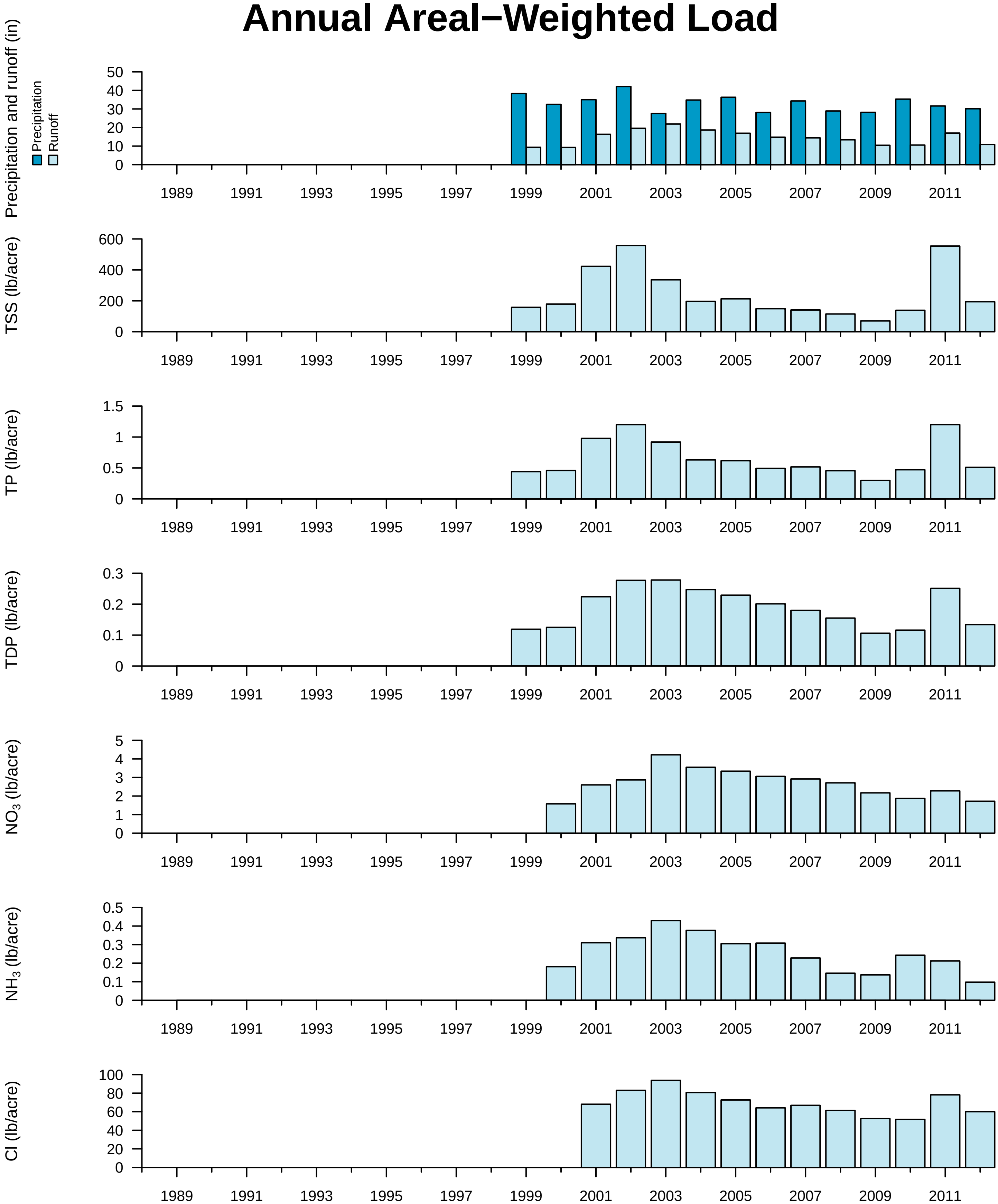
*First full year of sampling for TSS, TP, and TDP began in 1999, NO3 and NH3 began in 2000, and Cl began in 2001.
Bars represent 95% confidence intervals as calculated in Flux32.

Figure BR−8: Browns Creek*
Annual Flow−Weighted Mean Concentration



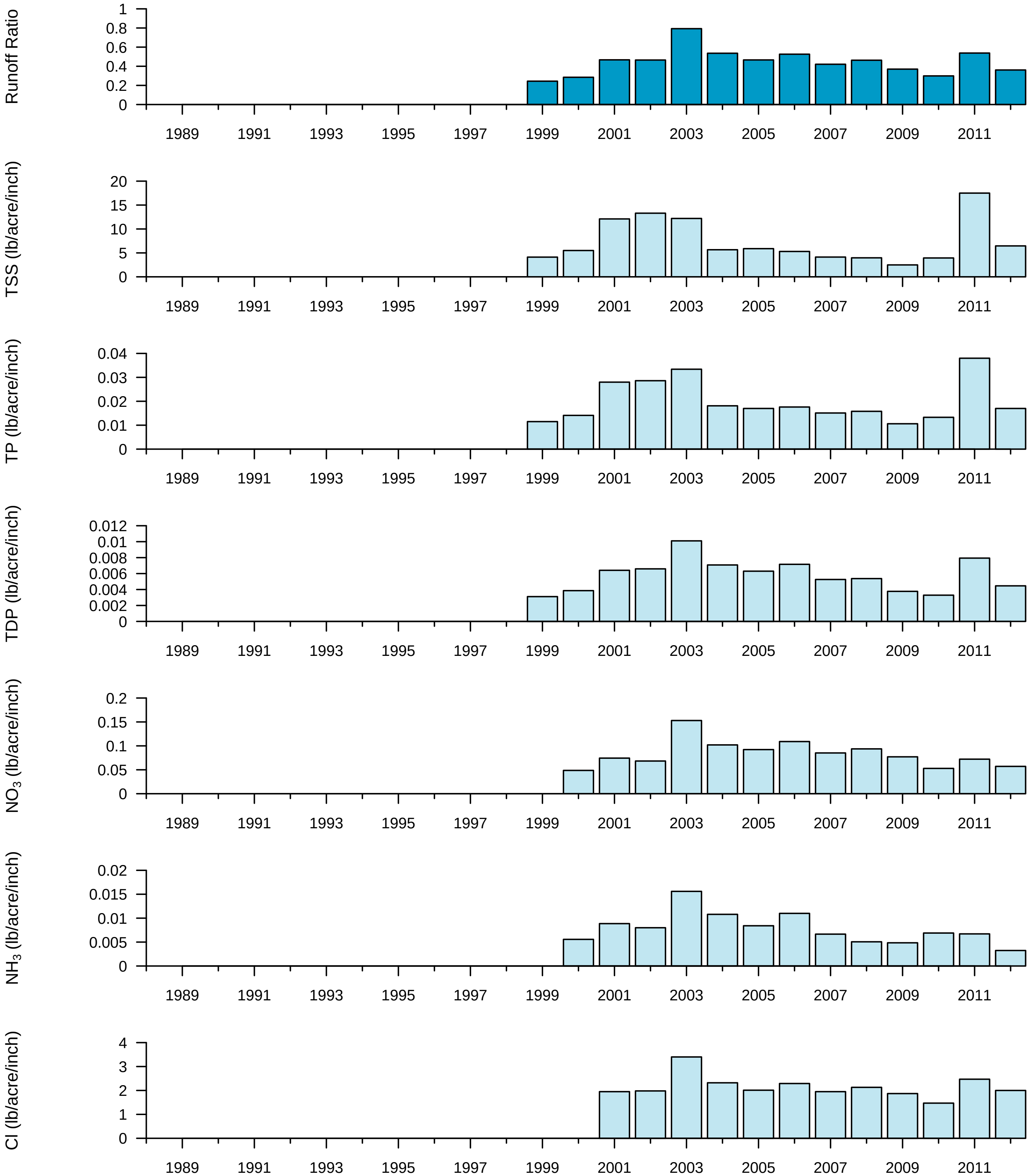
*First full year of sampling for TSS, TP, and TDP began in 1999, NO3 and NH3 began in 2000, and Cl began in 2001.

Figure BR−9: Browns Creek*
Annual Areal−Weighted Load



*First full year of sampling for TSS, TP, and TDP began in 1999, NO3 and NH3 began in 2000, and Cl began in 2001.

Figure BR−10: Browns Creek*
Annual Precipitation−Weighted Areal Load



*First full year of sampling for TSS, TP, and TDP began in 1999, NO3 and NH3 began in 2000, and Cl began in 2001.

Figure BR−11: Browns Creek Mass Load by Month

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

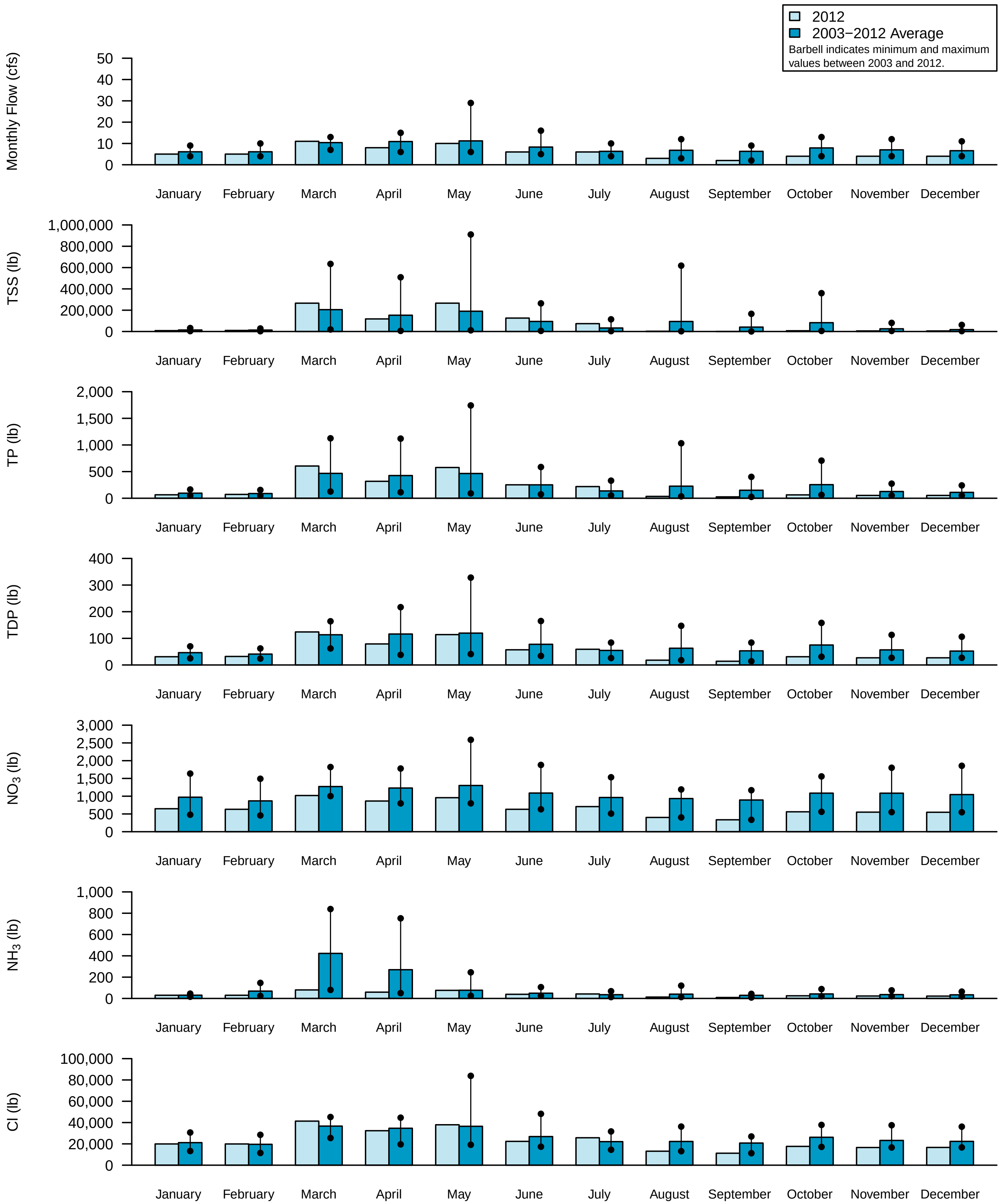
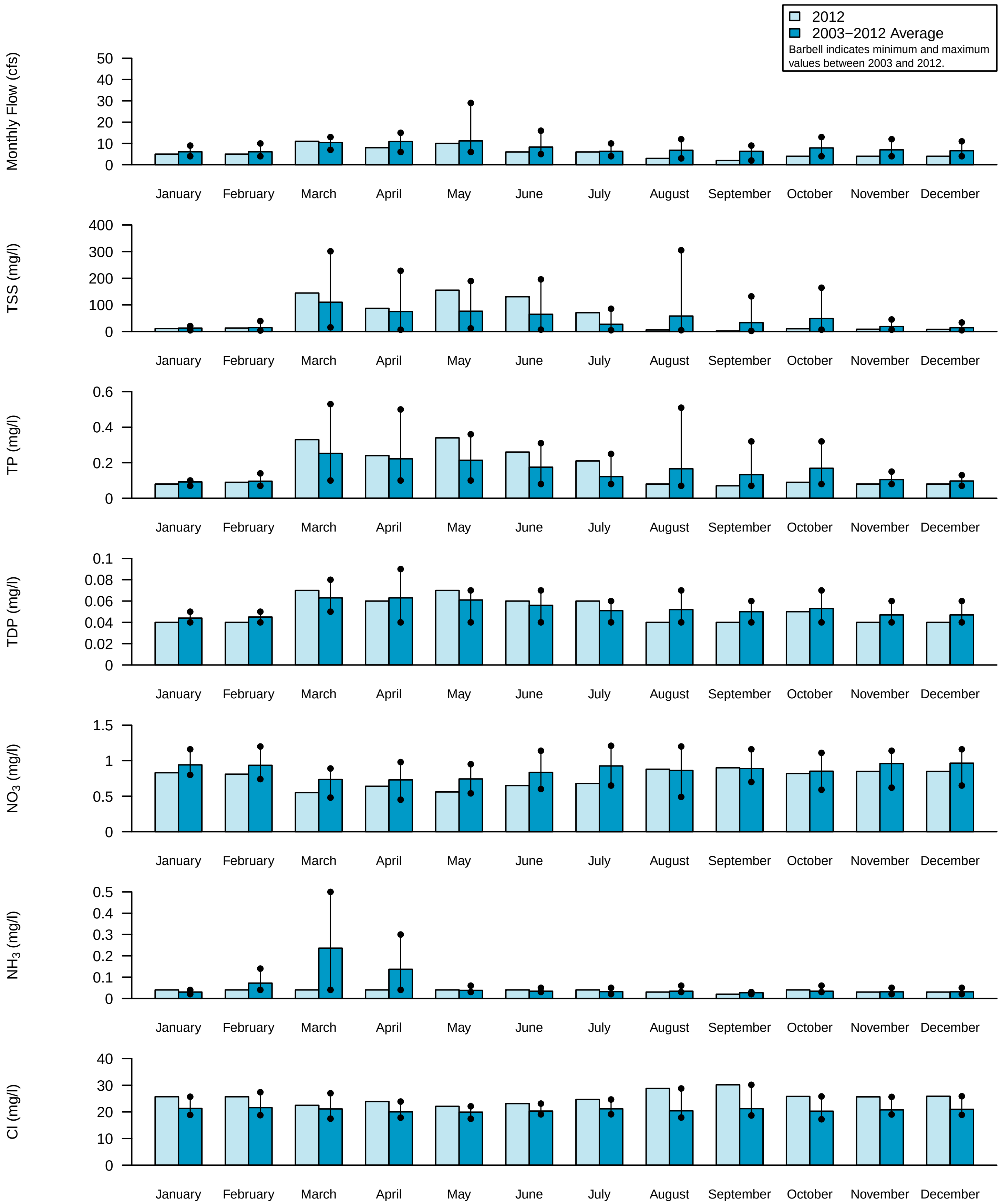


Figure BR−12: Browns Creek
Flow−Weighted Mean Concentation by Month

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



Dissolved Oxygen Assessment

Dissolved oxygen (DO) is the concentration of oxygen gas dissolved in the water. It is vital to aquatic organisms and mediates biochemical reactions. DO is influenced by water temperature, flow velocity, nutrient levels, and the presence of aquatic plants and algae. DO measurements provide a quick assessment of water quality and ecosystem health.

The dynamics of DO in a groundwater-fed stream, like Browns Creek, are more complex than that of an only surface-fed stream. This is due to the oxygen depleting, or reducing, origin of the water. As the water flows through the aquifer to the stream, it can intersect organic material or iron rich soils. These interactions deplete DO. As noted by the WCD (2007), recharge waters could begin with 8-12 mg/l DO concentrations in the upland areas of the St. Croix Moraine and end with DO concentrations below 1 mg/l near Browns Creek.

Daily Minimum DO

Browns Creek is a MnDNR designated Class 2A Trout Stream. This classification invokes stringent water quality standards to promote and protect trout and their habitat. To be in compliance with the standard, the daily minimum DO concentration must be at or above 7 mg/l; 5 mg/l is the daily minimum DO standard for other recreational streams.

Actual daily minimum DO values were determined from the continuous monitoring record during 2008-2012. In both the summer and winter monitoring seasons for the period of record, Browns Creek was generally compliant with the water quality standard (Tables BR-4 and BR-5).

In the summer (May-September) 1.2% of the daily minimum values did not comply with the water quality standard (7 of 601 assessed days).

Table BR-4: Browns Creek Summer Daily Minimum Dissolved Oxygen

Year	Number of Days Assessed	Number of Days where Daily Minimum DO <7mg/l	Percent of Days where Daily Minimum DO <7mg/l
2008	147	0	0
2009	139	1	0.7
2010	153	1	0.7
2011	91	0	0
2012	71	5	7
Total	**601**	**7**	**1.2**

In winter (October-April) none of the 178 daily minimum values were below 7 mg/l. Each year includes more than 30 winter observations. However, the winter data did not include any results from November-March, so the assessment is incomplete. It is unlikely that the DO concentrations were out of compliance during the unmonitored period.

Table BR-5: Browns Creek Winter Daily Minimum Dissolved Oxygen

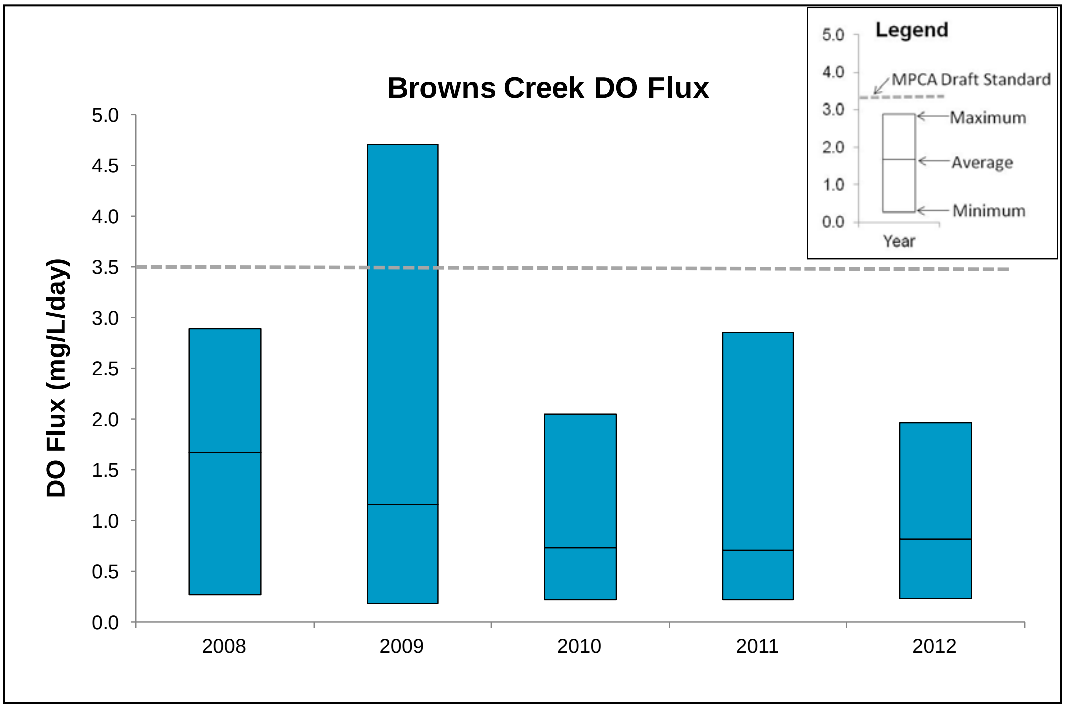
Year	Number of Days Assessed	Number of Days where Daily Minimum DO <7mg/l	Percent of Days where Daily Minimum DO <7mg/l
2008	30	0	0
2009	34	0	0
2010	36	0	0
2011	40	0	0
2012	38	0	0
Total	**178**	**0**	**0**

Daily DO Flux

An alternative method to assess DO concentrations in streams is to monitor the daily flux of DO. DO flux is the difference between the daily maximum and daily minimum DO. DO concentrations naturally exhibit a diel (daily) cycle. Photosynthesizing aquatic plants and algae increases DO concentrations throughout daylight hours. At night, DO decreases when photosynthesis stops and respiration continues. A high daily flux value indicates eutrophication, a condition resulting from excessive nutrients in the water.

Browns Creek is in the Central Region of Minnesota for the purposes of daily DO flux assessment. In the Minnesota River Nutrient Criteria Development (MPCA, 2013a), the MPCA has set a draft standard of daily DO flux less than or equal to 3.5 mg/l for streams in the Central Region of Minnesota.

Figure BR-13: Browns Creek Daily Dissolved Oxygen Flux



Actual daily minimum and maximum DO values were determined from the continuous DO record. The difference between the values is the daily DO flux. The minimum, average, and maximum DO flux were calculated for each year (Figure BR-13). During the assessed period (786 days over five years), the daily DO flux exceeded 3.5 mg/l four times in 2009 (0.51%). From 2010-2012 Browns Creek complied with the draft standard. This suggests that Browns Creek is not currently affected by excess eutrophication.

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 recommendations of the U.S. Environmental Protection Agency (USEPA), 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 5th, 25th, 50th, 75th, and 95th 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 Browns Creek monitoring station daily average flows and sample data, along with the most appropriate MPCA draft numerical standard as listed in Table BR-6. 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 standards 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 (suspended) chlorophyll, biochemical oxygen demand (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 1999-2012 flow duration curve and load duration curves for TSS, TP, NO_3, and Cl for the Browns Creek monitoring station (mile 0.3, at Dellwood Road) are shown in Figure BR-14.

The range of flows and the flow duration curve shape describe the flow regime of the stream system. Flow duration analysis of daily average flows indicates the upper 10^{th} percentile flows ranged between approximately 16.2-109 cfs, while the lowest 10^{th} percentile flows ranged from 2.0-4.5 cfs. The steep curve in the High Flow category indicates that high flows last for short periods of time, usually because of short-lived rain induced floods. The flat line in the Low Flow category indicates that Browns Creek maintains flows throughout the year, which can be attributed to the groundwater source of stream flow.

The load duration curves provide insight as to how flow conditions affect the stream load compliance with state standards. At low flows, the Browns Creek loads were below the loads dictated by the draft standards for TSS, TP, Cl, and the drinking water standard for NO_3. As the flows increased, the TSS and TP daily loads fell both above and below the dark lines designating the standard. Under high flows all of the TSS and TP samples exceeded the standards. Regardless of flow conditions, both NO_3 and Cl loads are consistently below the drinking water and Cl draft standards, respectively. This lack of variation in the daily loads of NO_3 and Cl an additional line of evidence pointing to a NO_3 and Cl groundwater contamination.

Table BR-6: Browns 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[2] (Class 2)	River Nutrient Region (RNR)[3] of Monitoring Station	Cl Draft Stnd[4] (mg/l)	TSS Draft Stnd[5] (mg/l)	TP Draft Stnd[6] (ug/l)	NO3 DW Stnd[7] (mg/l)
Browns Creek at Dellwood Rd. (BR 0.3)	1B, 2A	Central	230	10	100	10

[1] Minn. Rules 7050.0470 and 7050.0430

[2] Trout stream identified in Minn. Rule 7050.0470

[3] MPCA, 2010.

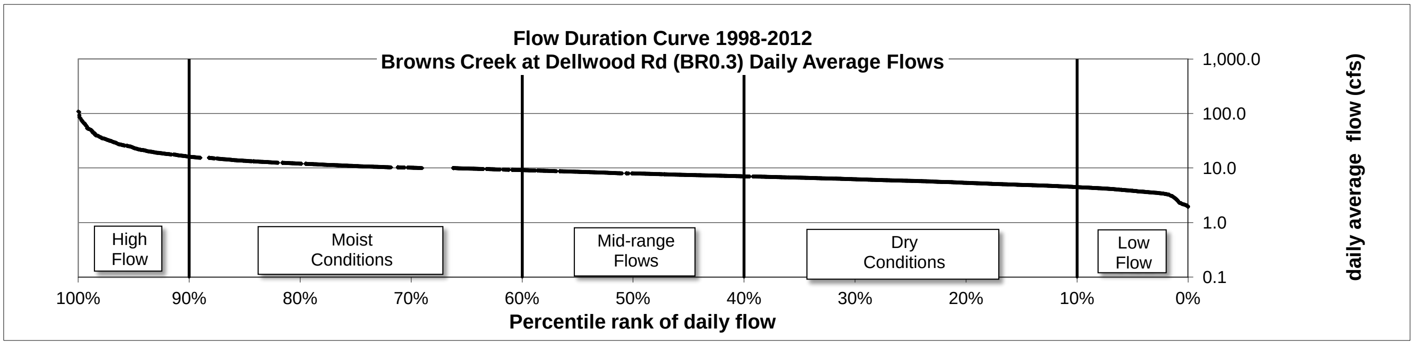
[4] Mark Tomasek, MPCA, personal communication, March 2013. MCES used 230 mg/l as the draft Cl standard pending results of USEPA toxicity tests.

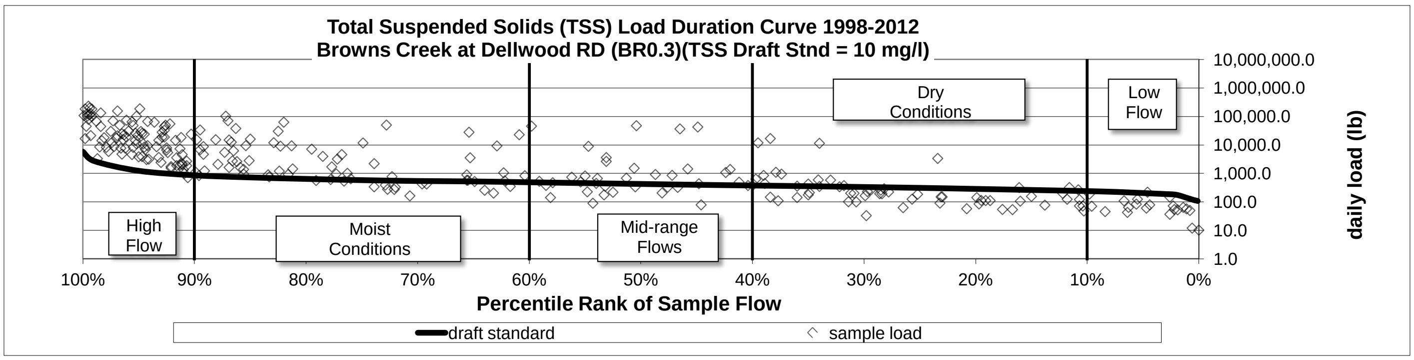
[5] MPCA, 2011. Draft standard states TSS standard concentration for Class 2A and 2B water must not be exceeded more than 10% of the time over a multiyear data window, with an assessment period of April through September.

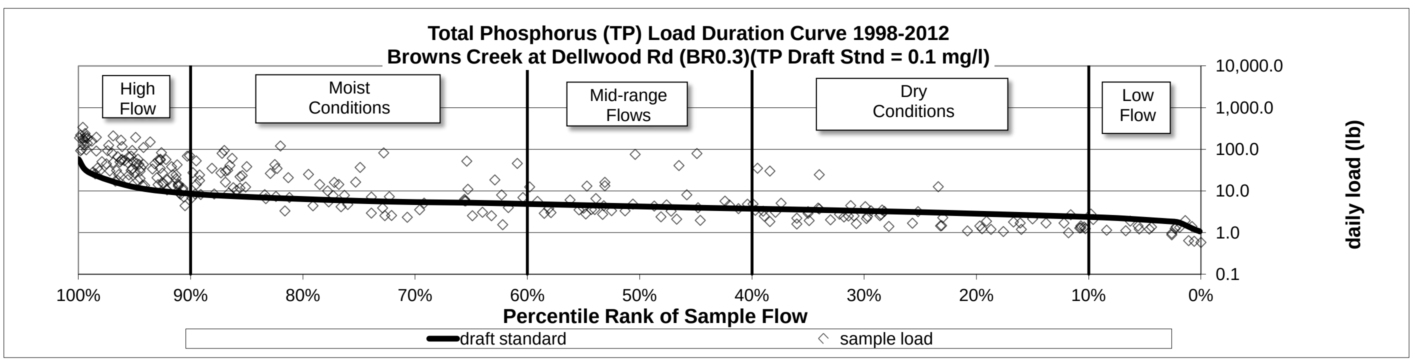
[6] MPCA, 2013a. To violate standard, concentration of causative variable (TP) must be exceeded, as well as one or more response variables: sestonic chlorophyll, BOD_5, DO flux, and/or pH.

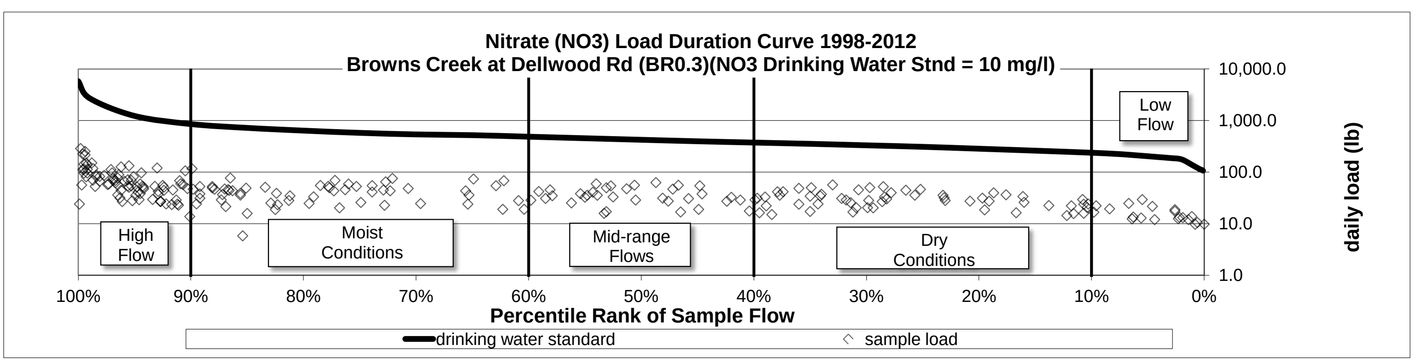
[7] MCES used the NO_3 drinking water standard of 10 mg/l pending results of USEPA toxicity tests and establishment of a draft NO_3 standard for rivers and streams.

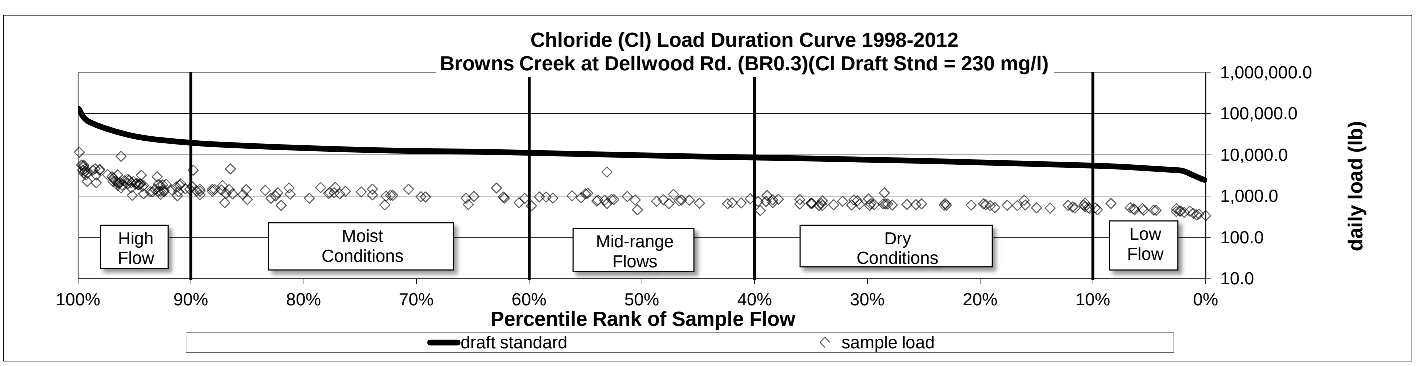
Figure BR-14: Browns Creek Flow and Load Duration Curves, 1998-2012











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.

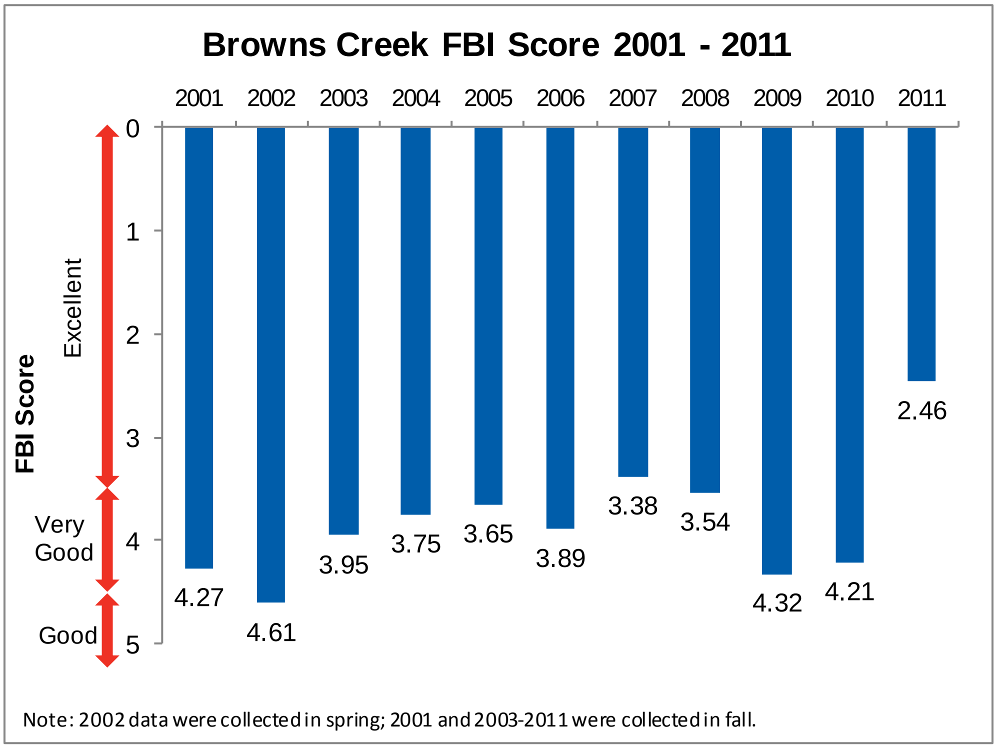
MCES has been sampling macroinvertebrates in Browns Creek at the monitoring station since 2001. The 2002 macroinvertebrates were sampled in late spring; the remaining years (2001, 2003-2011) were collected in the fall (September or October).The entire dataset was analyzed with three metrics: Family Biotic Index (FBI), Percent Intolerant Taxa, and Percent POET Taxa. A subset of the data, 2004-2009 and 2011, was analyzed using the multi-metric, Minnesota-specific, Macroinvertebrate Index of Biological Integrity (M-IBI) (MPCA, 2014b).

Family Biotic Index (FBI)

The FBI is a common water quality assessment. Each family is assigned a tolerance value that describes its ability to tolerate organic pollution, such as insecticides or herbicides. The values range from 0 to 10; zero is intolerant of pollution, 10 is quite tolerant of pollution. The tolerance values are used to calculate a weighted tolerance value for the sample, allowing for comparisons from year to year.

The Browns Creek FBI scores ranged from excellent water quality (2007) to very good water quality (2009), indicating the possible presence of organic pollution (Figure BR-15). The 2002 FBI value scored in the good range, but this cannot be compared to the other scores as it was collected during a different time of the year. The FBI scores appear to be decreasing over time, possibly indicating a decrease in organic pollution since the early 2000s.

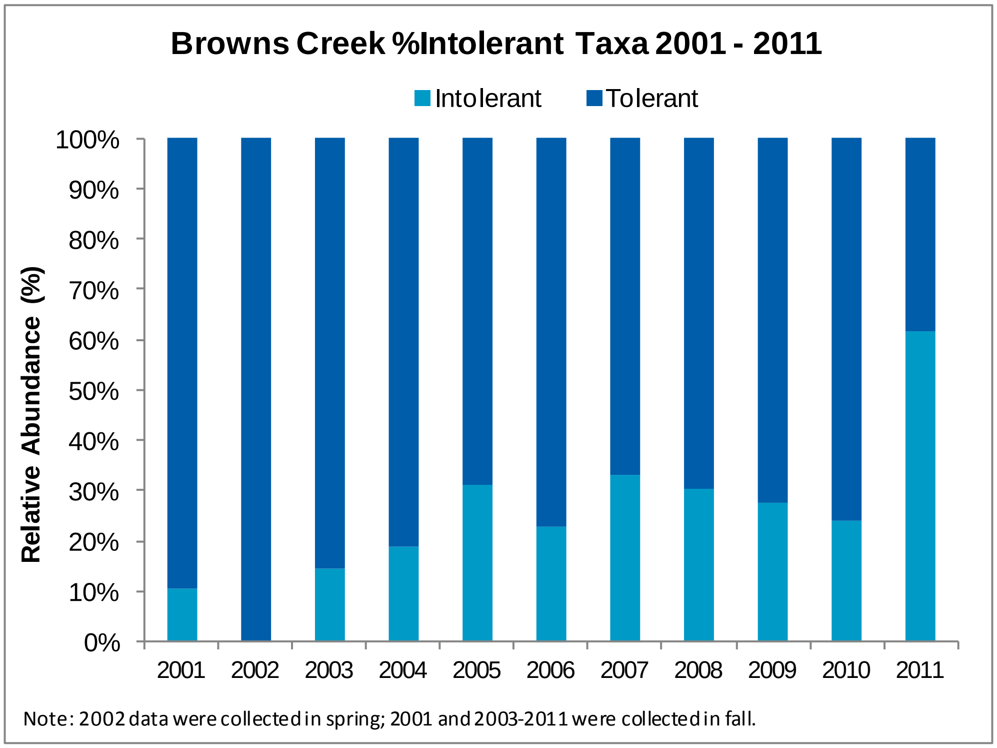
Figure BR-15: Browns Creek Annual Family Biotic Index (FBI) Scores, 2001-2011



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 BR-16). The presence of moderate numbers of intolerant taxa is an indicator of good aquatic health (Chirhart 2003). Browns Creek intolerant taxa were greater than 10% of the sample every year except 2002. The 2002 score may have been influenced by the spring collection time. The highest percent intolerant taxa, 62%, occurred in 2011.

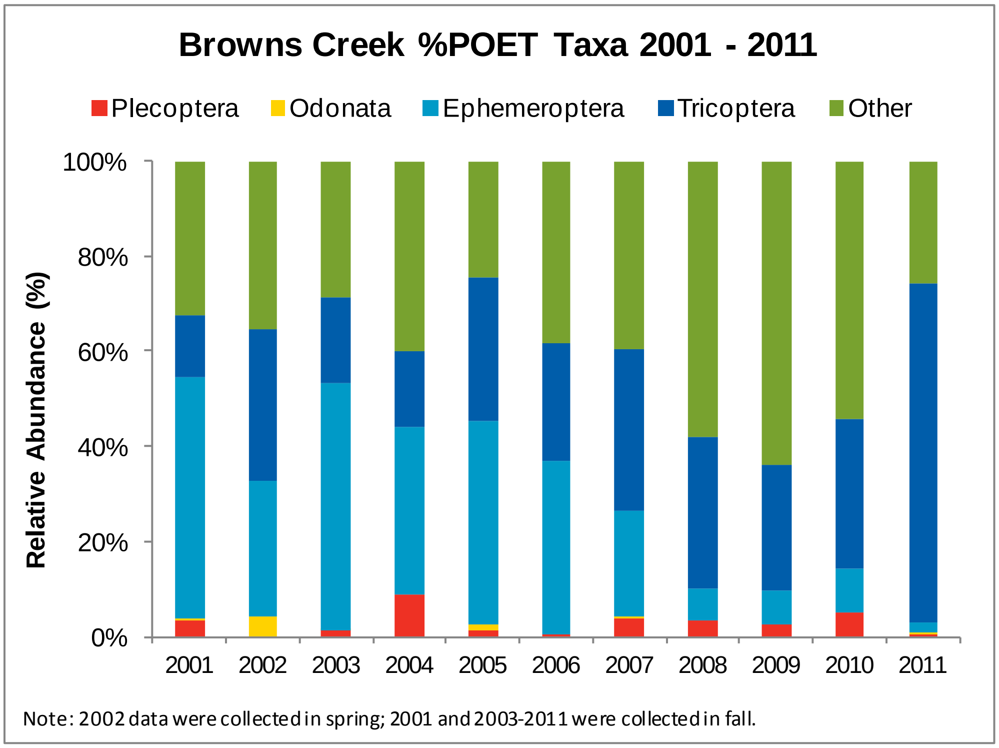
Figure BR-16: Browns Creek Percent Abundance of Pollution Intolerant Taxa, 2001-2011



Percent POET Taxa

The taxonomic richness metric, Percent POET Taxa (Figure BR-17), 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 2005, followed closely by 2011 (75% and 74% respectively).

Figure BR-17: Browns Creek Percent Abundance of POET Taxa, 2002-2011



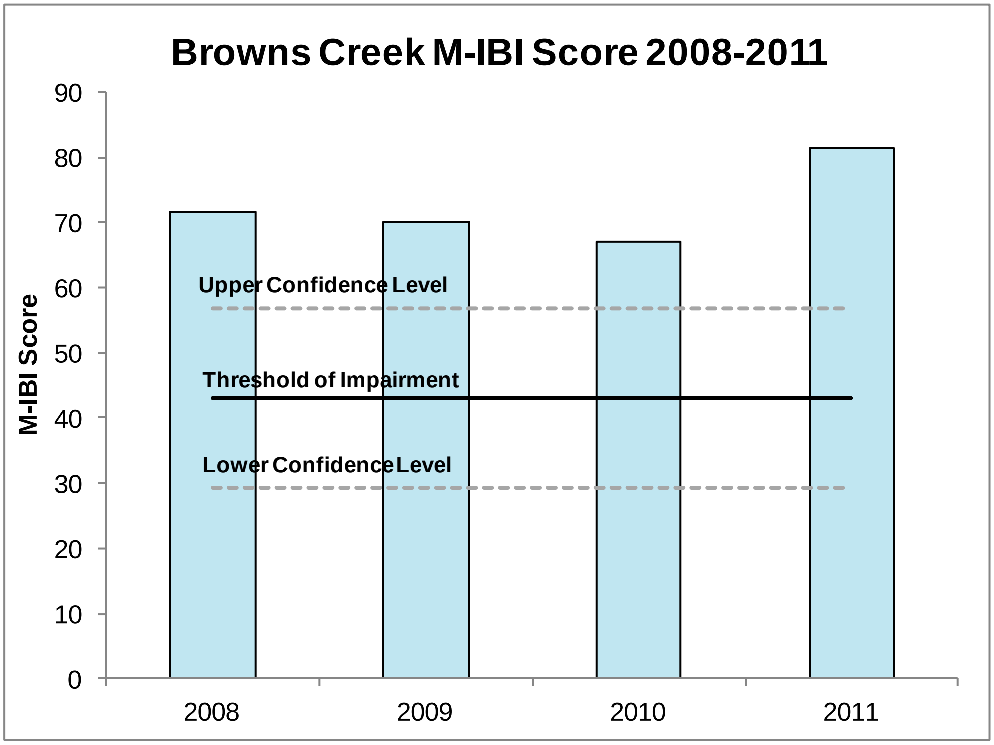
Macroinvertebrate Index of Biotic Integrity (M-IBI)

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 (MPCA, 2014b). 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 four years of monitoring Browns Creek resulted in M-IBI scores above the impairment threshold and the upper confidence level (Figure BR-18). This indicates that the water quality is likely able to sustain the needs of aquatic life.

MCES is planning additional future analysis to fully investigate our biological monitoring data and the sample collection program.

Figure BR-18: Browns Creek Annual Macroinvertebrate Index of Biological Integrity (M-IBI) Scores, 2008-2011



Trend Analysis

Trend analysis was completed for the historical record of TP, NO_3, and TSS using the U.S. Geologic Survey (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 variations 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 periods of 10 to 90 years, finding that peak flow due to snowmelt was the only stream flow 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 base flows 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 natural storage. MCES staff plan to repeat the following trend analyses in approximately 5 years. At that time, we anticipate sufficient data will have been collected to assess changes in flow rate, as well as to update the pollutant trends discussed below.

MCES staff assessed trends for the period of 1998-2012 on Browns Creek for TSS, TP, and NO_3, using daily average flow, base flow 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 all changes in watershed management, climactic changes, or 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)

Four trends were identified for TSS flow-adjusted concentrations in Browns Creek during the assessment period from 1998 to 2012 (Figure BR-19, top panel). The assessment was performed using QWTREND run without the precedent five-year flow setting. The trends were statistically significant (p value $=1.9 \times 10^{-5}$):

- Trend 1: 1998 to 2003, TSS flow-adjusted concentrations increased from 8.9 mg/l to 28.3 mg/l (218%) at a rate of 3.2 mg/l/yr.
- Trend 2: 2004, TSS flow-adjusted concentrations dropped sharply from 28.3 mg/l to 14.0 mg/l (-51%) at a rate of -14.3 mg/l/yr.
- Trend 3: 2005-2007, TSS flow-adjusted concentrations continued to decrease from 14.0 mg/l to 9.8 mg/l (-30%) at a rate of -1.4 mg/l/yr.
- Trend 4: 2008-2012, TSS flow-adjusted concentrations increased from 9.8 mg/l to 23.8 mg/l (142%) at a rate of 2.8 mg/l/yr.

The five-year trend in TSS flow-adjusted concentration in Browns Creek (2008-2012) was calculated to compare with other MCES-monitored streams, shown in the report section ***Comparison with Other Metro Area Streams***. TSS flow-adjusted concentrations increased from 9.8 mg/l to 23.8 mg/l (142%) at a rate of 2.8 mg/l/yr. Based on the QWTREND results, the water quality in Browns Creek in terms of TSS has declined during 2008-2012.

Total Phosphorus (TP)

Three trends were identified for TP flow-adjusted concentration in Browns Creek for the assessed period of 1998 to 2012 (Figure BR-19, middle panel). The assessment was performed using QWTREND run without the precedent 5-year flows. The trends were statistically significant (p value = 0.021):

- Trend 1: 1998-2003, TP flow-adjusted concentrations increased from 0.08 mg/l to 0.13 mg/l (78%) at a rate of 0.01 mg/l/yr.
- Trend 2: 2004, TP flow-adjusted concentrations decreased from 0.13 mg/l to 0.10 mg/l (27%) at a rate of -0.04 mg/l/yr.

- Trend 3: 2005-2012, TP flow-adjusted concentrations increased from 0.10 mg/l to 0.12 mg/l (20%) at a rate of 0.003 mg/l/yr.

The five-year trend in TP flow-adjusted concentration in Browns Creek (2008-2012) was calculated to compare with other MCES-monitored streams, shown in the report section ***Comparison with Other Metro Area Streams***. TP flow-adjusted concentrations slightly increased (14%) from 0.10 mg/l to 0.12 mg/l at a rate of 0.003 mg/l/yr. Based on the QWTREND results, the water quality in Browns Creek in terms of TP has declined during 2008-2012.

Nitrate (NO_3)

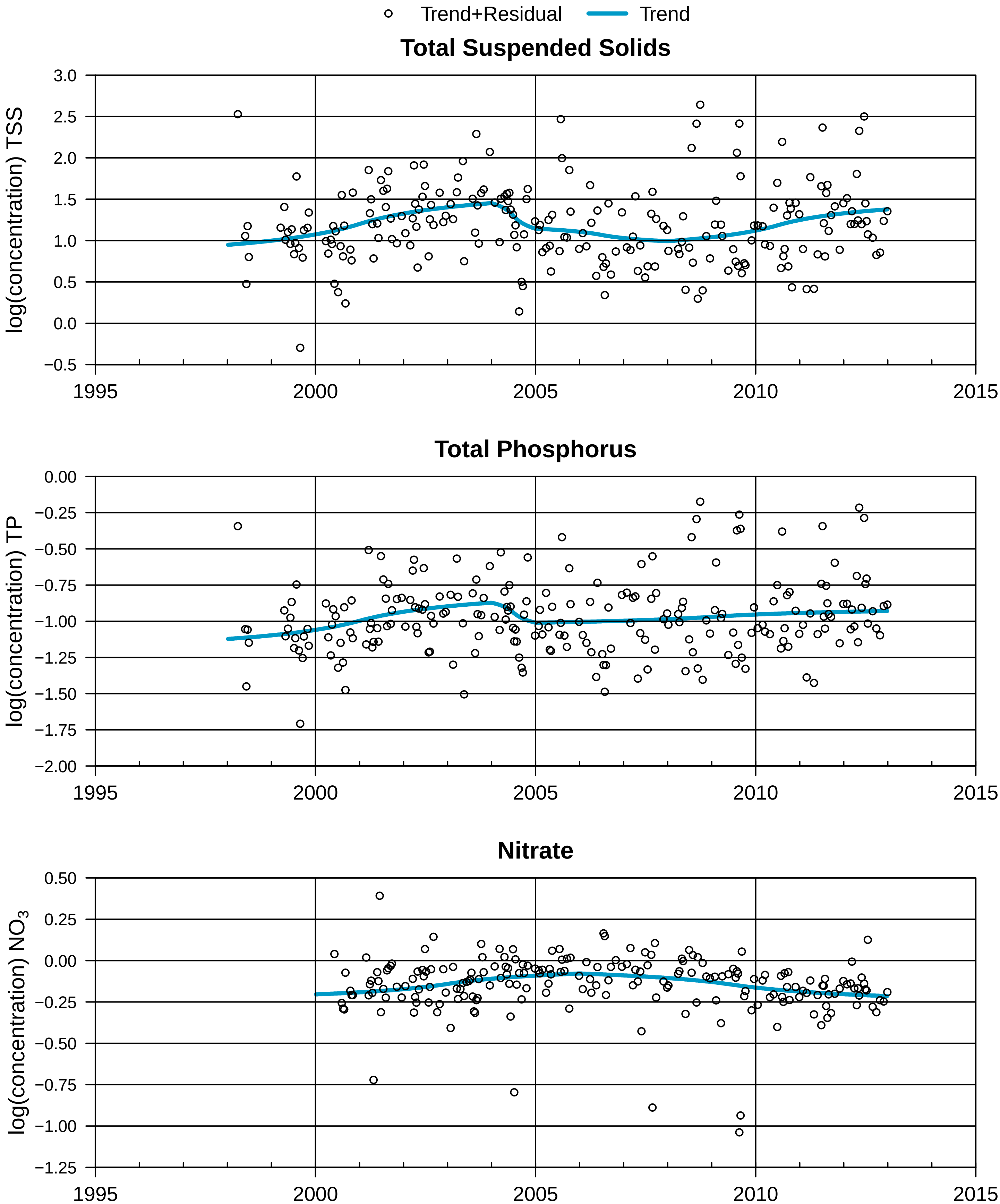
Two trends were identified for NO_3 flow-adjusted concentration in Browns Creek for the assessed period from 1998 to 2012 (Figure BR-19, lower panel). The assessment was performed using QWTREND run without the precedent 5-year flows. The trends were statistically significant (p value = 5.2×10^{-5}):

- Trend 1: 2000-2005, NO_3 flow-adjusted concentration slightly increased from 0.62 mg/l to 0.84 mg/l (34%) at a rate of 0.04 mg/l/yr.
- Trend 2: 2006-2012, NO_3 flow-adjusted concentrations decreased from 0.84 mg/l to 0.61 mg/l (-27%) at a rate of -0.03 mg/l/yr.

The five-year trend in NO_3 flow-adjusted concentration in Browns Creek (2008-2012) was calculated to compare with other MCES-monitored streams, shown in the report section ***Comparison with Other Metro Area Streams***. NO_3 flow-adjusted concentrations decreased from 0.78 mg/l to 0.61 mg/l (-22%) at a rate of -0.03 mg/l/yr. Based on the QWTREND results, the water quality in Browns Creek in terms of NO_3 has improved during 2008-2012.

The QWTREND analysis does not directly identify factors influencing changes in water quality. However, the three most recent TSS trends and the 2004 TP trend correspond with large-scale watershed improvement projects in Browns Creek. The data suggest the Stillwater diversion in 2003 had a large, positive impact on water quality by reducing the amount of TP and TSS in the stream. The 2005-2007 TSS trend period, with decreasing TSS flow-adjusted concentrations, corresponds with the installation of a new infiltration trench as an improvement to the Trout Habitat Protection Project. The most recent trend period, 2008-2012, had a large increase in TSS, but it also corresponded with stormwater management projects and stream bank modifications at the Stillwater Country Club and Oak Glen Golf Courses. Future trend assessment will clarify if the recent trend in TSS flow-adjusted concentration continues to increase, or if it can be attributed to the installation of these projects as the TSS flow-adjusted concentrations decrease.

Figure BR−19: Browns Creek Trends for TSS, TP and NO_3



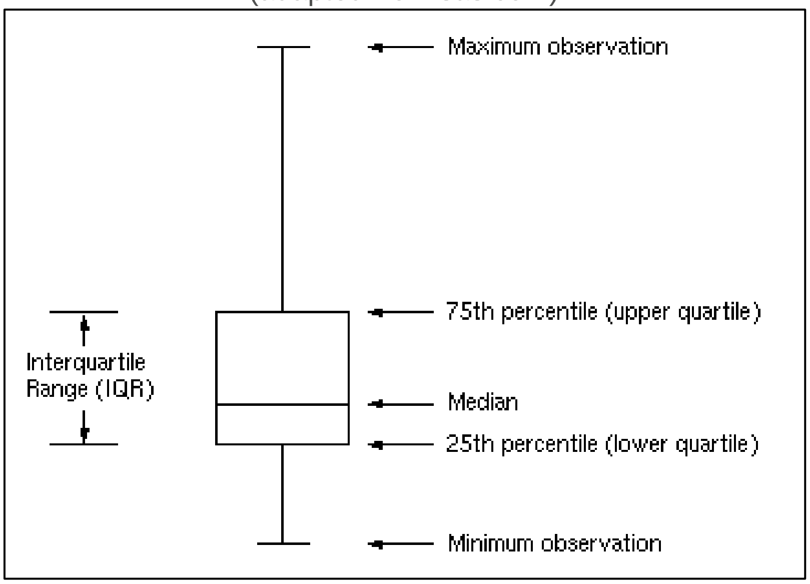
Comparison with Other Metro Area Streams

Chemistry

Box-and-whisker plots are used to summarize the comparison of the historical flow, TSS, TP, and NO_3, and Cl data for Browns Creek with those of the other metropolitan area streams monitored by MCES and with the major receiving water (in this case, the St. Croix River). The comparisons are show in Figure BR-21 to Figure BR-24 and Table BR-7.

Figure BR-20 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 extents of the whiskers designate the maximum and minimum values.

Figure BR-20: 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), 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. The annual areal yield does account for the changing size of the Browns Creek watershed throughout the period of interest.

Total Suspended Solids. The median annual FWM concentration for TSS in Browns Creek was greater than all of the other St. Croix River tributaries (Figure BR-21). It was also higher than the St. Croix River TSS concentration (as measured at Stillwater, Minnesota; 51 mg/l vs. 8.5 mg/l, respectively), indicating that Browns Creek was serving to increase the TSS concentration in the St. Croix. It is apparent that those tributaries entering the St. Croix River have significantly lower FWM TSS concentrations and annual yields (expressed in lb/acre) than the majority of other tributaries entering the Mississippi or Minnesota Rivers monitored by

MCES. This reflects the pristine waters and virtually undisturbed areas along the St. Croix River watershed (Gunard, 1985).

Median annual runoff ratio for Browns Creek was greater than all metropolitan area streams, with the exception of Eagle and Valley Creeks. Both creeks are fed by groundwater flows, which increase the runoff ratios for both watersheds. If Browns Creek flow was influenced by wetlands, lakes, or other impoundments on the stream channel, one would expect a relatively lower runoff ratio (as in, for example, Minnehaha Creek or Carnelian-Marine).

Total Phosphorus. Similar to TSS, the FWM TP concentration in Browns Creek was higher than that of the St. Croix River and thus served to increase the TP concentration in the river (Figure BR-22). All of the St. Croix River metropolitan area tributaries have lower FWM concentrations than most of the other MCES- monitored streams, with the exception of Eagle, Bassett, Minnehaha Creeks, and the Rum River. The Browns Creek median annual yield was higher than three other metropolitan area tributaries (Eagle Creek, Willow Creek, and Fish Creek), but lower than the other Mississippi and Minnesota River tributaries.

Nitrate. The Browns Creek median annual FWM NO_3 concentration of 0.9 mg/l was higher than the St. Croix River, and served as a contaminant to the river (Figure BR-23). However, it is lower than primarily agricultural watersheds like the Crow River, the Cannon River, and Bevens Creek. The median annual yield in Browns Creek is similar to the majority of other MCES-monitored tributaries.

Chloride. The Cl annual median FWM concentration was similar to other streams in the St. Croix watershed, but Browns Creek had the second highest total annual load and annual yield in the catchment (Figure BR-24). This is notable, as Browns Creek is substantially urbanized for a St. Croix tributary, but still does not have a comparable Cl load to other metro area urban catchments. The annual yield is more similar to the agricultural watersheds. This demonstrates the effectiveness of the Stillwater diversion to restrict urban pollutants, like Cl, from Browns Creek.

Macroinvertebrates

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

The M-IBI scores for Browns Creek were above the MPCA impairment threshold (Figure BR-25). This includes the median, which suggests that this stream reach habitat and water quality typically were able to sustain the needs for aquatic life. These results were similar to the other cold water streams, like Eagle, Silver, and Valley Creeks. The cold water, spring-fed streams appear to have less negative stressors on their macroinvertebrate communities than the warm water, surface-fed streams in the metropolitan area.

Figure BR−21: Total Suspended Solids for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

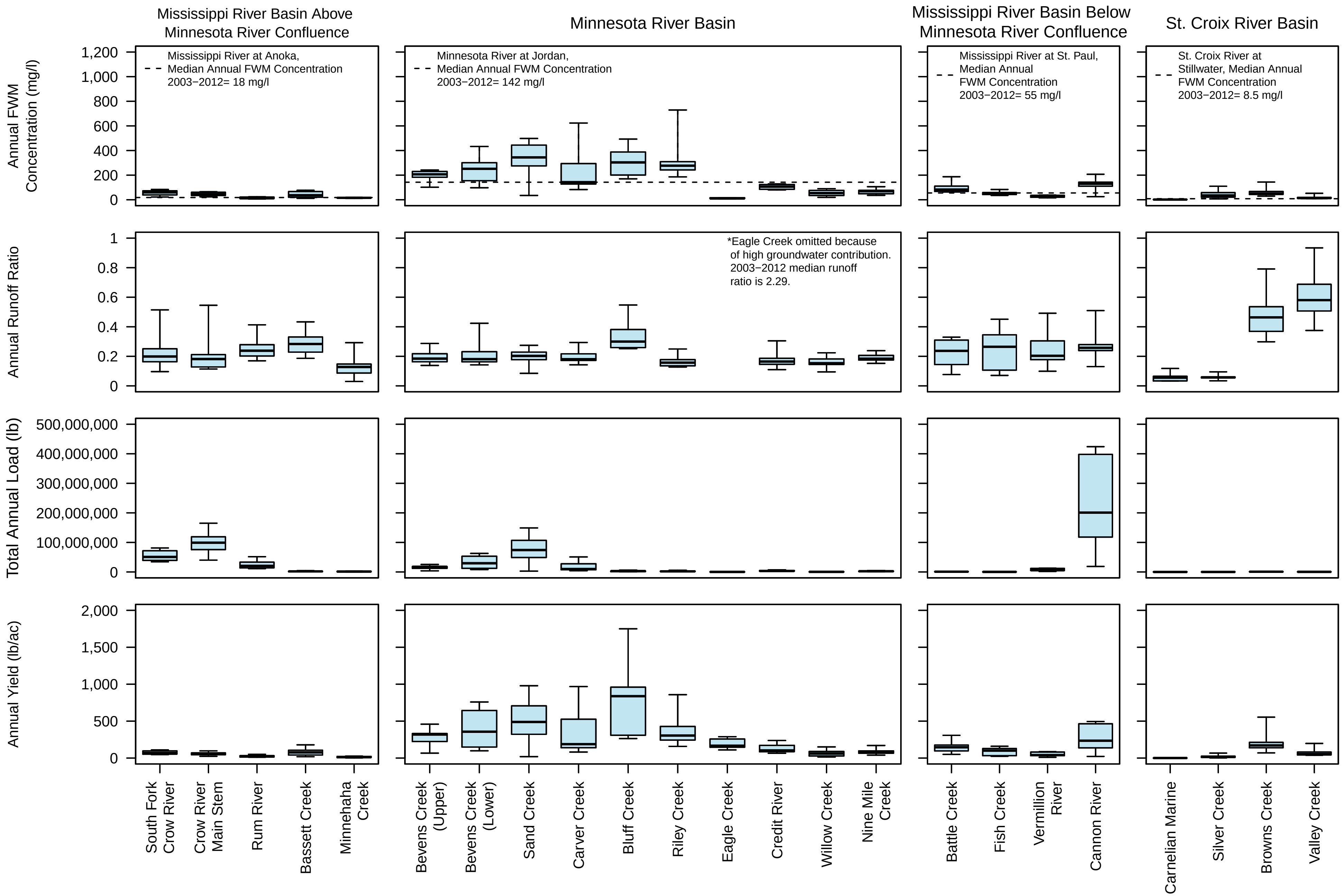


Figure BR−22: Total Phosphorus for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

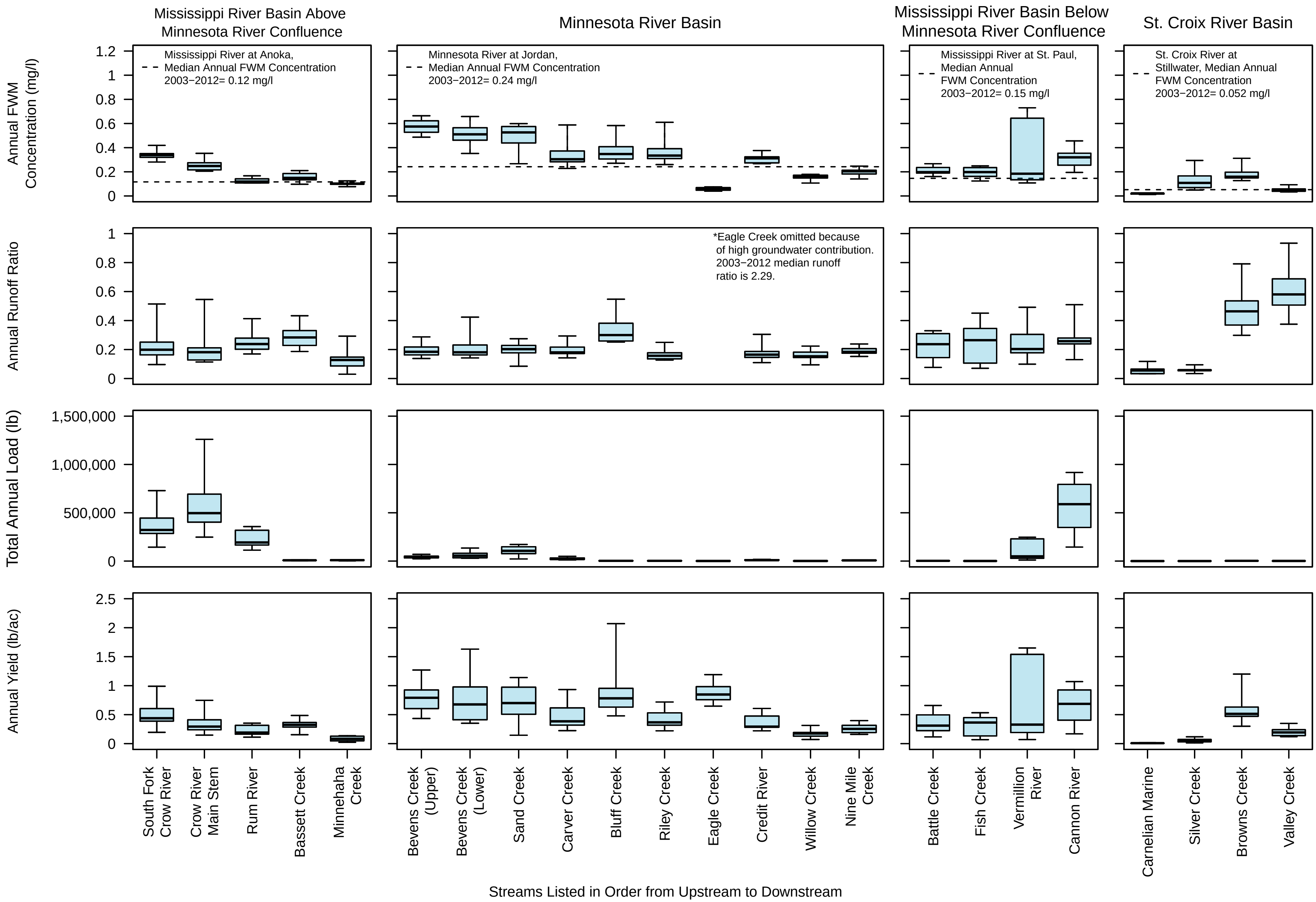


Figure BR−23: Nitrate for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

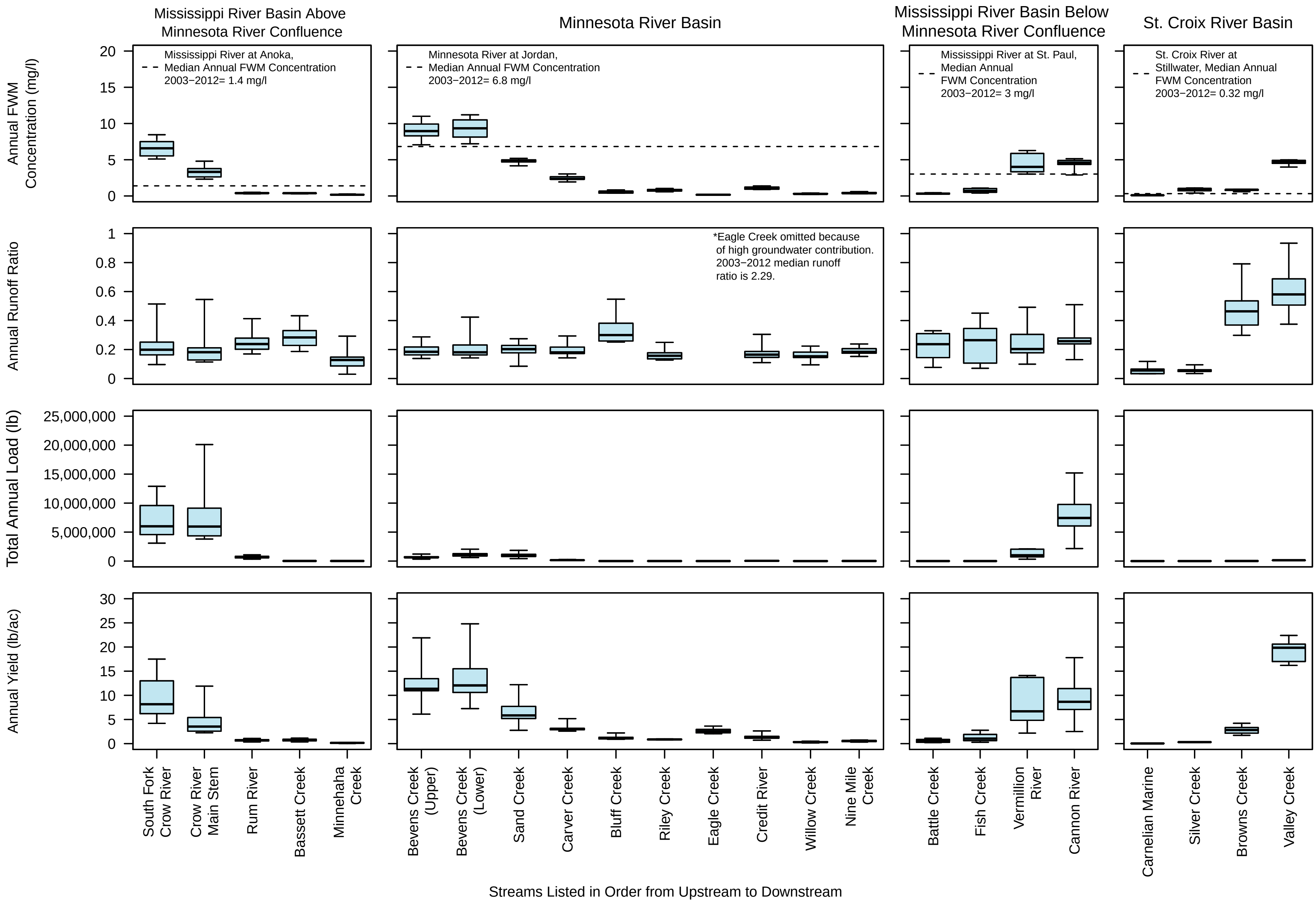


Figure BR−24: Chloride for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

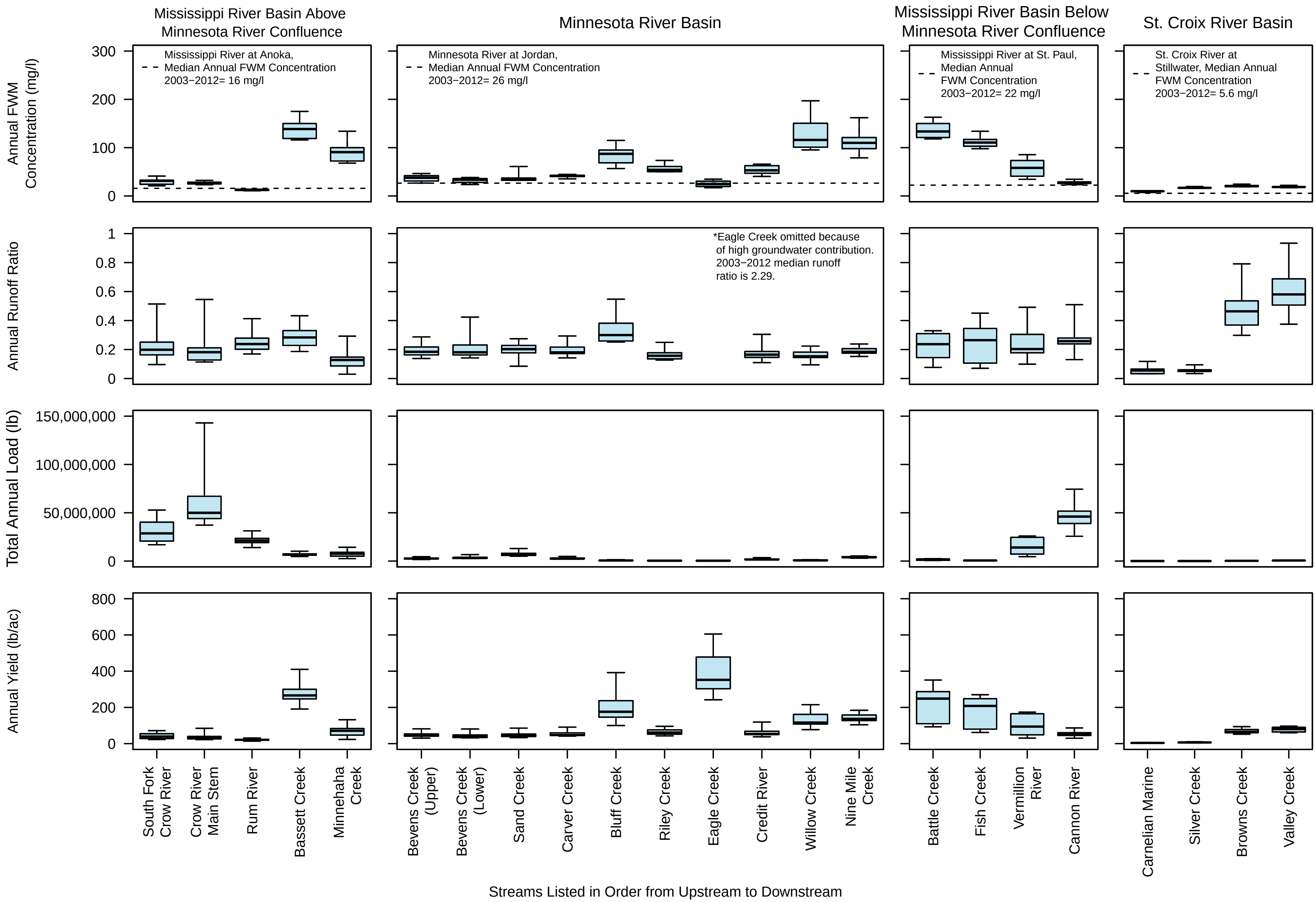


Table BR-7: Annual Median Concentrations, Loads, and Yields for MCES-Monitored Streams, 2003-2012

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)

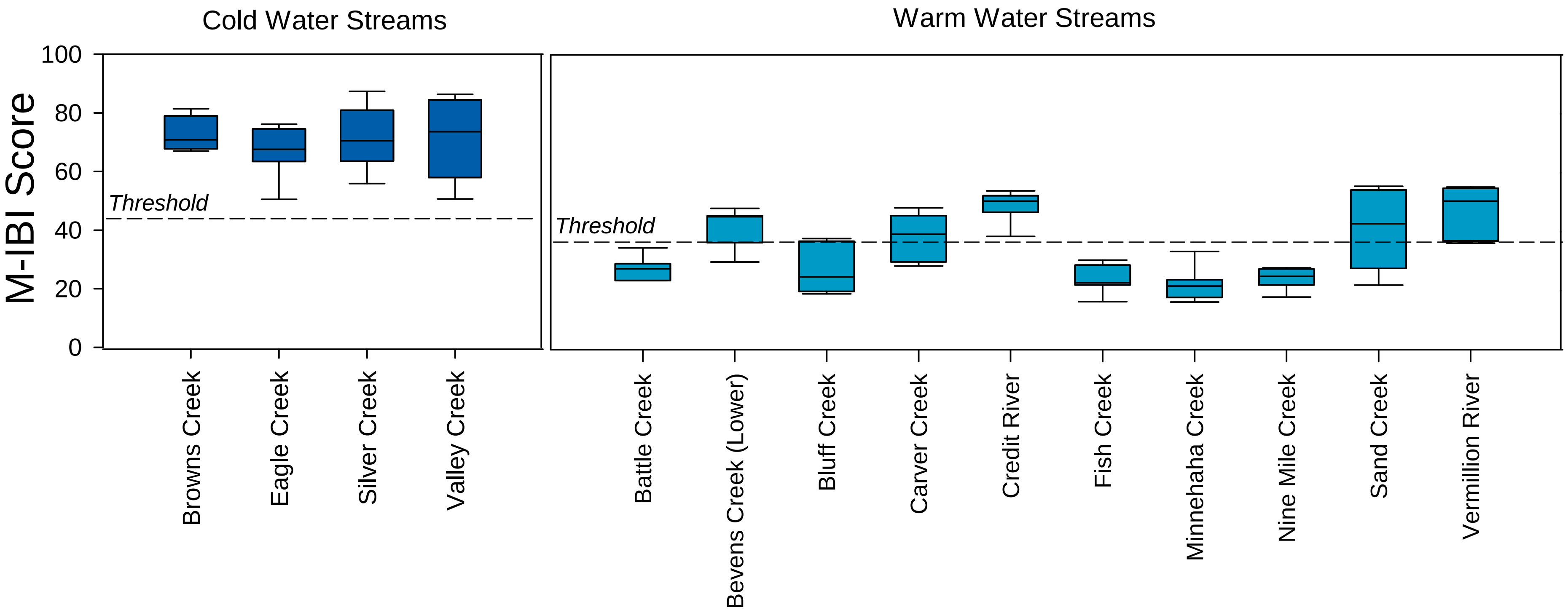
[2] FWM conc = annual flow-weighted mean concentration estimated using Flux32 (Walker, 1999).

[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 BR-25: 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.

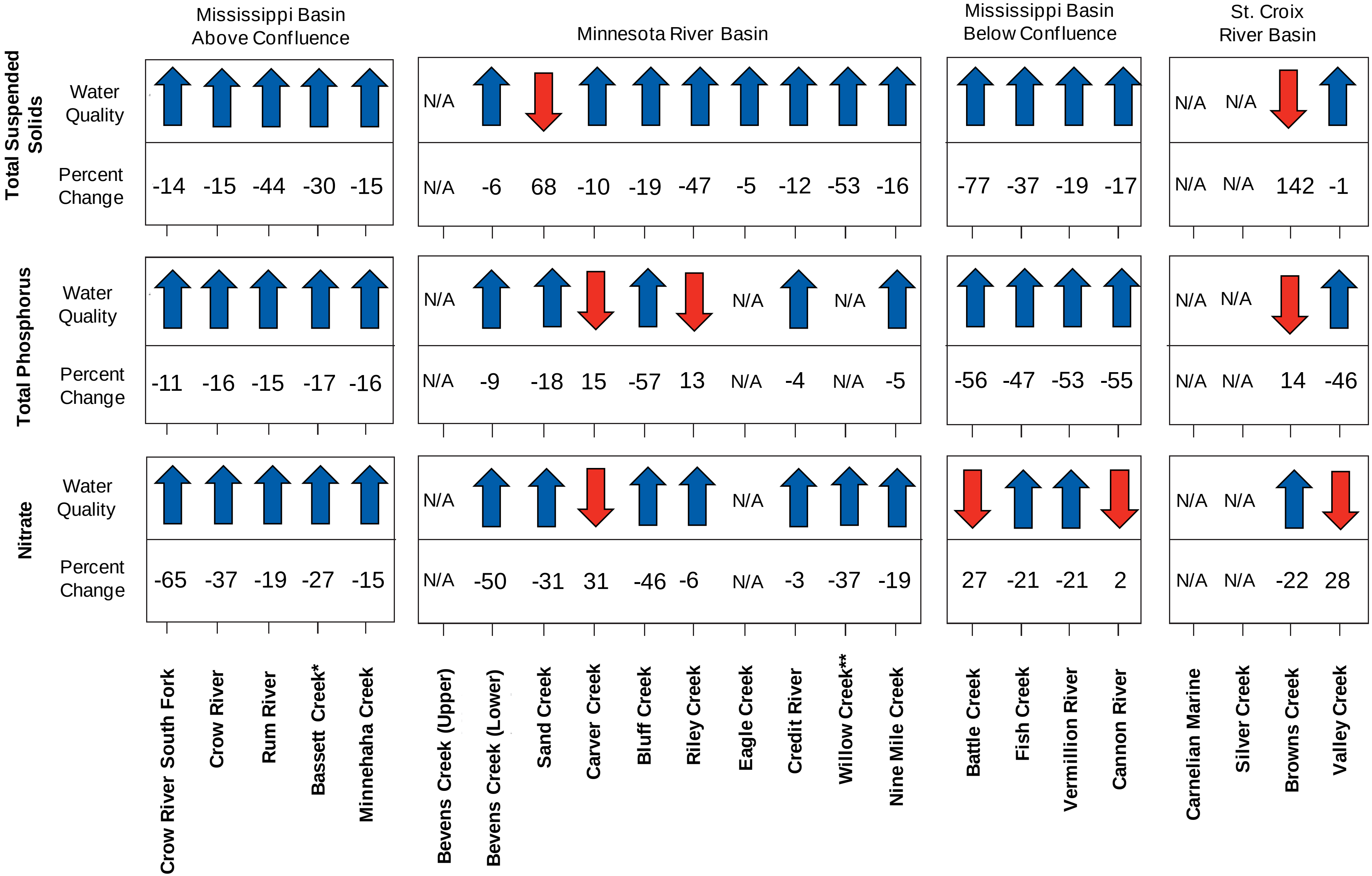
Estimated changes for TSS, TP, and NO_3 in MCES-monitored streams are presented below in two ways. First, tabulated results with directional arrows indicate improving (blue upward arrow) and declining (red downward arrow) water quality, paired with percent change in flow-adjusted concentration estimated for 2008-2012 (Figure BR-26). Second, changes are shown by three seven-county metropolitan area maps (one each for TSS, TP, and NO_3 trends), with stream watersheds colored to represent improving and declining water quality (Figure BR-27).

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).

Browns Creek is one of 15 streams to have decreasing NO_3 flow-adjusted concentrations since 2008, suggesting an improvement in water quality. It is also one of five metro area streams to have an increasing trend in TSS and TP flow-adjusted concentrations over the same time period (Figures BR-26 and BR-27). However, this does correspond with the development and installation of large-scale watershed improvement projects. The construction of these projects could have disturbed a considerable amount of sediment. Further monitoring will show if the trend represents the installation of the projects or if this is a continuing water quality challenge for Browns Creek.

Figure BR-26: 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)



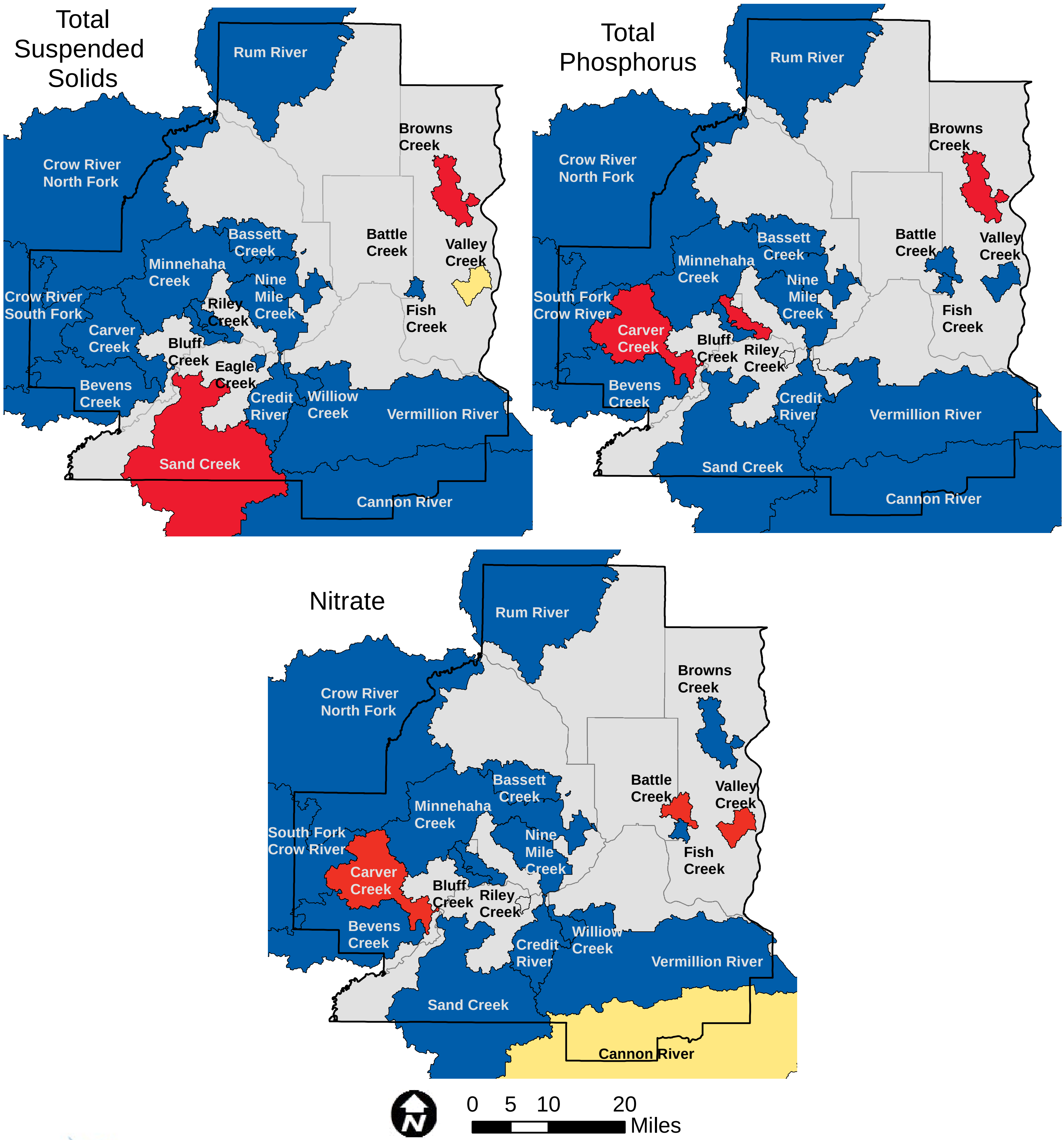
Blue arrows indicate improved water quality; Red arrows indicate declining water quality.

“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 BR-27: 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

Browns Creek is a MnDNR designated Class 2A Trout Stream and a groundwater-fed tributary to the St. Croix River. The watershed lies entirely in Washington County, and contains portions of the cities of Stillwater, Oak Park Heights, Lake Elmo, Grant, Hugo, and May and Stillwater townships. It is a mix of urban, agricultural, and forested areas. The southern portion of the watershed is highly urbanized and gradually becomes more forested or agricultural to the north. There are no major point source pollutant contributions to Browns Creek.

The north and west portions of the watershed have rolling hills and the topography steepens as the creek converges with the St. Croix River. Originally, there were two headwater branches of Browns Creek that eventually converged to form the main branch. The North Branch of Browns Creek begins at spring-fed wetlands in May Township. The South Branch of Browns Creek historically began at the outlet of Long Lake, but was diverted in 2003, hydrologically separating the reach from Browns Creek.

Browns Creek has had a long history of water quality improvement projects to improve the habitat and population of brown trout. The MCES monitoring station is located 0.3 miles upstream of the convergence with the St. Croix River, in the city of Stillwater, Minnesota.

The water quality in Browns Creek is affected by several factors, including the contributing drainage area, frequency and intensity of precipitation events, land use activities, the soil infiltration capacity, and the ground water quality.

The TSS and phosphorus in Browns Creek (both FWM concentration and annual yield) is the highest amongst the St. Croix River tributaries, but moderate when compared to the other MCES-monitored metropolitan area tributaries. The data show that all monitored solute concentrations and loads were greatly reduced after the Stillwater diversion rerouted the urban runoff away from the stream, but the TSS and TP loads showed the greatest reduction, 67% and 58%, respectively. The loads and concentrations are also influenced by the intensity and duration of storm events. Large storm events flush TSS and phosphorus constituents from the riparian and near stream areas. Trend analysis indicates both TSS and TP concentrations are currently increasing. These increases may reflect management practices, as large-scale watershed improvement projects were recently installed that may have, in the short term, increased the sediment load in Browns Creek.

The NO_3 and Cl loads and concentrations are likely driven by aquifer recharge and groundwater quality. Past and current agricultural and water treatment activities may have contaminated the groundwater in the watershed. All crops benefit from amending soils with fertilizers. Unfortunately, these applications combined with the high infiltration rates of the catchment soils may have resulted in a contaminated aquifer, and by extension, the creek as well. This process of cropland leaching into groundwater accounts for 30% of nitrogen contributions to surface water in the state of Minnesota (MPCA, 2013b).

The Browns Creek NO_3 and Cl concentration and loads are higher by an order of magnitude than those in the neighboring catchment of Silver Creek (similar soils and geology, but less developed). Browns Creek is more similar to other agricultural MCES-monitored metropolitan area tributaries. Additional Cl sources could be attributed to road salts, leaking septic systems, or the use of water softeners.

The Browns Creek DO measurements provide a quick assessment of water quality and ecosystem health. The daily minimum DO values in both the summer and winter monitoring seasons were generally in compliance with the MPCA water quality standard. Over 2010-2012, Browns Creek complied with the draft DO daily flux standard. This suggests that Browns Creek water quality is good and is not currently affect by excess nutrients and eutrophication.

The results from the biological monitoring suggest that Browns Creek has a diverse, healthy macroinvertebrate community and good water quality. While the FBI scores indicated the presence of some organic pollution during most years of monitoring, there were pollution intolerant taxa were present in every sample except 2002. All of the M-IBI scores were above the upper confidence level and the threshold of impairment, with the most recent score (2011) the highest calculated over the period of study. Overall, the monitored stream reach habitat and water quality were able to sustain the needs of aquatic life.

As one of 15 designated trout streams in the metropolitan area, much effort has been expended to mitigate negative impacts on the stream and improve the habitat in Browns Creek. The combination of consistently cool temperatures from groundwater discharge, a stable macroinvertebrate food source, lowered in-stream siltation, and shady riparian areas provide a good habitat for the brown trout communities. The Browns Creek Watershed District and their partners are working to reduce the negative stressors and increase water quality so that the trout populations will continue to thrive.

Recommendations

This section presents recommendations for monitoring and assessment of Browns Creek, as well as recommendations for partnerships to implement stream improvements. MCES recognizes that cities, counties, and local water management organizations, like BCWD, 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:

- WCD and BCWD collect flow and water quality data from Browns Creek upstream of the MCES station. As resources allow, MCES staff can assist to calculate and analyze the load data from the upstream monitoring stations to help identify the geographic origins and potential sources of the chemical loads in the main branch of Browns Creek.
- MCES has made every effort to ensure proper watershed boundaries have been identified and internal drainages, rerouted flows, or other factors included in calculations of watershed areas. Final watershed boundaries used in this report should be forwarded to the MnDNR for inclusion in the statewide drainage boundary geospatial data set.
- As resources allow, MCES should provide BCWD, WCD and other local water managers with information about the heightened potential for surface waters to be impacted by groundwater changes in the Browns Creek watershed. This information should be included in watershed and local surface water management plan updates.
- MCES and partners should identify the groundwater-sheds to highlight land uses that may be geographically outside of the watershed, but could still impact the water quality.
- MCES should participate in future assessments and plan preparations for Browns Creek, especially metropolitan area WRAPs (Watershed Restoration and Protection Strategies) led by the MPCA.
- MCES and partners (especially BCWD, WCD, and the Science Museum of Minnesota St. Croix Research Station) 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.
- As resources allow, MCES should provide technical and financial assistance to BCWD to further reduce TP concentrations in Browns Creek as required by the recently-approved Lake St. Croix Excess Nutrients TMDL (MPCA, 2012c).

Citations

Almendinger, J.E. 2003. Watershed hydrology of Valley Creek and Browns Creek: Trout streams influenced by agriculture and urbanization in eastern Washington County, Minnesota, 1998-99. Marine on St. Croix, Minnesota: St. Croix Watershed Research Station, Science Museum of Minnesota.

Böhlke, J.K. 2002. Groundwater recharge and agricultural contamination. Hydrogeology Journal 10:153-179. doi:10.1007/s10040-001-0183-3.

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., 2012. Browns Creek TMDL Implementation Plan. Emmons & Olivier Resources, Inc. Oakdale, MN.

Gunard, K.T. 1985. Minnesota surface-water resources: nation water summary 1985 – hydrologic events and surface-water resources. U.S. Geological Survey, v. 37, no.4, pg. 303.

Legislative Coordinating Commission. 2013. Brown's Creek thermal load reduction. *In* Minnesota's Legacy. <http://www.legacy.leg.mn/projects/browns-creek-thermal-load-reduction> (accessed 10.05.13).

Metcalf and Eddy. 2003. Wastewater Engineering: Treatment Disposal and Reuse, fourth ed. Tata McGraw-Hill, New York.

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.

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 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.

Pitt, D.G., Bell, R., Whited, D., Roos, S. 2003. An atlas of watershed structure in the Browns Creek and Valley Creek basins. Minneapolis: Department of Landscape Architecture, University of Minnesota.

Rehm, G. and M. Schmitt. 1997. Potassium for crop production. Minnesota Extension Service. Minneapolis: University of Minnesota.

Sander, A., Novotny, E., Mohseni, O., Stefan, H. 2008. Potential for groundwater contamination by road salt in Minnesota. Project Reports 509. St. Anthony Falls Laboratory. Minneapolis: University of Minnesota. <http://purl.umn.edu/115336> (accessed 15.04.13).

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 (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.

Washington Conservation District. 2007. Phase I of the Brown's Creek Biological TMDL – Stressor Identification. Stillwater: Washington Conservation District. <http://www.bcwd.org/Resources/BCTMDL_StressorID_Workplan.pdf> (accessed 13.05.13).

Washington Conservation District. 2010. Brown's Creek Watershed District 2010 Water Monitoring Report. Stillwater: Washington Conservation District. <http://www.bcwd.org/Resources/2010_Monitoring_Report.pdf> (accessed 10.05.13).

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