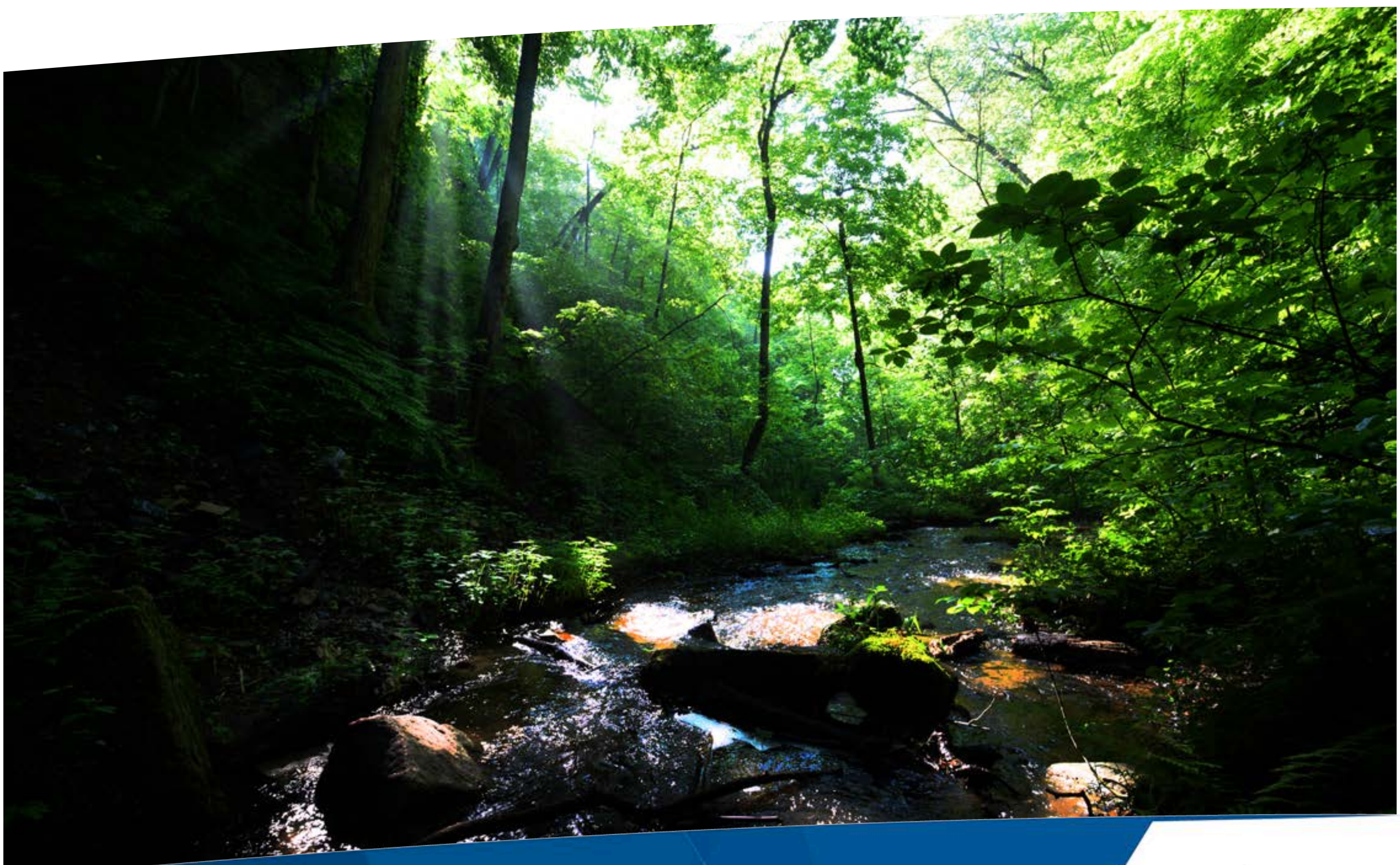
Comprehensive Water Quality Assessment of Select Metropolitan Area Streams

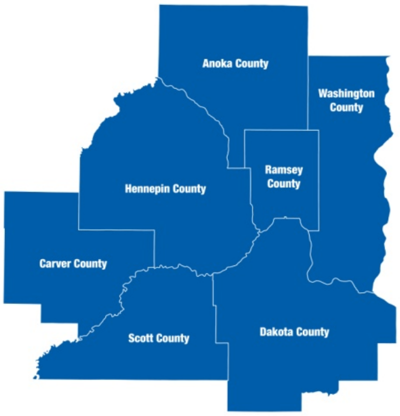
SILVER CREEK



METROPOLITAN COUNCIL

December 2014

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



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

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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, *Silver 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, Silver 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 Silver Creek.

Cover Photo

The photo on the cover of this section depicts Silver Creek at the MCES monitoring site near Stillwater, Minnesota.

Recommended Citations

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Contents

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Introduction

Silver Creek (Figure SI-1) is located in the eastern metropolitan area and is a tributary to the St. Croix River. It drains approximately 8.6 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 and Grant, and May and Stillwater townships.

Figure SI-1: Silver Creek at Highway 95

This report:

- documents those characteristics of Silver Creek and its watershed most likely to influence stream flow and water quality.
- lists examples of recent improvement projects completed by local governmental units (LGUs).
- presents the results from assessments of flow, water quality, and biological data.
- presents general observations about changes in stream chemistry concentrations and flow.
- draws conclusions about possible effects of landscape features, climatological changes, and human activities on flow and water quality.
- compares Silver 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 summary-data reports.

Partnerships and Funding

MCES has supported water quality monitoring of Silver Creek since 1999 as part of its Watershed Outlet Monitoring Program (WOMP). MCES partners with the Carnelian-Marine St. Croix Watershed District (CMSCWD) and the Washington Conservation District (WCD) to operate and maintain the monitoring station. The WCD has also been responsible for periodic collection of samples from Silver Creek upstream of Fairy Falls at CSAH-11, north of Stillwater.

CMSCWD also partnered with MCES to monitor the Carnelian-Marine Outlet WOMP station. Data from this station is discussed in a separate section in this report.

Monitoring Station Description

The MCES monitoring station is located on Silver Creek near Hwy 95 in Stillwater, Minnesota, 0.1 mile upstream from the creek's confluence with the St. Croix River. This site was established in 2002, due to its ease of accessibility. From 1999-2001, the monitoring site was located one-half mile upstream.

The monitoring site is situated in a groundwater discharge (or upwelling) zone of Silver Creek, approximately 0.25 miles below Fairy Falls. Visible groundwater seeps and springs flow from the side slopes and base of the bedrock walls immediately below Fairy Falls. The groundwater seeps do not always discharge enough water to maintain a perennial flow at the monitoring station during low flow periods.

The monitoring station includes a tipping bucket rain gauge (Texas Electronics), continuous flow monitoring (Teledyne ISCO Area-Velocity Sensor), baseflow grab sample collection, and event-based composite sample collection (Teledyne ISCO Sampler). A dense tree canopy cover precludes the collection of precipitation data at the MCES station. However, precipitation data are obtained from the Minnesota Climatology Working Group, Stillwater Station Number 218037.

Daily precipitation totals from this station were used to create the hydrograph in the ***Hydrology*** discussion later in this section. 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

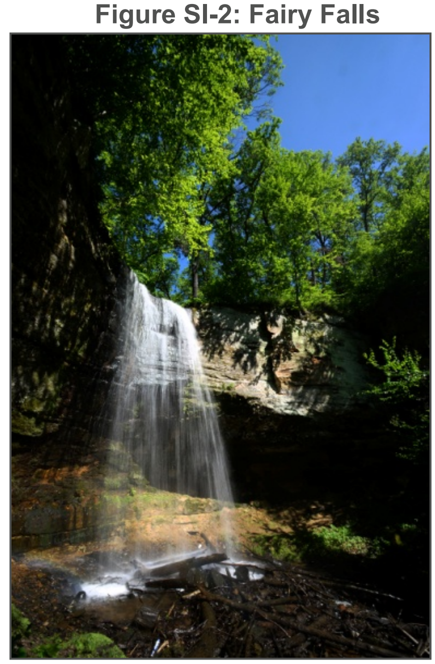
Stream and Watershed Description

The Silver Creek watershed lies entirely in Washington County, falls within the geographic jurisdiction of the Metropolitan Council (Council District 12), and has a drainage area of approximately 8.6 square miles. Silver Creek originates at a series of lakes − Silver Lake, Loon Lake, South and North Twin Lakes, and Carol Lake − in the southwest part of Stillwater Township. The creek generally flows to the southeast for 2.5 miles where it discharges into the St. Croix River. The CMSCWD's Silver Creek Corridor Management Plan (Emmons and Olivier Resources, Inc., 2004) indicates that downstream of Norell Avenue, the creek flows through a groundwater-dependent "rich fen" community. The Minnesota Department of Natural Resources (MnDNR, 2014) describes a fen as a type of open wetland plant community dominated by sedges, with continuous inundation of water that allows dead plant material to accumulate and form peat. A rich fen is one of three types of fens found in Minnesota, and is characterized by shallow, less-acidic peat, dominant presence of narrow-leaf sedges, and additional presence of more broad-leafed wetland plants.

Below Stonebridge Trail North, Silver Creek flows through an impoundment known as Fairy Pond. The Silver Creek Corridor Management Plan indicates the flows from Fairy Pond are typically controlled by an outlet control structure installed by Washington Conservation District (WCD) in the 1960s and occasionally a beaver dam. Heavy rains in 2002 washed out the beaver dam and partially drained the pond.

The lower part of Silver Creek is an ecologically sensitive area that encompasses the land directly above Fairy Falls (located approximately 0.25 miles upstream of the St. Croix River confluence) and the gorge below (Figure SI-2). This property is owned and maintained by the National Park Service. Downstream of Fairy Falls (a 50-foot drop), groundwater springs and seeps emerge where the underlying Jordan Sandstone layer meets St. Lawrence shale, and supplement the Silver Creek flows. The waterfall and seeps move water over and through highly erodible sandstone, which may affect the water quality of Silver Creek. The lower gorge hosts a variety of natural communities including maple-basswood forest, oak forest and woodland, mixed hardwood seepage swamp, rich fen, dry cliff, moist cliff, talus slope, and bedrock-bluff prairie (Emmons & Olivier Resources, Inc., 2004). This level of ecological diversity is unusual for Washington County.

Figure SI-2: Fairy Falls



In addition to Silver Creek, there are many other open water bodies within the watershed. South Twin Lake (31 acres), North Twin Lake (61 acres), and Carol Lake (45 acres) are to the southwest of Silver Creek. Silver Lake (48 acres), Loon Lake (53 acres), and Louise Lake (41 acres) are to the north of Silver Creek.

The Silver Creek watershed encompasses a total of 5,559 acres, of which 5,538 acres (99.6%) is upstream of the monitoring station (Figure SI-3, Table SI-1). The watershed is 25.4% agricultural land (25.5% monitored) and 17.4% developed urban land (17.3% monitored). Impervious coverage is distributed fairly evenly throughout the watershed in large lot residential properties and roads. Portions of the cities of Grant and Stillwater (unmonitored only) are included in the watershed, but neither is heavily developed. Based on the United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) 2009 Cropland Data Layer, of the agricultural land in the watershed, 32% is planted in corn and 10% in soybeans, all within the monitored portion of the watershed. According to a statewide estimate of potentially draintiled fields by University of Minnesota researchers (D. Mulla, University of Minnesota, personal communication, 2012), 1% of the agricultural land in the watershed is potentially draintiled. Other primary land covers in the watershed are forest, grasses/herbaceous, and wetlands.

Table SI-1: Silver Creek Land Cover Classes[1]

Land Cover Class	Monitored		Unmonitored		Total	
	Acres	Percent	Acres	Percent	Acres	Percent
5-10% Impervious	193	3.5%	<0.1	<0.1%	193	<0.1%
11-25% Impervious	593	10.7%	5	22.3%	598	22.3%
26-50% Impervious	18	0.3%	1	4.3%	19	4.3%
51-75% Impervious	10	0.2%	2	7.4%	12	7.4%
76-100% Impervious	145	2.6%	3	12.8%	148	12.8%
Agricultural Land	1,412	25.5%	<0.1	<0.1%	1,412	<0.1%
Forest (all types)	1,109	20.0%	10	46.8%	1,119	46.8%
Open Water	149	2.7%	<0.1	<0.1%	149	<0.1%
Barren Land	<0.1	<0.1%	<0.1	<0.1%	<0.1	<0.1%
Shrubland	8	0.1%	<0.1	<0.1%	8	<0.1%
Grasses/Herbaceous	1,292	23.3%	1	5.3%	1,293	5.3%
Wetlands (all types)	609	11.0%	0.2	1.1%	609	1.1%
Total	**5,538**	**100.0%**	**21**	**100.0%**	**5,559**	**100.0%**

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

The geologic history of a watershed dictates many soil and hydrologic properties and surface topography. The Silver 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 in the northwest portion of the watershed. Silver Creek watershed also contains a high proportion of organic deposits from glacial lakes that once covered the area (Patterson et al., 1990).

Nearly all of the soils in the Silver Creek watershed are glacier outwash-associated loamy sands or silty loams. STATSGO soils data from the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA), characterize these soils as Type B soils that have moderately low runoff potential, and are primarily found in the lowest elevations of the watershed (USDA, 2009). The stream channel is primarily Type D soils that have a high clay content and low infiltration capacities. The STATSGO soil survey provides a general representation of soil conditions. For installation of infiltration-based practices (like raingardens), soil borings should be taken from the exact location of the proposed site to precisely assess soil type and level of soil filling or disturbance.

The watershed topography is fairly steep, culminating with a steep drop into the St. Croix River (Figure SI-4). The maximum watershed elevation is 1043.2 above mean sea level (MSL) and the minimum elevation is 681.2 MSL within the monitored area. Within the monitored area, 4%

of the slopes are considered steep, and an additional 1% considered very steep. Steep slopes are those of 12-18%, and very steep slopes are those 18% or greater (MnDNR, 2011). The gradient of the creek channel averages 88.9 feet/mile.

Figure SI-3

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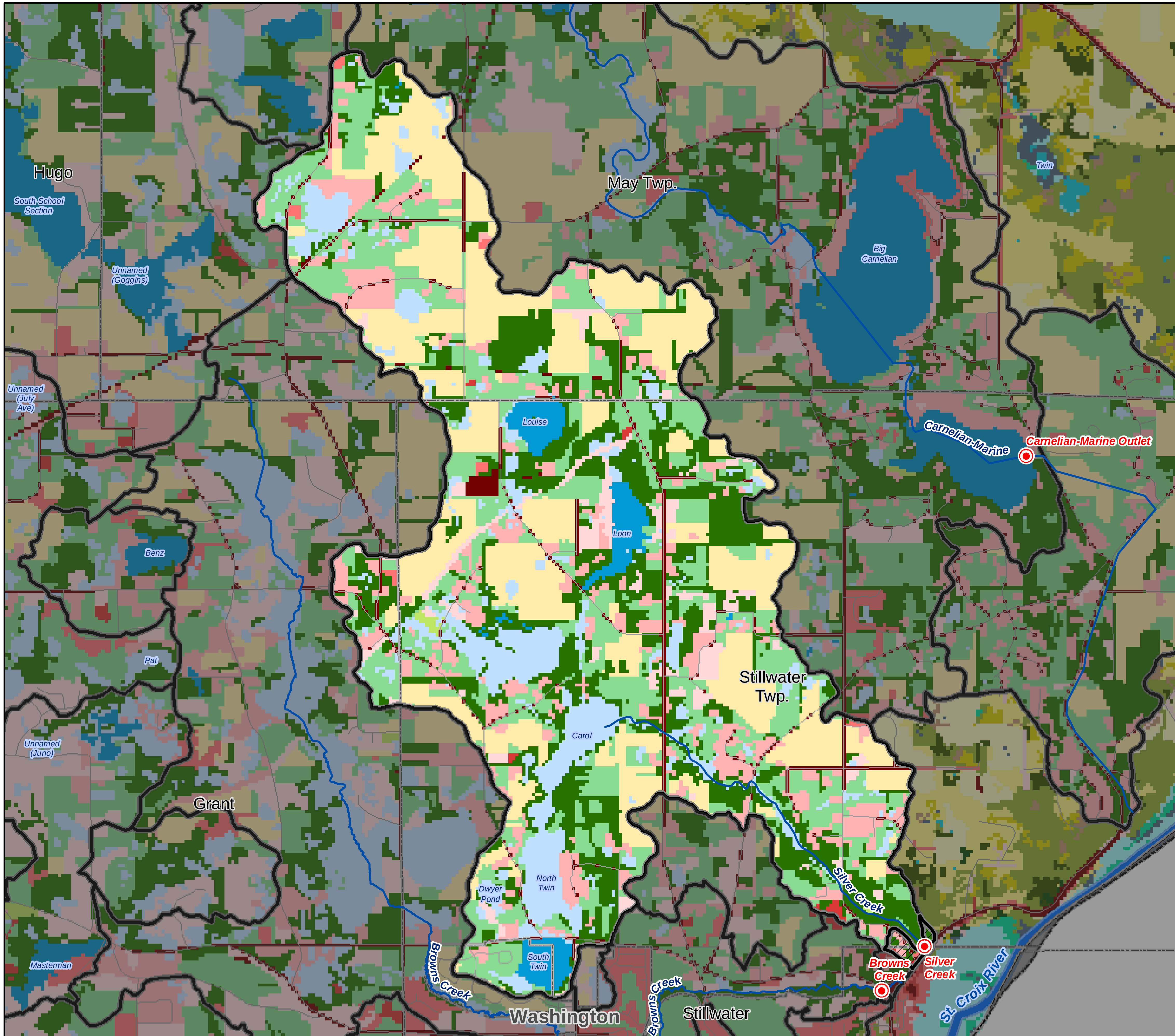
MLCCS-NLCD Hybrid Land Cover

Silver Creek



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

MLCCS-NLCD Hybrid Land Cover

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

Data Source: MnDNR

MLSSC/NLCD Hybrid Land Cover
Silver Creek

Land Cover Class	Monitored Acres	Monitored Percent	Unmonitored Acres	Unmonitored Percent	Total Acres	Total Percent
5-10% Impervious	193	3.5%	0	0.0%	193	3.5%
11-25% Impervious	593	10.7%	5	22.3%	598	10.8%
26-50% Impervious	18	0.3%	1	4.3%	19	0.3%
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Shrubland	8	0.1%	0	0.0%	8	0.1%
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Total	**5,538**	**100.0%**	**21**	**100.0%**	**5,559**	**100.0%**

0 0.5 1 1.5
Miles

The Silver Creek watershed is a relatively undeveloped watershed with agricultural lands, hobby farms, and rural-low density residential developments. There are no point sources of pollutants permitted by the Minnesota Pollution Control Agency (MPCA) within the watershed. The Silver Creek watershed has one registered feedlot with 21 animal units (AUs). This feedlot is within the monitored portion of the watershed (Figure SI-5).

The rural-residential nature of the Silver Creek watershed and a lack of a centralized municipal sewer system necessitate the use of on-site septic systems to manage wastewater. A well-maintained septic system percolates wastewater through the soils, where microorganisms treat and purify the effluent before it enters the shallow groundwater. However, failing septic systems can negatively influence the water quality by leaching pollutants (nutrients, pharmaceuticals, and other toxic chemicals) into the shallow groundwater. The Washington County Department of Public Health and Environment is the regulatory authority for these systems, and they permit, inspect, and track the maintenance of all septic systems in the county (Washington County, 2014).

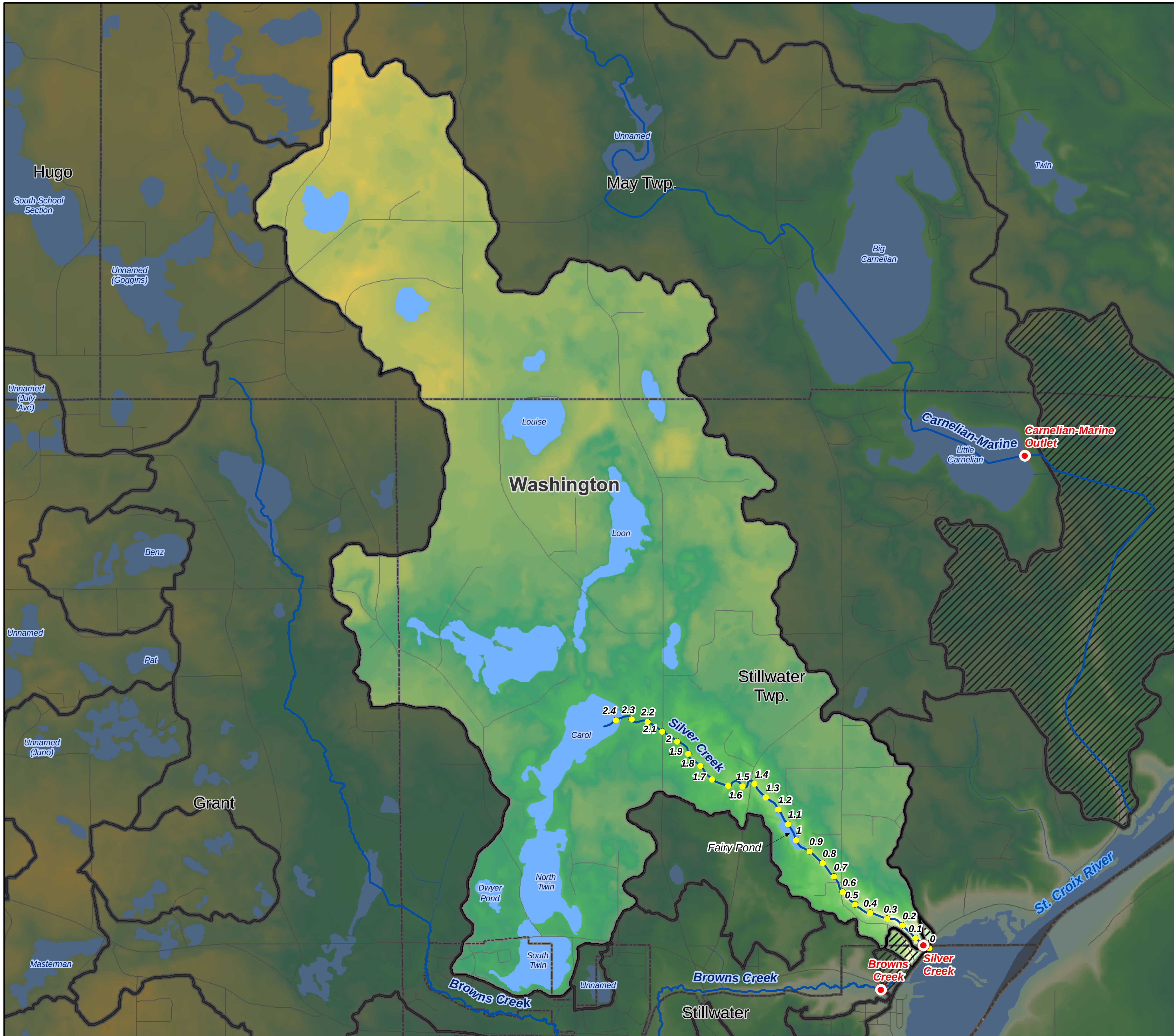
In 2003, the CMSCWD formed a steering committee and convened public meetings with the sole purpose of creating a management plan for the Silver Creek watershed. The resulting plan suggested 19 actions to improve and manage the watershed (Emmons & Olivier, Inc., 2004). As of 2010, 14 actions had been implemented, as listed below:

- Established grade control to limit stream incision.
- Re-sloped and stabilized vertical banks to prevent bank erosion.
- Selectively thinned trees and shrubs to remove invasive species and to promote native species.
- Protected the rich fen.
- Established vegetation management for the rich fen.
- Expanded the riparian corridor and separated the stream from grazing areas.
- Completed a hydrologic model of the Silver Creek watershed.
- Maintained or reduced the stormwater rates and volumes upstream of Fairy Falls.
- Limited thermal impacts on Silver Creek to preserve trout stream habitat.
- Addressed, through the work of the National Park Service, the issues involving recreation use within the lower reaches of Silver Creek.
- Established management of the dry prairie-woodland plant communities along the south facing slope above Fairy Pond.
- Restored the oak woodland and black ash seepage swamp areas along the riparian corridor.
- Restored the native plant communities along the riparian corridor.
- Replaced culvert with a designed crossing for fish and wildlife under 94th Street.

Once the stream habitat and corridor meets the necessary requirements, the Minnesota Department of Natural Resources (MnDNR) hopes to establish a small population of heritage brook trout in the lower reaches of this creek (Emmons &Olivier Resources, Inc., 2010). For further information about these plans, please see the CMSCWD website.

Figure SI-4

Watershed Topography
Silver Creek



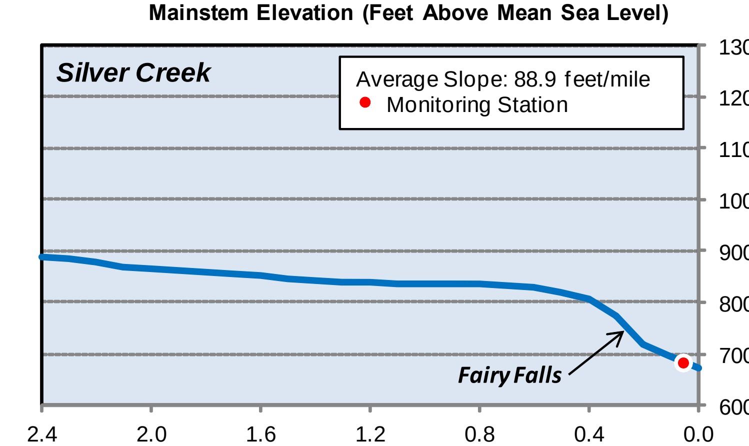
MCES Stream Monitoring Sites
USGS Flow Stations
Stream Mile Markers
Mainstems (Monitored and Unmonitored)
Lake Names
Monitored Watershed Boundaries
Unmonitored Watershed Areas
Public Waters Inventory
Other Rivers and Streams
City and Township Boundaries
County Boundary
NCompass Street Centerlines, 2012

Elevation
Feet Above Mean Sea Level

High : 1594
1400
1200
1000
800
Low : 643

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

Mainstem Elevation (Feet Above Mean Sea Level)



0 0.5 1 1.5
Miles

Figure SI-5

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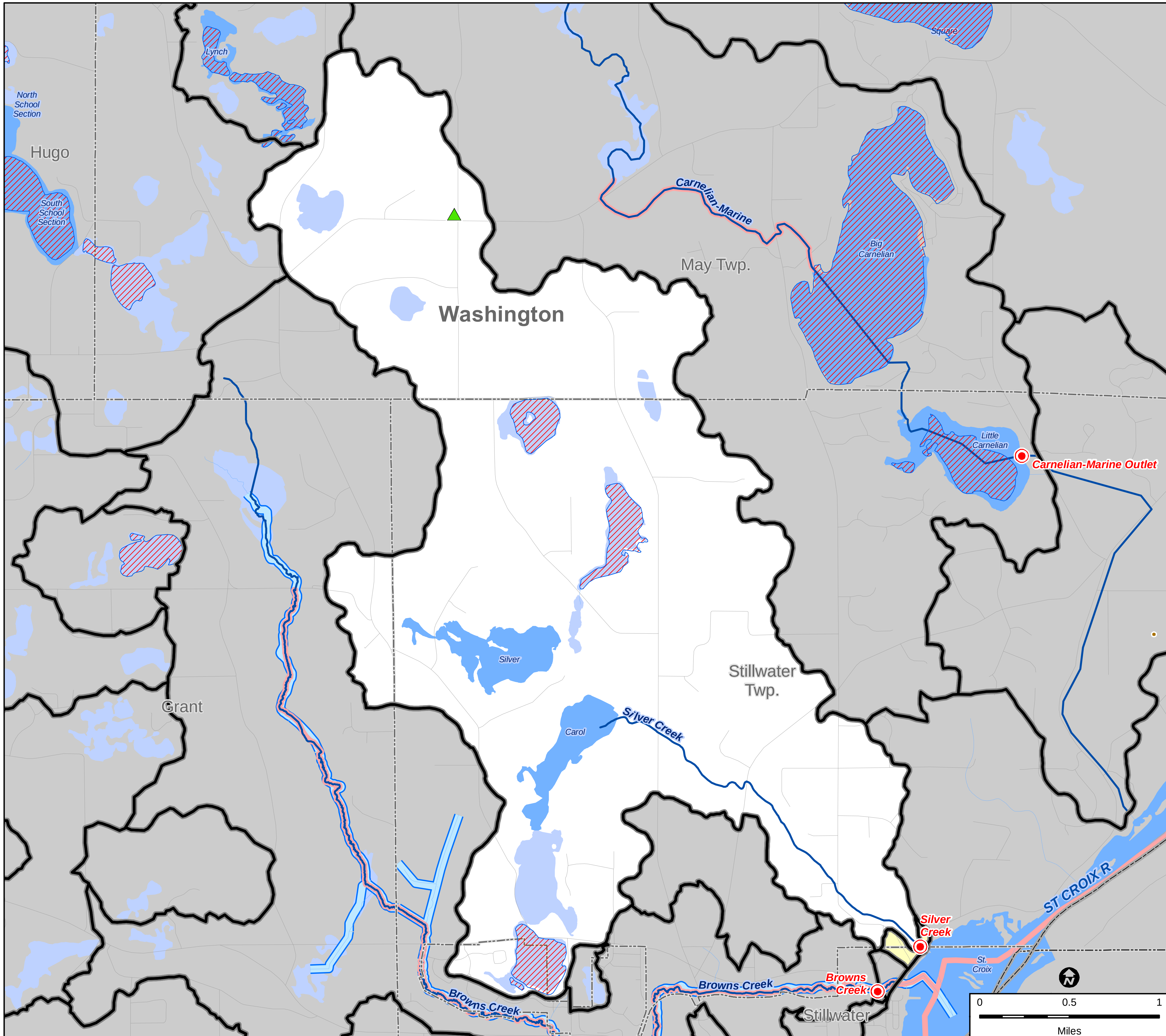
Public and Impaired Waters and Potential Pollution Sources

Silver Creek



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

Industrial Discharges **
Industrial Stormwater
Industrial & Individual Wastewater
Cooling, Potable Treatment & Dewatering

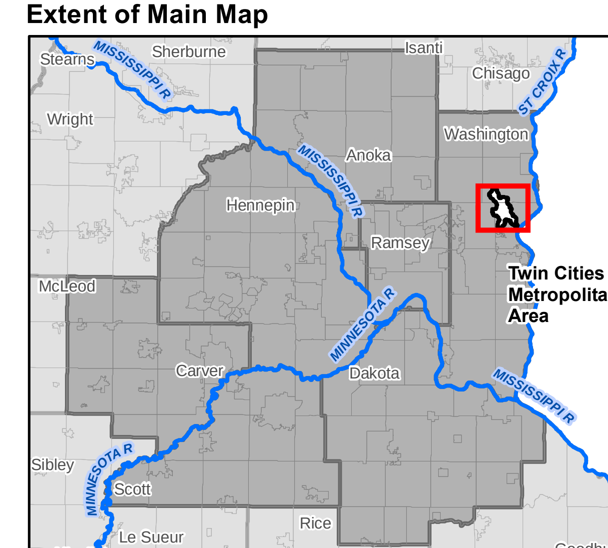
Domestic Wastewater Discharges **
Class A
Class B
Class C
Class D
Class Unknown

Feedlots with 100 or more animal units **
100 - 249
250 - 499
500 - 999
1000 or more

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

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

Extent of Main Map



Water Quality Impairments

The Silver Creek watershed contains three lakes that are included on the MPCA 2014 303d (Impaired Waters) list (Table SI-2, Figure SI-5) (MPCA, 2014a). Loon Lake, Louise Lake, and South Twin Lake are all impaired for aquatic recreation due to high levels of nutrients. In 2012, the U.S. Environmental Protection Agency (USEPA) approved the CMSCWD's multi-lake TMDL (Total Maximum Daily Load study) Implementation Plan that addresses the nutrient impairments (Emmons & Olivier Resources, Inc. et al., 2012). The majority of the recommendations focus on fisheries management, private and public projects, and educational outreach.

Table SI-2 : Silver Creek Watershed Impaired Lakes as Identified in the MPCA 2014 Impaired Waters List

Lake Name	Lake ID	Affected Use[1]	Approved Plan	Needs Plan
Loon (Main Lake)	82-0015-02	AQR	Nutrients	–
Louise	82-0025-00	AQR	Nutrients	–
South Twin	82-0019-00	AQR	Nutrients	–

[1] AQR = aquatic recreation

Hydrology

MCES has monitored flow on Silver Creek at the monitoring station near Hwy. 95 in Stillwater, Minnesota, since 1999. Flow measurements are collected at 15-minute intervals and converted to daily averages. The hydrograph of Silver Creek, which displays daily average flow, daily precipitation, and the flow associated with grab and composite samples, indicates the variation in flow rate from season to season and from year to year (Figure SI-7), and the effect of precipitation events on flow.

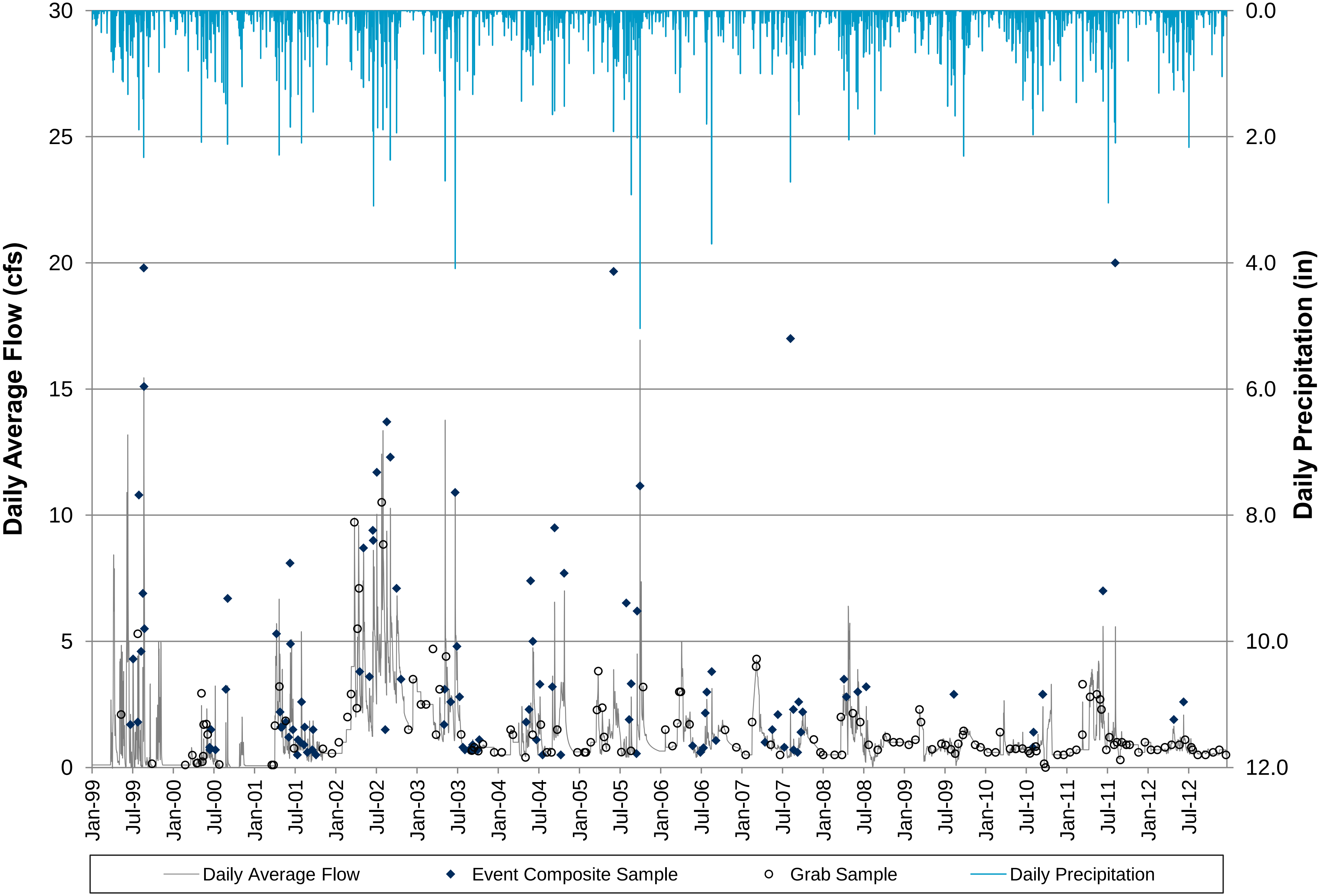
Figure SI-6: Silver Creek below Fairy Falls

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

The variations in flow are 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 does not cause surface run off or overland flows. During the years 1999-2012, the average runoff ratio was 0.06, indicating an average of 94% 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. As mentioned in the stream and watershed description, the Silver Creek watershed primary soil type (Type B) facilitates moderately high infiltration. Given this characteristic, the infiltrated precipitation likely recharges the groundwater aquifers that eventually discharge into Silver Creek.

Analysis of the duration of daily average flows indicates the upper 10th percentile flows for period 1999-2012 ranged between approximately 2.6-16.9 cubic feet per second (cfs), while the lowest 10th percentile flows ranged from 0 to 0.10 cfs (See Figure SI-15 in the ***Flow and Load Duration Curves*** section of this report).

Figure SI-7: Silver Creek Daily Average Flow, Sample Flow, and Precipitation, 1999-2012*



*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 regional groundwater flow system and may be impacted by groundwater pumping. While regional in nature, this analysis serves as a screening tool to increase awareness about the risk that groundwater pumping may have for surface water protection and to direct local resources toward monitoring and managing the surface waters most likely to be impacted by groundwater pumping. Additional information, including assumptions and analytical methodologies, can be found in the 2010 report.

Figure SI-8: Groundwater-Fed Seep Flowing to Silver Creek below Fairy Falls

To assess the vulnerability of Silver 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 watershed, the entire length of Silver Creek extending to the St. Croix River proper was identified as potentially vulnerable. Special emphasis should be placed on the lower portion of Silver Creek, where there are several groundwater seeps (Figure SI-8) and a rich fen. Several basins within the watershed were also identified as vulnerable to groundwater withdrawals, including Louise Lake, Loon Lake, Silver Lake, Carol Lake, North and South Twin Lakes, plus a number of surrounding smaller unnamed wetlands and fens.

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 mass 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 Silver Creek (1999-2012).

Figures SI-9 to SI-12 illustrate annual loads expressed as mass, as flow-weighted mean (FWM) concentration, as mass-per-unit area (lb/ac), and as mass-per-unit area-per inch of precipitation (lb/ac/in), as well as three hydrological metrics (annual average flow rate, depth of flow (annual flow per unit area) and precipitation depth coupled with runoff ratio). A later section in this report (***Comparison with Other Metro Area Streams***) offers graphical comparison the Silver Creek loads and FWM concentrations with the other MCES-monitored metropolitan area tributaries.

The first charts in Figures SI-9 and SI-10 plot the annual flows from 1999 to 2012. The highest average annual flow, and thus the highest volume of flow, occurred during 2002 (approximately

3.39 cfs average annual flow); the lowest average annual flow, and lowest volume of flow, occurred in 2000 (approximately 0.22 cfs average annual flow). The mean average annual flow for the entire data record was 1.2 cfs, which is close to the median average annual flow of 1.1 cfs, suggesting the average annual flows were evenly distributed around the mean annual flow.

The flow metrics indicate a gradual decrease in flows from 2002 to 2010. This trend was also observed by the Washington Conservation District. The 2010 watershed district annual report stated that the station flows were primarily supported by the groundwater seeps below Fairy Falls during this period, as Fairy Falls frequently had low or nonexistent flows (CMSCWD, 2010). Note that the high flows measured in 2002 are likely a response to both precipitation and the rupture of the beaver dam at the outlet of Fairy Pond during a period of high flow.

The annual mass loads for monitored pollutants exhibited year-to-year variation, not always mirroring the pattern in annual flows (Figure SI-9). Every annual load plot shows the highest load in the year 2002. The loads that year were likely influenced by the destruction of a beaver dam at the outlet of Fairy Pond, which lowered the pond level and allowed release of sediment. The TSS, TP, and NH_3 loads during most years seem to be driven by concentration rather than flow, as they did not follow the pattern of annual flows. Similarly, NO_3 and Cl did not follow the flow pattern, but unlike TSS, TP, and NH_3, the NO_3 and Cl loads were relatively consistent throughout the study period. TDP is the only parameter that followed the pattern shown by stream annual flows. The 2012 TSS and TP loads and other parameters were not calculated due to poor statistical quality metrics estimated by Flux32.

The annual FWM concentrations provide greater insight to the loading dynamics in Silver Creek (Figure SI-10). The high loads in 2002 were produced due to high flows, as only TSS had the highest FWM concentration during that year. This is expected, as TSS concentrations are closely related to stream discharge. In addition, high sediment load was likely delivered to the stream after the rupture of the beaver dam at Fairy Pond during high flows in the summer of 2002. After 2002, TSS FWM concentrations declined and remain low. The TP, TDP, and NH_3 demonstrated high inter-annual variation in FWM concentrations, suggesting an influence of hydrologic routing and biological activity. The NO_3 FWM concentrations gradually increased from 2001 to 2010, but were fairly consistent from 2004 through 2008, when the flow was primarily from the groundwater source. The Cl FWM concentrations appeared relatively constant over the entire record.

Figures SI-11 and SI-12 present the areal and precipitation-weighted loads, respectively. These graphics are presented to assist local partners and watershed managers, and will not be discussed here.

The Flux32 loads and FWM concentrations were also compiled by month to allow analysis of time-based patterns in the loads in Silver Creek (Figure SI-13 and SI-14). The results for each month are expressed in two ways: the monthly results for the most recent year of data (2012 for flow, TDP, NO_3, NH_3, and Cl; 2011 for TP and TSS) and the monthly average for 2003-2012 (with a bar indicating the maximum and minimum value for that month).

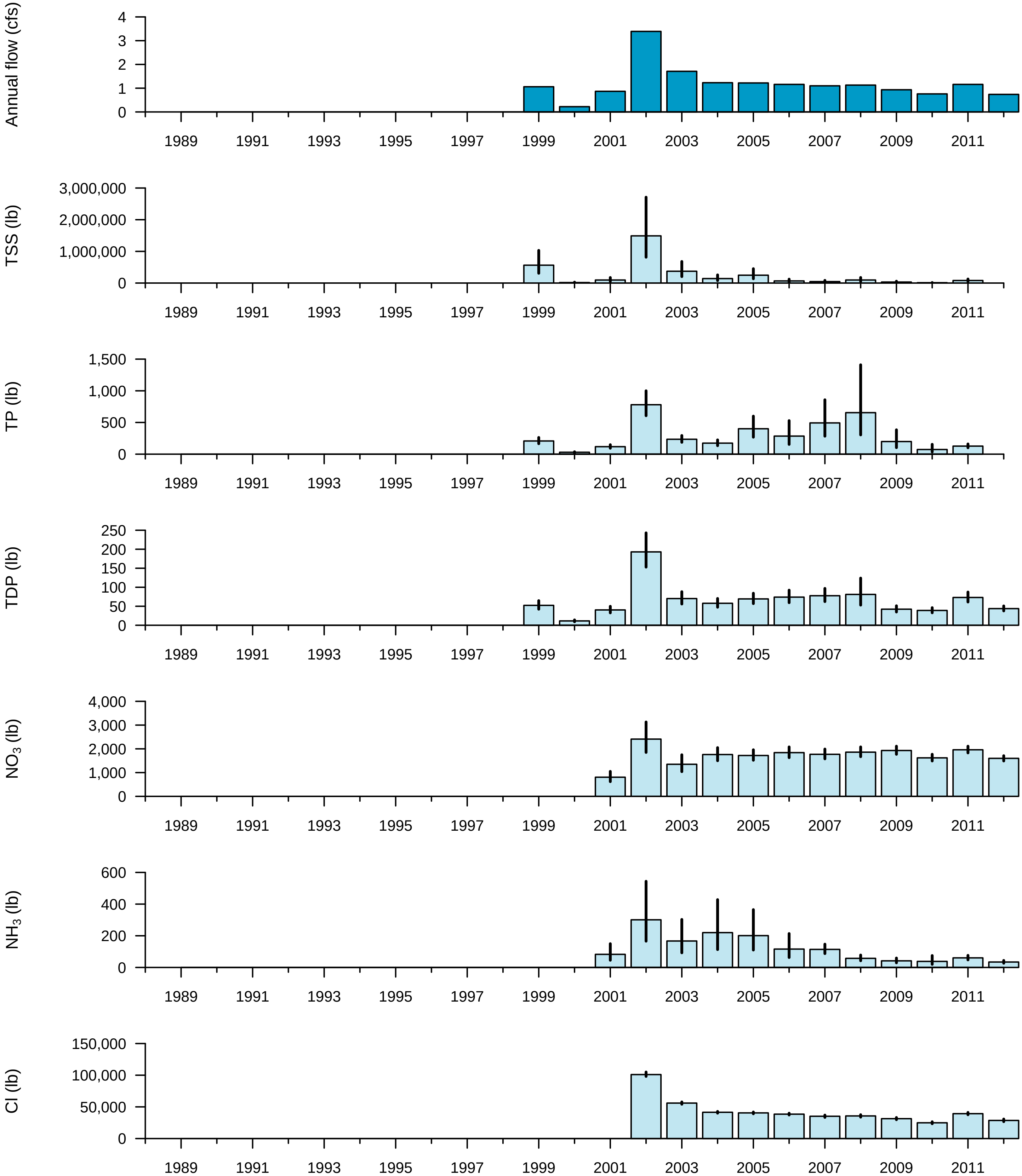
The Silver Creek ten-year average loads of TSS, TP, TDP, NO_3, and Cl did not clearly demonstrate peak month load (Figure SI-13). The winter loads (November-February) were lower than other seasons. After winter, the average monthly loads varied only slightly or were relatively consistent throughout the year. The only pollutant that did have a peak monthly load was NH_3 in March/April. A possible explanation could be the release 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, creating a large source of NH_3 in the soils (Brooks et al., 2011). The spring snowmelt events produce a large volume of water to flow over the unfrozen soils and flush and transport the NH_3 into the stream. The remainder of the year had low levels of NH_3 loads in the stream. It is notable that this peak did not appear in the 2012 Silver Creek monthly average NH_3 mass loads. The other 2012 monitored loads did not demonstrate any other deviation from the 10-year monthly average.

Generally, the 10-year average and the 2012 Silver Creek monthly FWM concentrations were more dynamic than the monthly mass loads (Figure SI-14). The NO_3 FWM concentrations were stable in the winter and fall months, and then slightly decreased in spring/summer. Most likely these changes in concentration were due to biological activity. The TSS, TP, and NH_3 FWM concentrations were fairly low throughout the year, with the exception of the March/April NH_3 flush. The Cl FWM concentrations were very consistent on a monthly basis.

The steady levels of Cl and NO_3 (in the non-growing season) strongly support the observation that the flows at the monitoring station are primarily groundwater-fed. It is impossible to connect these concentrations to any specific source in the watershed. Potential sources of Cl and NO_3 could be related to fertilizer leaching, or sewage and water treatment. All crops benefit from amending soils with fertilizers. Unfortunately, these applications, combined with the high infiltration rates of the catchment soils, can result in a contaminated aquifer, and by extension, higher concentrations in the creek. This process of cropland leaching into groundwater accounts for 30% of nitrogen contributions to surface water in the state of Minnesota (MPCA, 2013b).

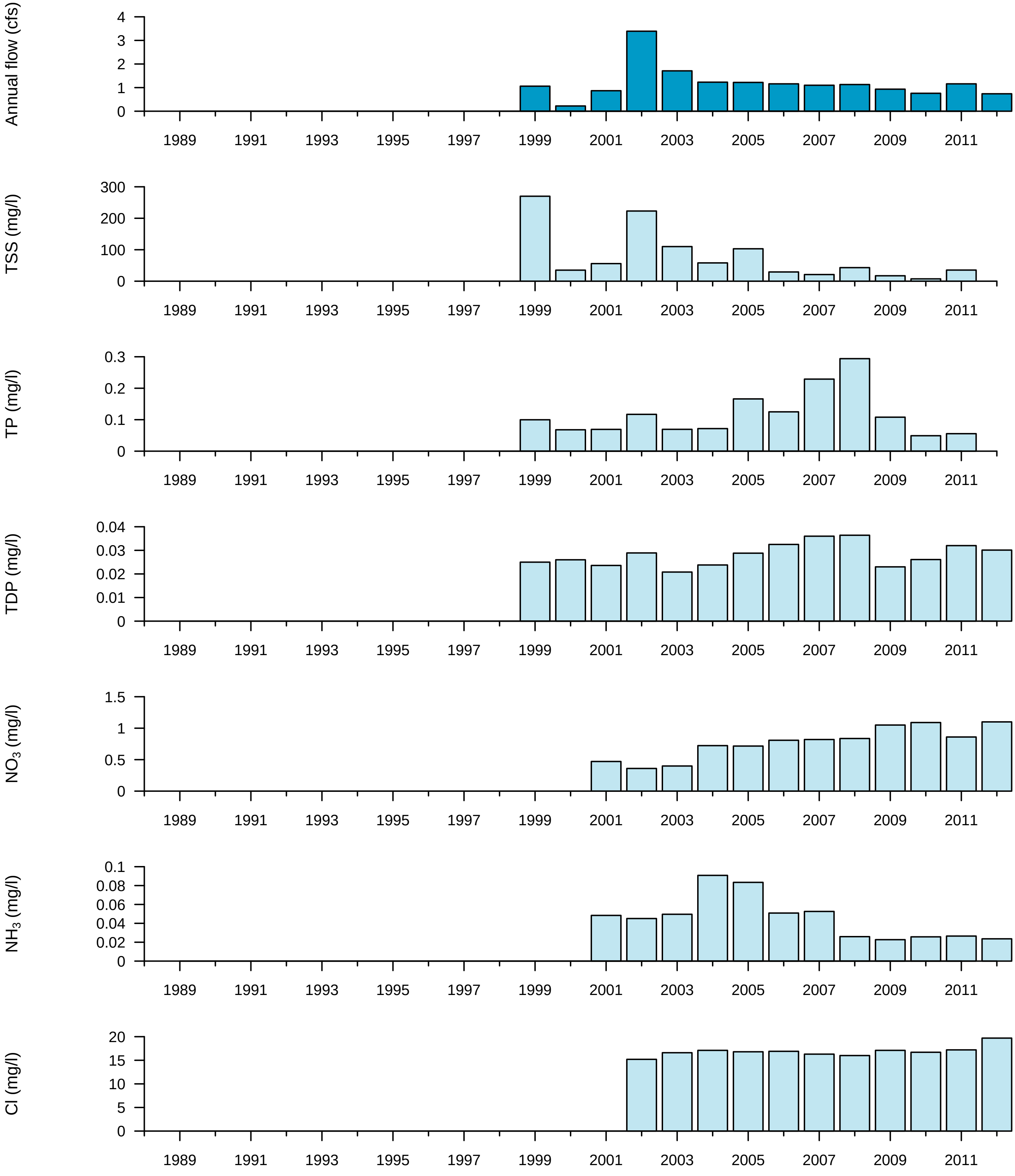
The lack of a centralized sewer system in this watershed necessitates the use of onsite septic systems to manage wastewater. The MPCA (2013a) state-wide estimated load of NO_3 from septic leachate and failed system release is about nine million pounds annually, and untreated domestic wastewater typically 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). When the NO_3 and Cl laden wastewater is released into a drain field, it infiltrates the soils and eventually enters the groundwater that feeds streams like Silver Creek.

Figure SI−9: Silver Creek*
Annual Mass Load



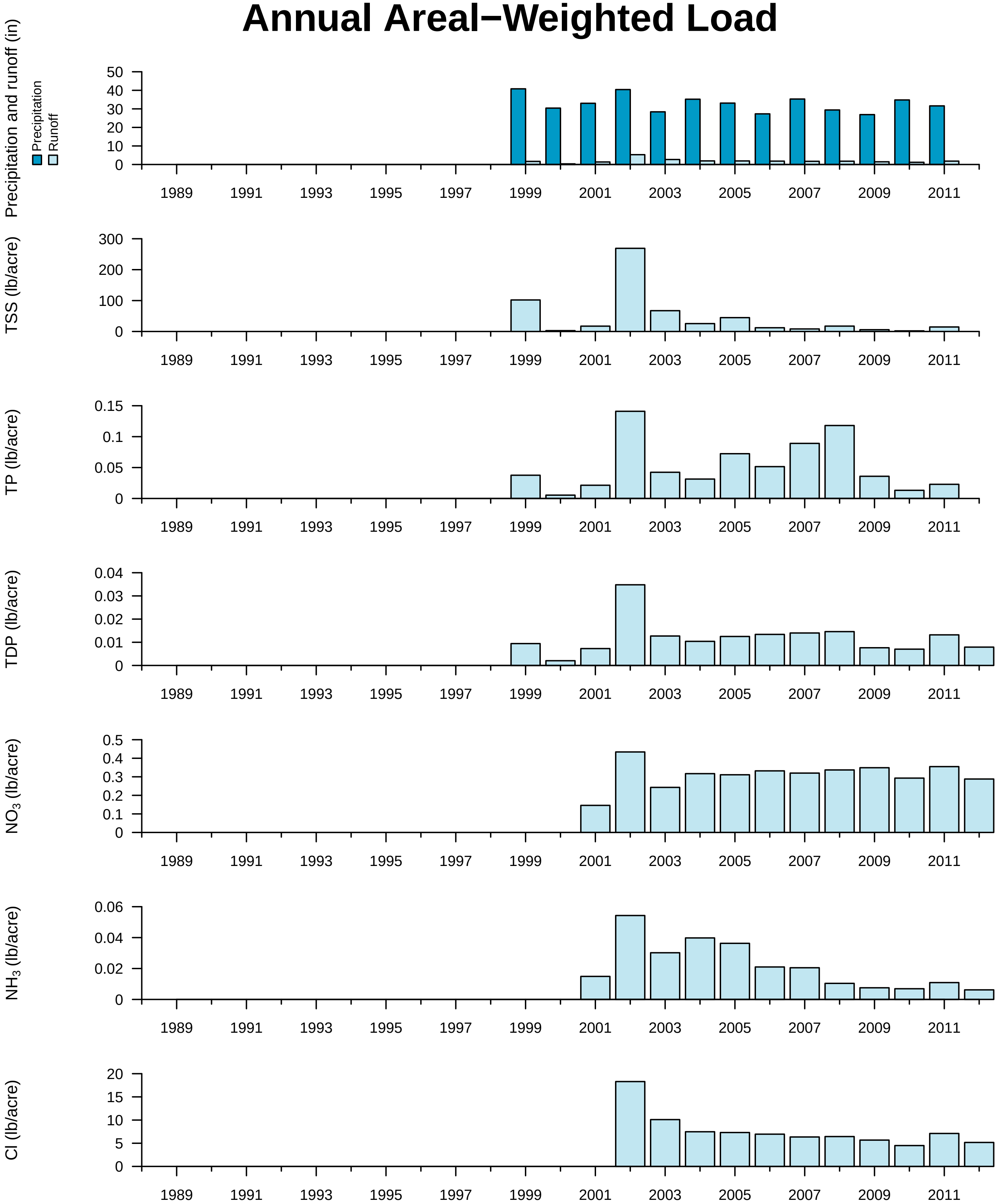
*TSS, TP, and TDP sampling began in 1999, NO3 and NH3 began in 2001, and Cl began in 2002.
Bars represent 95% confidence intervals as calculated in Flux32.

Figure SI−10: Silver Creek*
Annual Flow−Weighted Mean Concentration



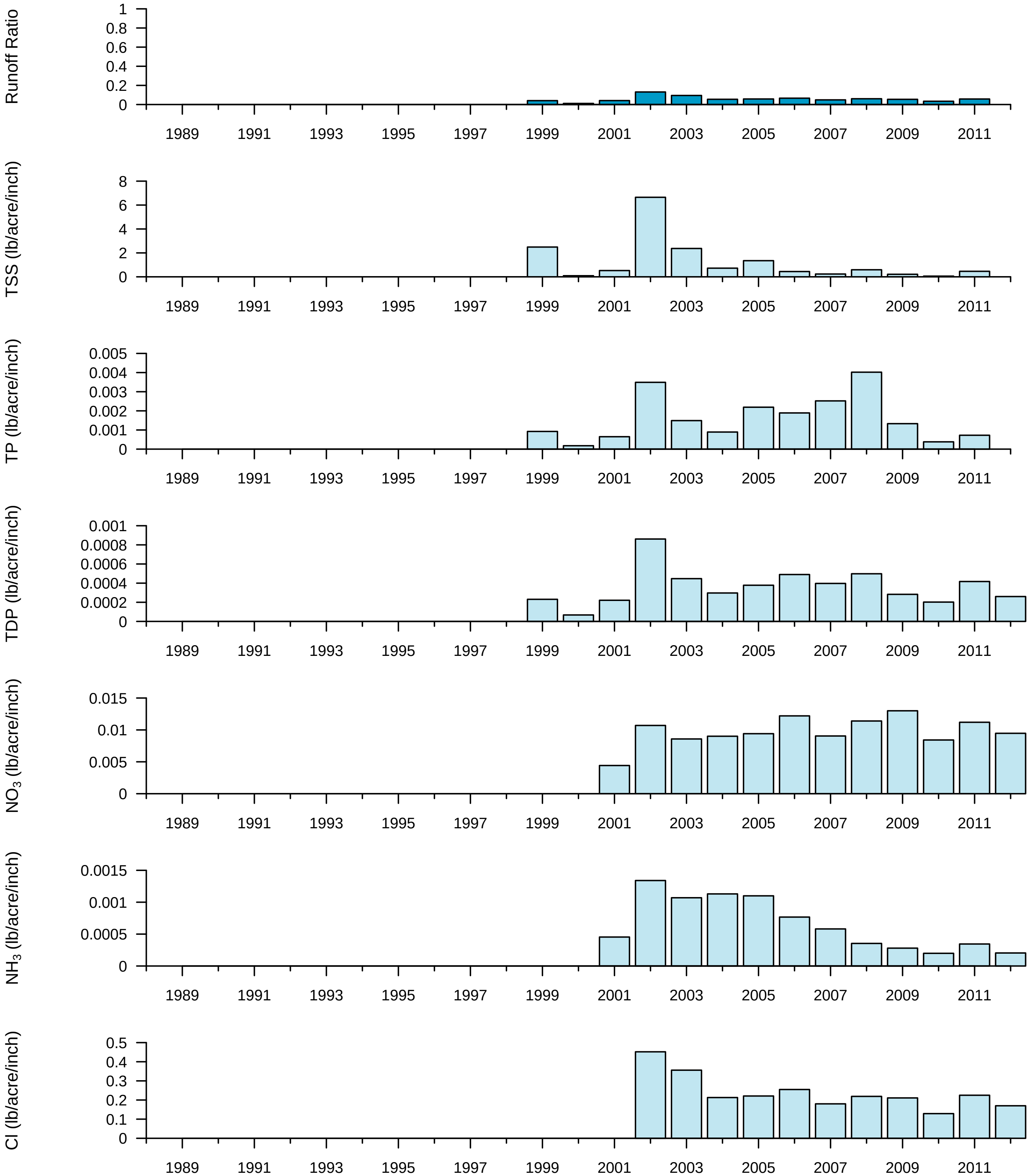
*TSS, TP, and TDP sampling began in 1999, NO3 and NH3 began in 2001, and Cl began in 2002.

Figure SI−11: Silver Creek*
Annual Areal−Weighted Load



*TSS, TP, and TDP sampling began in 1999, NO3 and NH3 began in 2001, and Cl began in 2002.

Figure SI−12: Silver Creek*
Annual Precipitation−Weighted Areal Load



*TSS, TP, and TDP sampling began in 1999, NO3 and NH3 began in 2001, and Cl began in 2002.

Figure SI−13: Silver Creek Mass Load by Month

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

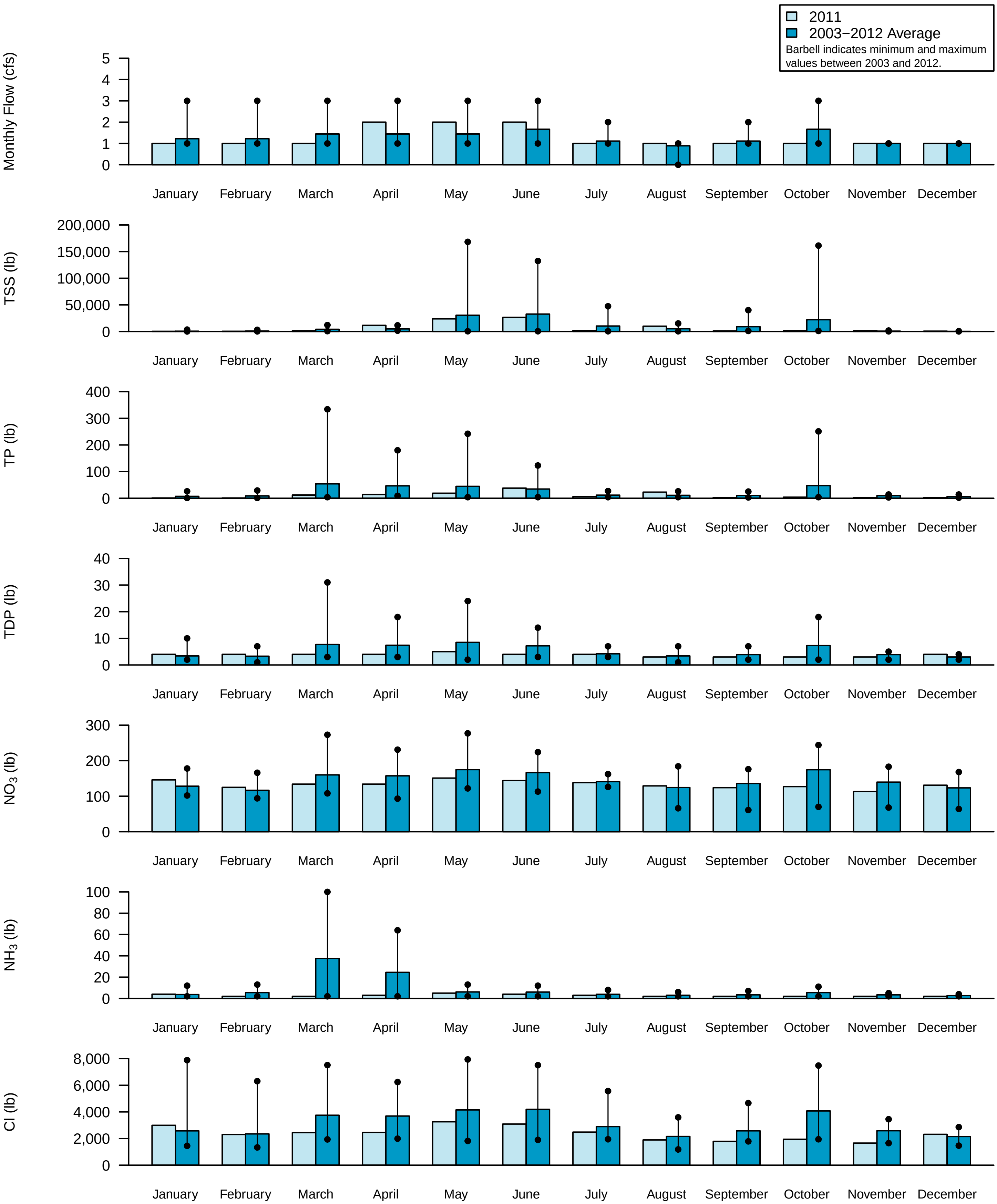
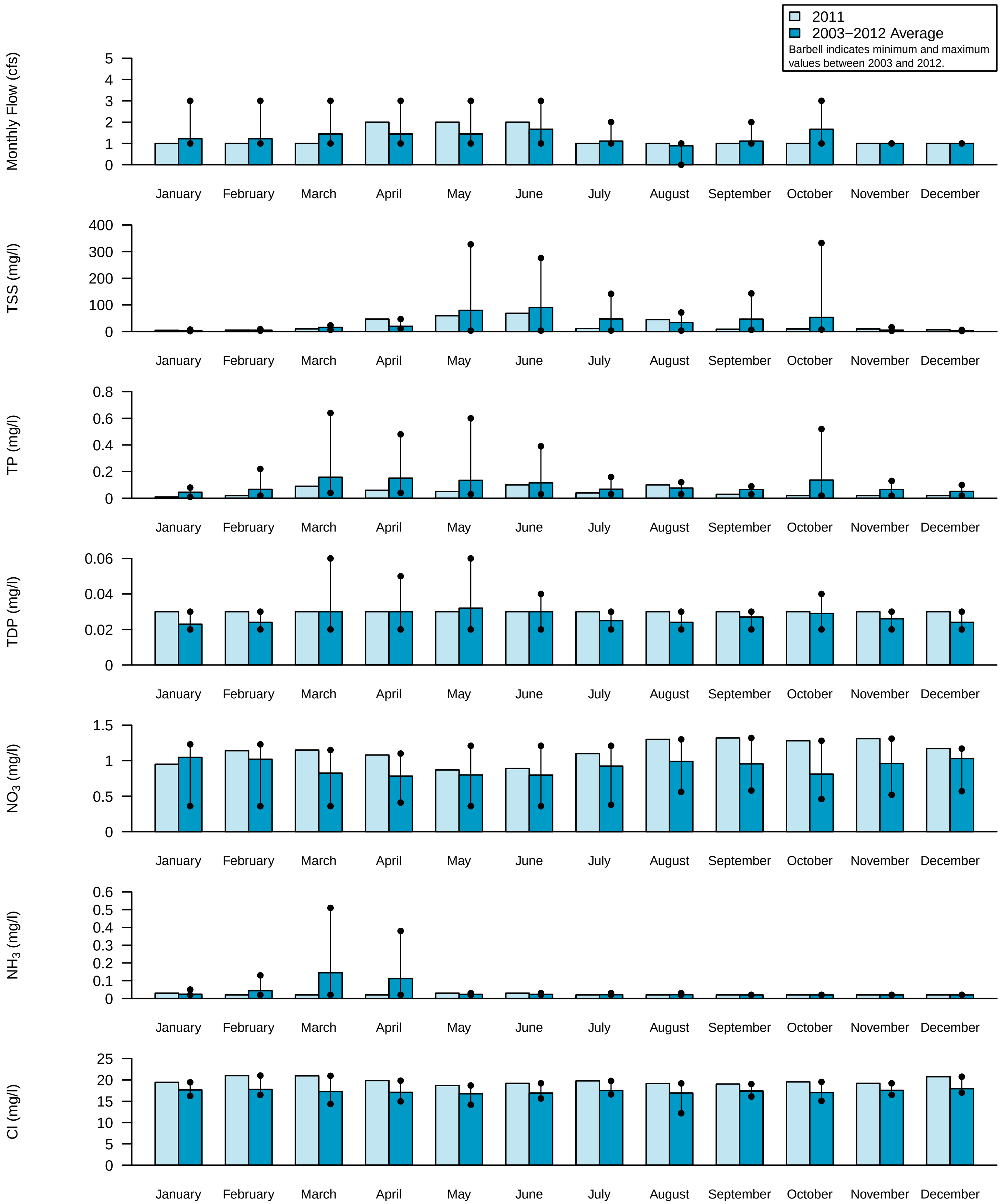


Figure SI−14: Silver Creek
Flow−Weighted Mean Concentation by Month

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



Flow and Load Duration Curves

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

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

- Develop flow duration curves using average daily flow values for entire period of record plotted against percent of time that flow is exceeded during the period of record.
- Divide the flow data into five zones: high flows (0-10% exceedance frequency); moist conditions (10-40%); mid-range flows (40-60%); dry conditions (60-90%); and low flows (90-100%). Midpoints of each zone represent the 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 Silver Creek monitoring station daily average flows and sample data, along with the most appropriate MPCA draft numerical standard as listed in Table SI-3. No draft standard has been set for NO_3, so MCES used the drinking water standard of 10 mg/l.

Most of the draft standards proposed by MPCA have accompanying criteria that are difficult to show on the load duration curves. For example, for a water body to violate the draft TP river criteria, the water body must exceed the causative variable (TP concentration), as well as one or more response variables: sestonic (suspended) chlorophyll, biochemical oxygen demand ($BOD_{5)}$, dissolved oxygen (DO) flux, and/or pH (MPCA, 2013b). 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 Silver Creek monitoring station (mile 0.1, at Hwy. 95) are shown in Figure SI-15.

The range of flows and the shape of the flow duration curve describe the flow pattern of the stream system. Flow duration analysis of daily average flows indicates the upper 10th percentile flows ranged between approximately 2.6 and 16.9 cfs, while the lowest 10th percentile flows ranged from 0 to 0.1 cfs. The steep curve in the High Flow category indicates that high flows last for short periods of time, usually attributed to rain-induced floods. Similarly, the steep curve in the Low Flow category indicates that Silver Creek does not always maintain flow throughout the year, but this condition is not a frequent occurrence (11 days of no flow out of 5,114 records). The line is broken at the Low Flow regime, strongly pointing to a need to more accurately measure the low flows.

The load duration curves provide insight about how flow conditions affect the compliance of stream concentrations with state standards. At low flows, the Silver Creek concentrations were mostly below those dictated by the draft standards for TSS, TP, Cl, and the drinking water standard for NO_3. As the flows increase, the TSS and TP daily concentrations fell both above and below the dark lines designating the standard. Under high flows, a large portion of the TSS and TP samples exceeded the standards. Regardless of flow conditions, both NO_3 and Cl loads were tightly grouped and consistently below the drinking water and Cl draft standards, respectively. This lack of spread in the daily loads of NO_3 and Cl shows the consistent, elevated levels of NO_3 and Cl in the groundwater.

Table SI-3: Silver Creek Beneficial Use and River Nutrient Region Classifications and Pollutant Draft Standards

Monitoring Station	Use Classification[1] for Domestic Consumption (Class 1) and Aquatic Life and Recreation (Class 2)	River Nutrient Region (RNR)[2] of Monitoring Station	Cl Draft Stnd[3] (mg/l)	TSS Draft Stnd[4] (mg/l)	TP Draft Stnd[5] (ug/l)	NO3 DW Stnd[6] (mg/l)
Silver Creek at Hwy 95 (SI0.1)	2B	Central	230	30	100	10

[1] Minn. Rules 7050.0470 and 7050.0430

[2] MPCA, 2010.

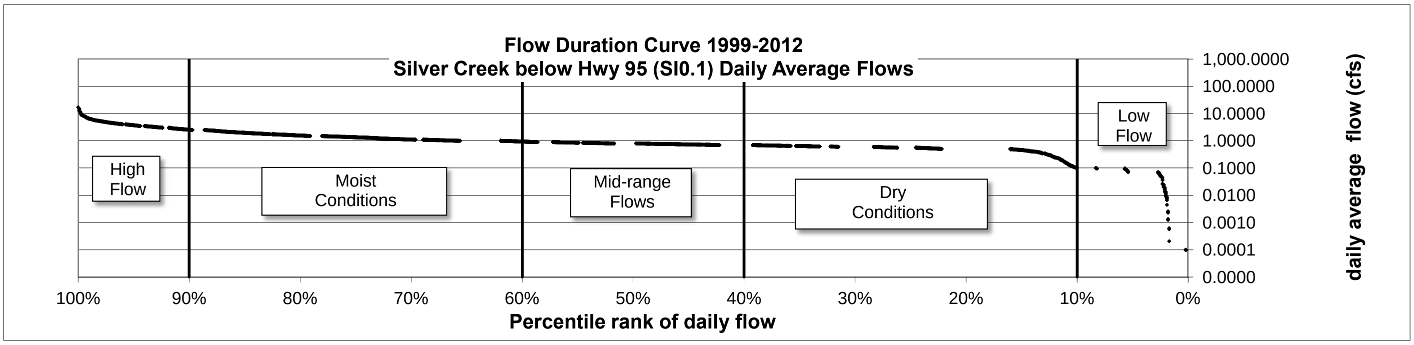
[3] Mark Tomasek, MPCA, personal communication, March 2013. MCES used 230 mg/l as the draft Cl standard pending results of USEPA toxicity tests.

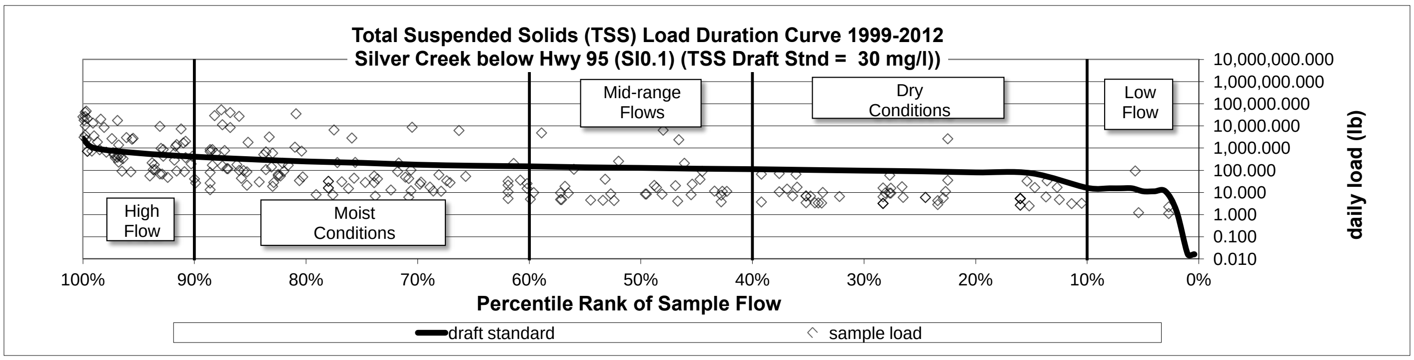
[4] MPCA, 2011a. Draft standard states TSS standard concentration for Class 2A and 2B water must not be exceeded more than 10% of the time over a multiyear data window, with an assessment period of April through September.

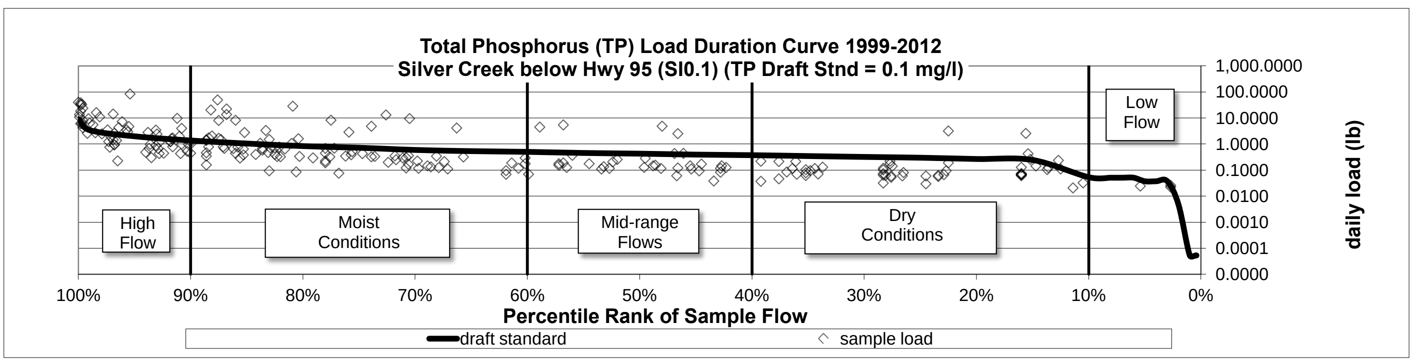
[5] MPCA, 2013b. To violate the standard, concentration of causative variable (TP) must be exceeded, as well as one or more response variables: sestonic chlorophyll, BOD_5, DO flux, and/or pH.

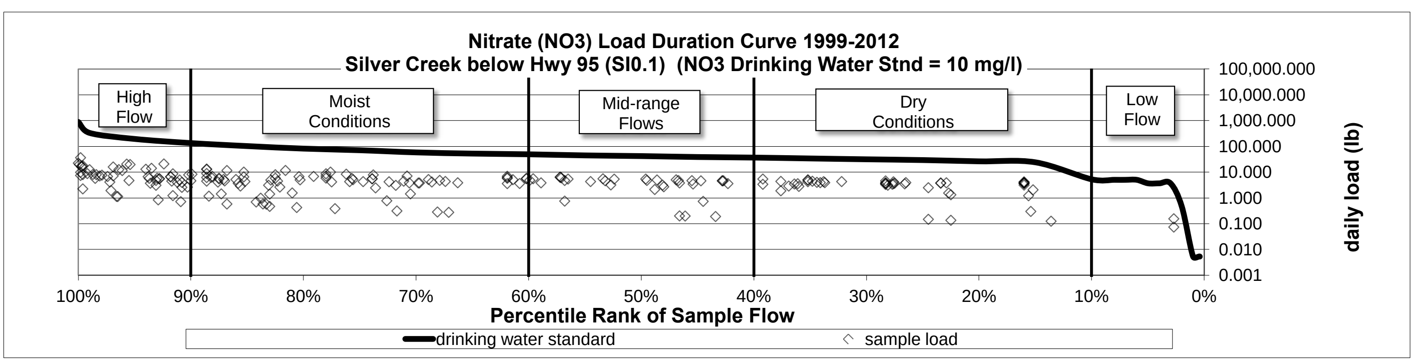
[6] MCES used the NO_3 drinking water standard of 10 mg/l pending results of USEPA toxicity tests and establishment of a draft NO_3 standard for rivers and streams.

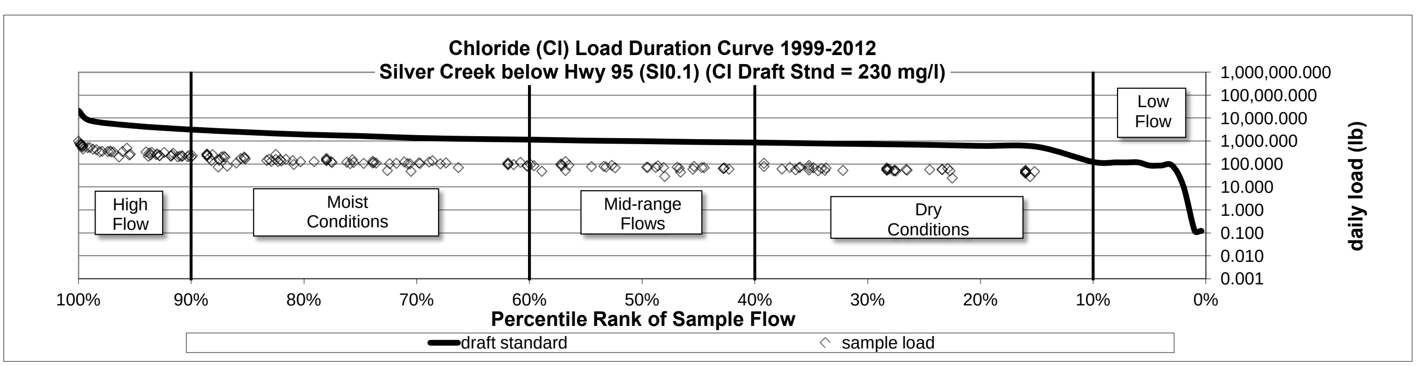
Figure SI-15: Silver Creek Flow and Load Duration Curves, 1999-2012











Aquatic Life Assessment Based on Macroinvertebrates

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

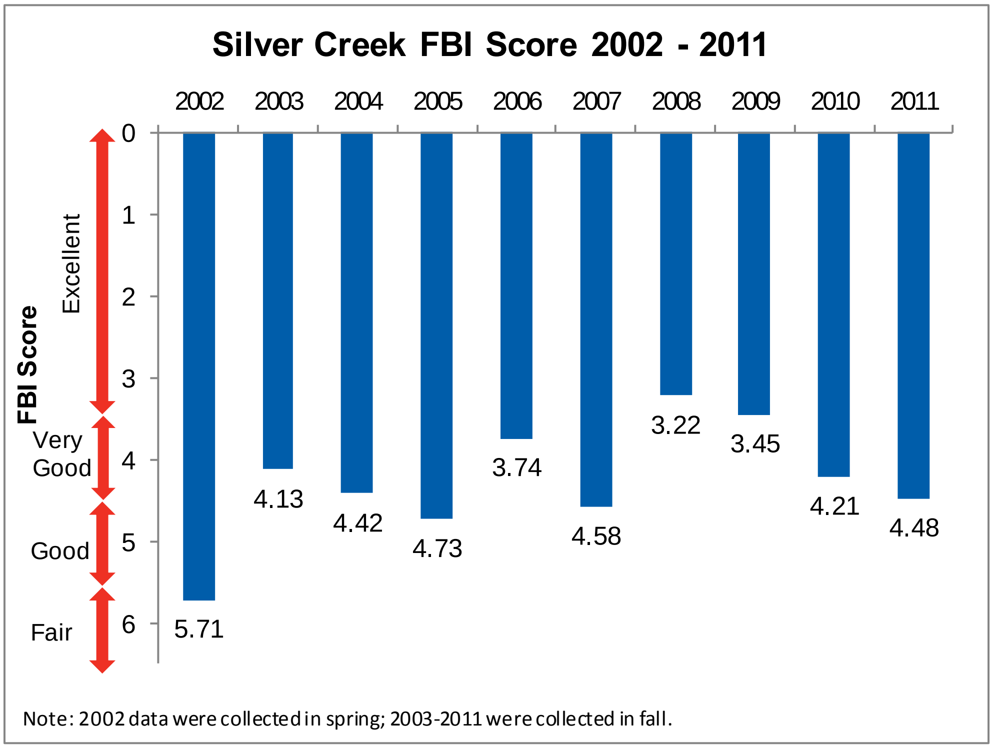
Each metric is independently important and clarifies one aspect of the ecosystem health: species richness, community diversity, water quality, and other factors. The results may have conflicting conclusions when comparing the single metric results. However, integrating the individual metrics into a multi-metric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

MCES has been sampling for macroinvertebrates in Silver Creek since 2002. In 2002, the macroinvertebrates were sampled in late spring; the remaining years (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 data, collected in 2004-2009 and 2011, was analyzed using the multi-metric, Minnesota-specific, MPCA Macroinvertebrate Index of Biological Integrity (M-IBI) (MPCA, 2014b).

Family Biotic Index (FBI)

FBI is a commonly used water quality assessment. Each family is assigned a tolerance value that describes its ability to tolerate organic pollution, such as insecticides or herbicides. The values range from 0 to 10; zero is intolerant to pollution, 10 is quite tolerant of pollution. The tolerance values are used to calculate a weighted average tolerance value for the sample, allowing for comparisons from year to year. The Silver Creek FBI scores ranged from excellent water quality (for years 2008, 2009) to good water quality (2005, 2007), indicating the presence of some organic pollution during most years (Figure SI-16). The 2002 FBI value scored in the fair range, but it cannot be compared to the other scores as it was collected during a different time of the year.

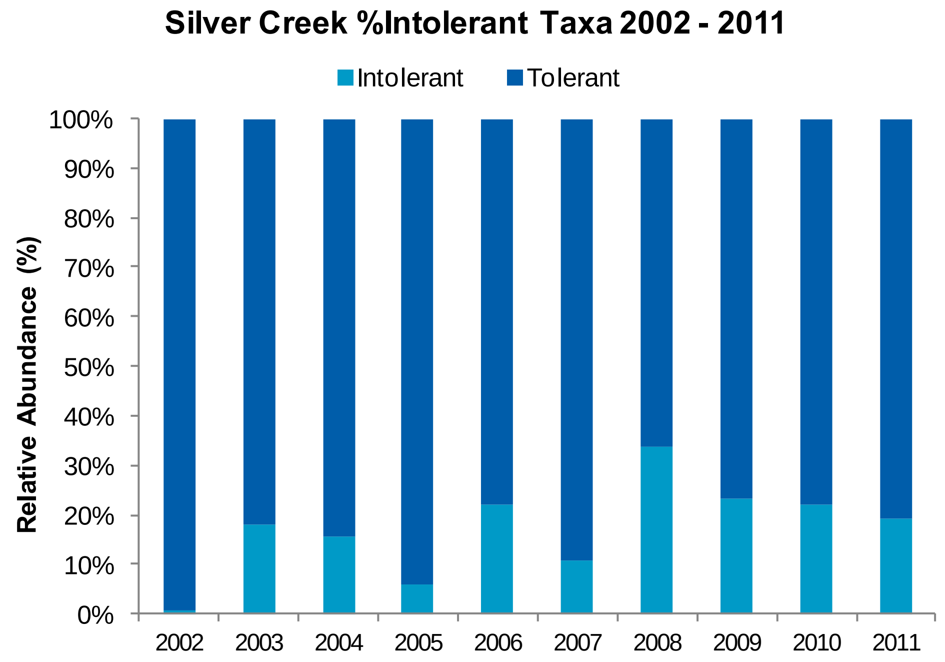
Figure SI-16: Silver Creek Annual Family Biotic Index (FBI) Scores, 2002-2011



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 SI-17). The presence of moderate numbers of intolerant taxa is an indicator of good aquatic health (Chirhart 2003). Silver Creek intolerant taxa were greater than 10% of the sample in all years except 2002 and 2005. The 2002 score may be attributed to the time of collection. The highest Percent Intolerant Taxa was 34% in 2008.

Figure SI-17: Silver Creek Percent Abundance of Pollution Intolerant Taxa, 2002-2011

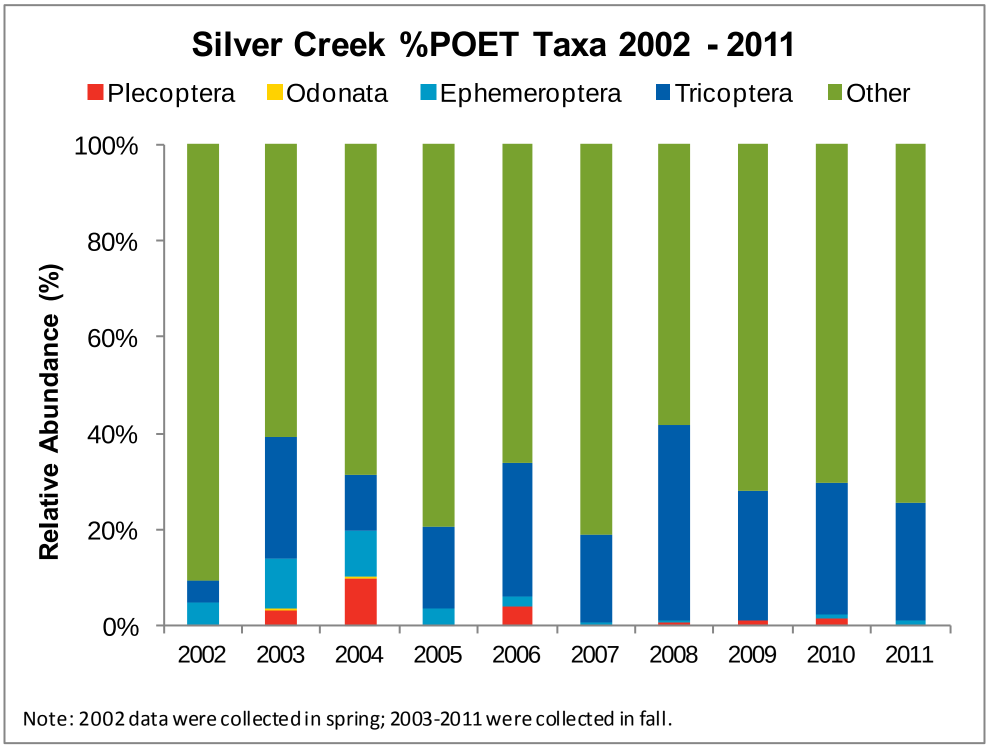


Note: 2002 data were collected in spring; 2003-2011 were collected in fall.

Percent POET Taxa

The taxonomic richness metric, Percent POET Taxa (Figure SI-18), is the percent of individuals in the sample that belong to the orders Plecoptera (stoneflies), Odonata (dragonflies and damselflies), Ephemeroptera (mayflies), and Trichoptera (caddisflies). Individuals in these orders vary in sensitivity to organic pollution and sedimentation. High percent POET values indicate high community diversity due to good water quality. The percent POET taxa values were highest in 2008 at 42%, and lowest in 2002 at 10%.

Figure SI-18: Silver 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. These composite scores are usually shown in context with a threshold value and confidence levels to aid in the assessment of the water quality. Higher scores indicate a more sustainable environment for water organisms.

Seven of the eight years of monitoring Silver Creek resulted in M-IBI scores above the impairment threshold and the upper confidence level (Figure SI-19). This suggests the stream was able to sustain the needs of aquatic life during the study period.

The 2004 score for Silver Creek was between the threshold of impairment and the upper confidence level. When the score falls between the confidence levels, it is difficult to confidently assess the water quality by biological assessment alone. It is necessary to incorporate other monitoring information, such as hydrology, water chemistry and land use change (MPCA, 2014b).

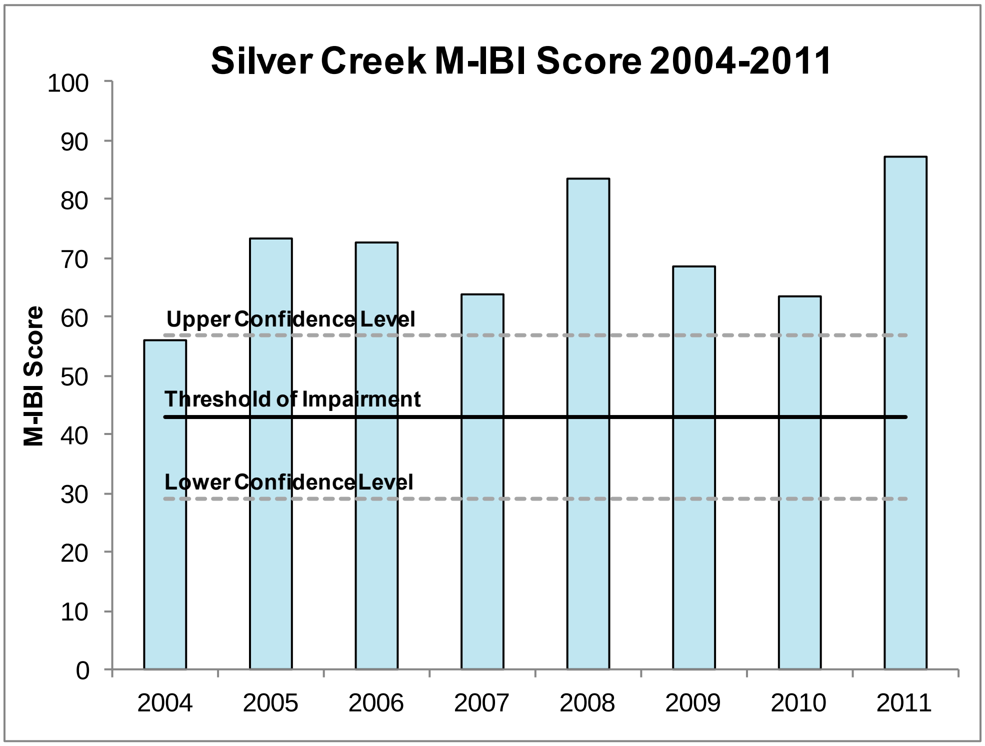
Understanding physical and chemical influences on M-IBI scores leads to a more complete assessment of water quality. When plausible physical or chemical explanations exist for M-IBI scores between the confidence levels, these scores may be assigned more or less weight in the final evaluation.

In 2004, the sample was collected two weeks after the second largest storm event of the year (15 September 2004, 6.6 cfs peak flow). Additionally, the sample coincided with rising limb of another storm event. Storm events can flush macroinvertebrates and change community composition. Sampling during increased flow could have affected the composition of the sample.

The 2004 M-IBI score is the only one in the period of record that is below the upper confidence level. Since a plausible hydrologic explanation exists for this M-IBI score, and since the stream consistently scored high in the subsequent years, this point has less weight in the overall evaluation.

The most recent M-IBI scores, 2010 and 2011, are above the upper confidence level. Most likely, stressors are not negatively affecting the macroinvertebrate community. MCES is planning additional future analysis to fully investigate our biological monitoring data and the sample collection program.

Figure SI-19: Silver Creek Annual Macroinvertebrate Index of Biological Integrity (M-IBI) Scores, 2004-2011



Trend Analysis

Trend analysis was attempted for the historical record of TP, NO_3, and TSS in Silver Creek using the U.S. Geological 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. However, because the station has flashy flows with events lasting less than one day, the data were not appropriate for analysis with QWTREND. MCES staff plan to repeat the trend analyses in 10 years. New statistical tools coupled with a longer data set may allow assessment of pollutant trends, as well as flow trends, at that time.

Due to relatively short flow record for any of the monitored streams, MCES did not attempt to assess increases or decreases in flow at this time. 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 period of 10 to 90 years, finding that peak flow due to snowmelt was the only streamflow statistic that has not changed at a significant rate. Peak flows due to rainfall events in summer were found to be increasing, along with the number of days exhibiting higher flows. Both summer and winter baseflows were found to be increasing, as well. Novotny and Stefan hypothesized that increases in annual precipitation, larger number of intense precipitation events, and more days with precipitation are driving the increased flows.

Alterations in land use and land management have also likely contributed to increasing flow rates. For example, Schottler et al. (2013) found that agricultural watersheds with large land use changes have exhibited increases in seasonal and annual water yields, with most of the increase in flow rate due to changes in artificial drainage and loss of natural storage.

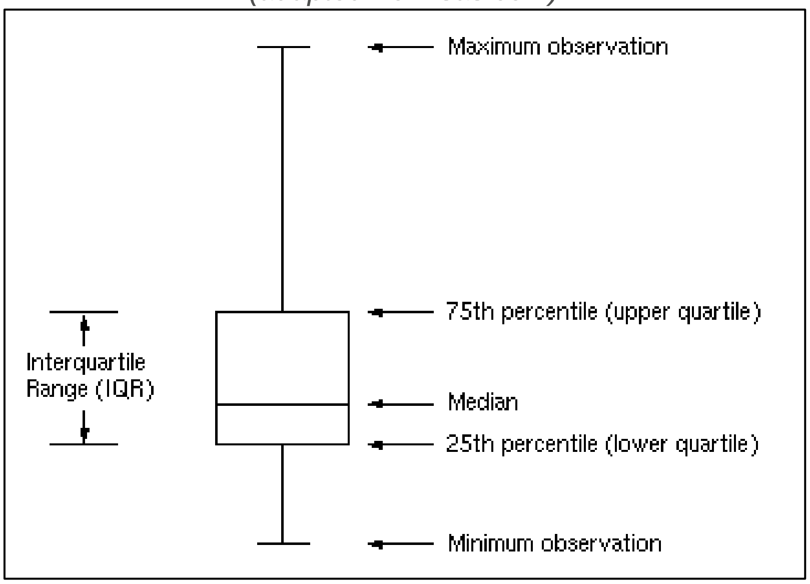
Comparison with Other Metro Area Streams

Chemistry

Box-and-whisker plots are used to summarize the comparison of the historical flow, TSS, TP, and NO_3, and Cl data for Silver 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 shown in Figure SI-21 to Figure SI-24, and Table SI-4.

Figure SI-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 SI-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.

Total Suspended Solids. Among the other St. Croix watersheds, the median annual TSS FWM concentration for Silver Creek was greater than Carnelian Marine and Valley Creek, but lower than Browns Creek (Figure SI-21). The FWM concentration in Silver Creek was also higher than that in the St. Croix River (as measured at Stillwater, Minnesota; ~35 mg/l vs. 8.5 mg/l, respectively), indicating that Silver Creek served to increase the TSS concentration in the St. Croix. It is apparent that those tributaries entering the St. Croix River had significantly lower TSS FWM concentrations and annual yields (expressed in lb/acre) than almost all of the 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 Silver Creek was the lowest among all metropolitan area streams, with the exception of Carnelian Marine Outlet (when it does flow). The source of Silver Creek water is a mix of surface flows and groundwater springs and seeps. If it was more heavily groundwater-sourced, the runoff ratio would be more like those observed in Eagle Creek and Valley Creek.

Total Phosphorus. Similar to TSS, the TP FWM concentration in Silver Creek was greater than that of the St. Croix River and thus served to dilute the TP concentration in the river (Figure SI-22). Silver Creek and the other St. Croix River tributaries also had lower FWM concentrations than most of the other MCES- monitored streams, with the exception of Eagle Creek, the Rum River, and Minnehaha Creek. The Silver Creek median TP annual yield was the second lowest in the metropolitan area, only Carnelian Marine Outlet is lower.

Nitrate. The Silver Creek median annual NO_3 FWM concentration of 0.8 mg/l was lower than the drinking water standard (Figure SI-23). However, in the context of other metropolitan area tributaries, this concentration was higher than ten other streams. The Silver Creek median NO_3 concentration was also greater than that in the St. Croix River, and thus served to increase the NO_3 concentration the river. The median annual yield in Silver Creek was higher than two other MCES-monitored tributaries, Minnehaha Creek and the Carnelian Marine Outlet.

Chloride. The Cl annual median FWM concentration in Silver Creek was the second lowest in the St. Croix watershed. Both Valley and Browns Creek had higher FWM concentrations and annual yields (Figure SI-24). This is notable, as all three streams have a groundwater component to their flows. Most likely the difference in Cl concentration between Browns Creek and Silver Creek is due to the lack of development in the Silver Creek watershed and difference in the amount of groundwater contribution to each of the streams' flow. Valley Creek has a similar percentage of urban lands as Silver Creek, but has a much higher concentration of Cl in the stream. This highlights the different sources of groundwater in Washington County, and the influence of bedrock composition, geologic fractures, and ground water quality and flow direction and volume on the surface water-ground water connections. When compared to the other MCES-monitored tributaries, the Silver Creek median Cl yield was the second lowest in the metropolitan area.

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 and this attribute does not correlate with major river basins.

The M-IBI scores for Silver Creek were above the MPCA impairment threshold (Figure SI-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 - Browns, Eagle, and Valley Creeks. The cold water, spring-fed streams appear to have fewer negative stressors on their macroinvertebrate communities than the warm water, surface-fed streams in the metropolitan area.

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. However, since the Silver Creek dataset was deemed insufficient to run the trends analysis, it cannot be compared to the other metropolitan area stream trends.

Please see the other stream sections in the series for the presentation of estimated changes for TSS, TP, and NO_3 in MCES-monitored streams.

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

Organized by Major River Basin

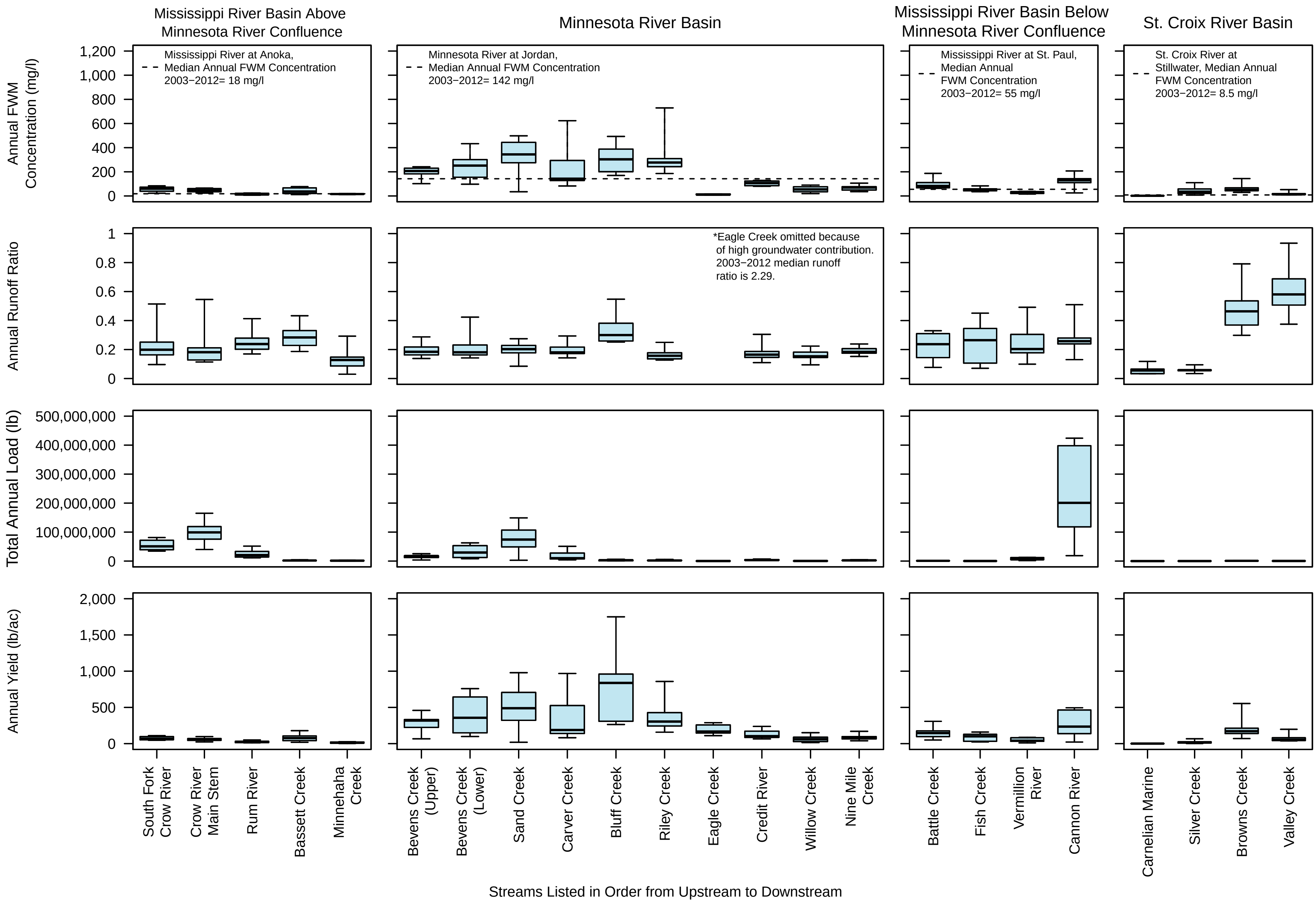


Figure SI−22: Total Phosphorus for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

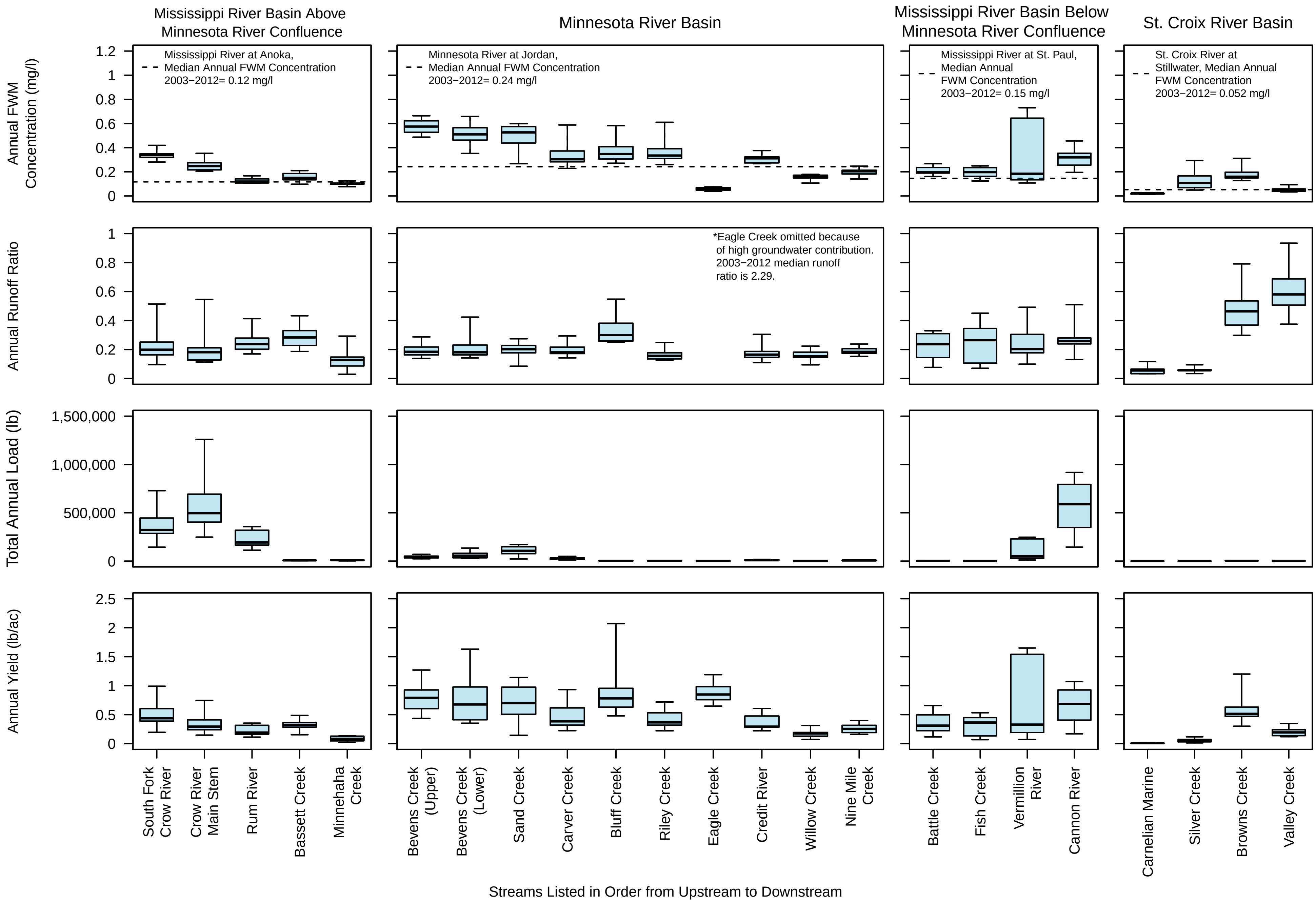


Figure SI−23: Nitrate for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

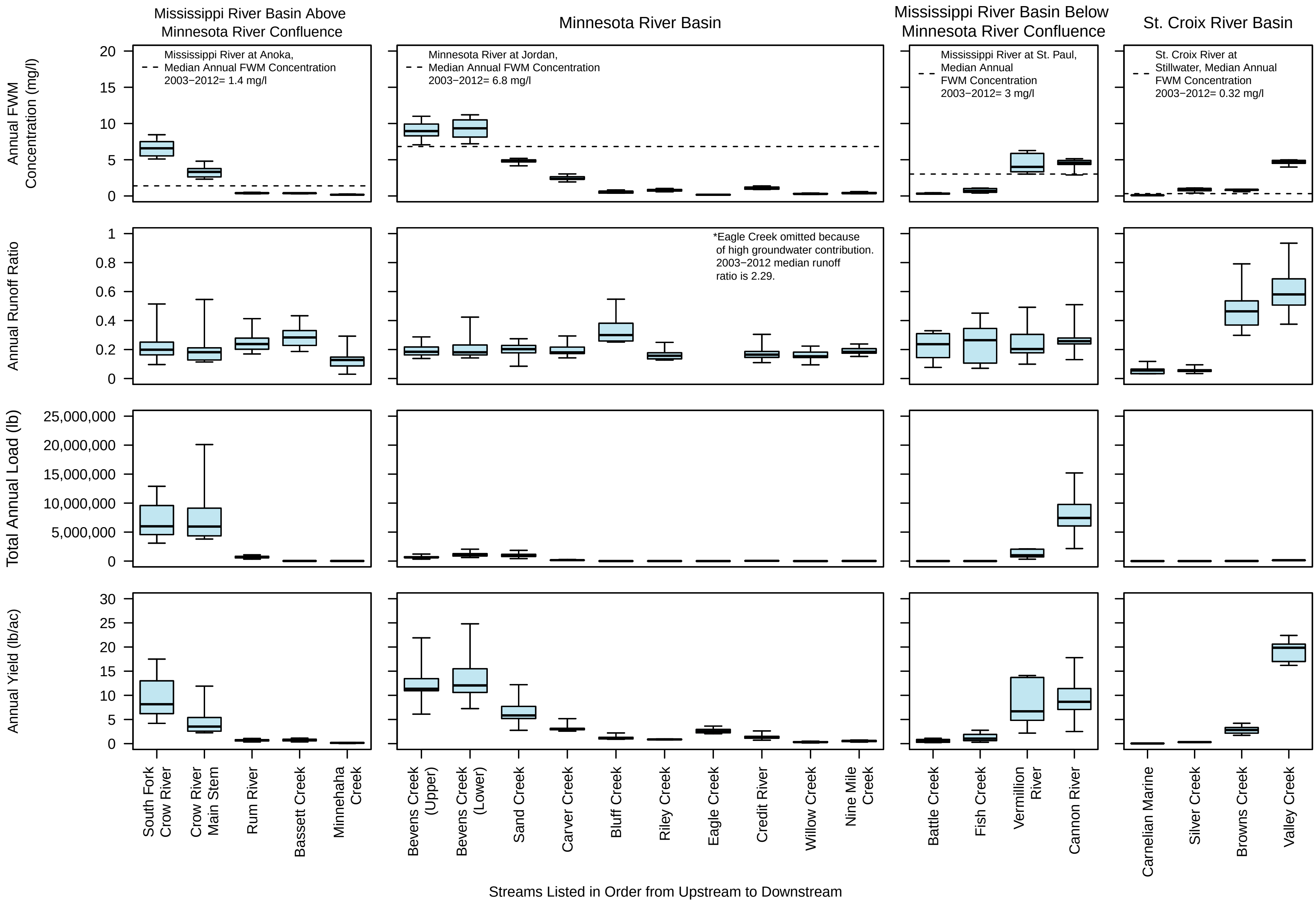


Figure SI−24: Chloride for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

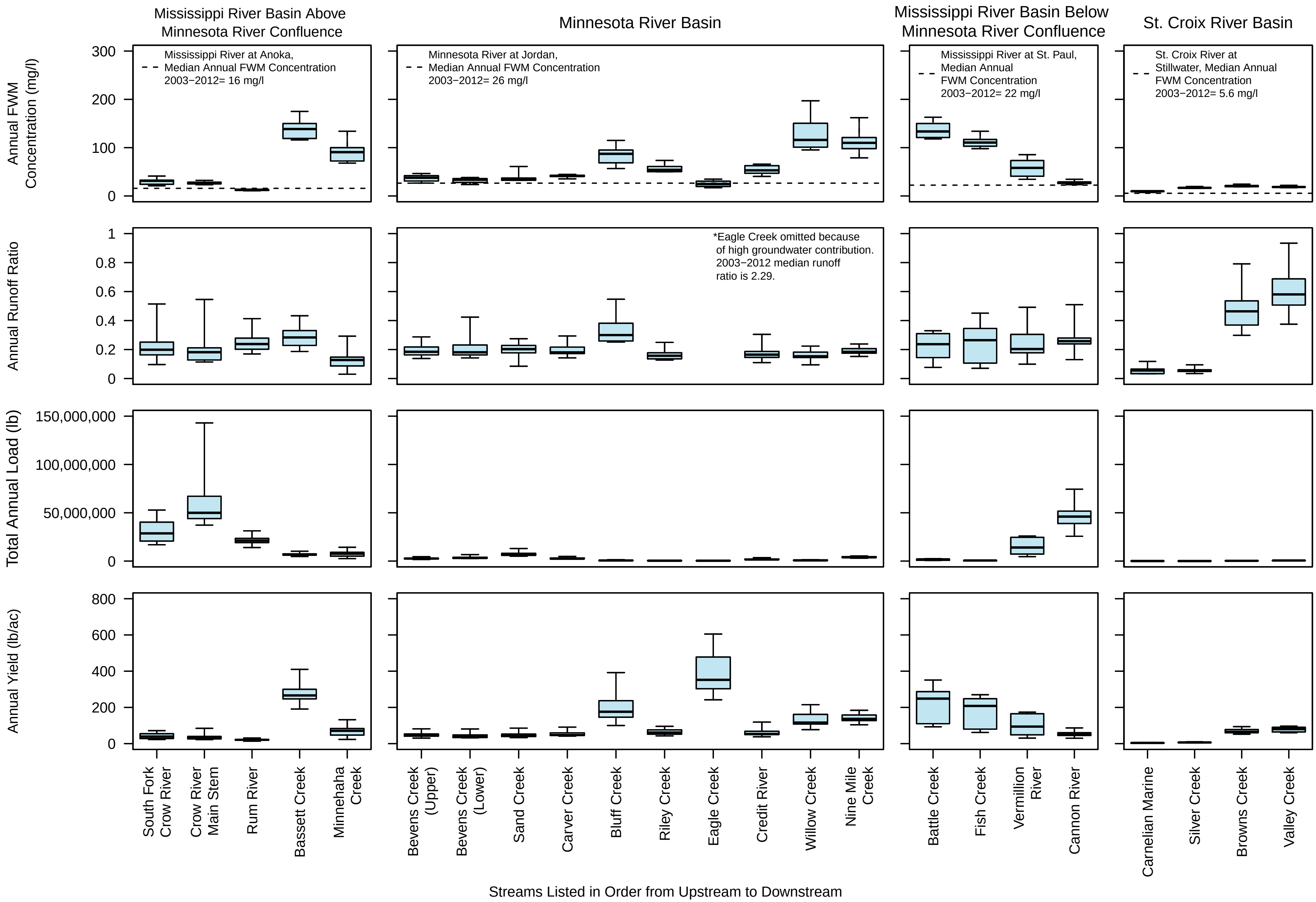


Table SI-4: Annual Median Concentrations, Loads, and Yields for MCES-Monitored Streams, 2003-2012

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)

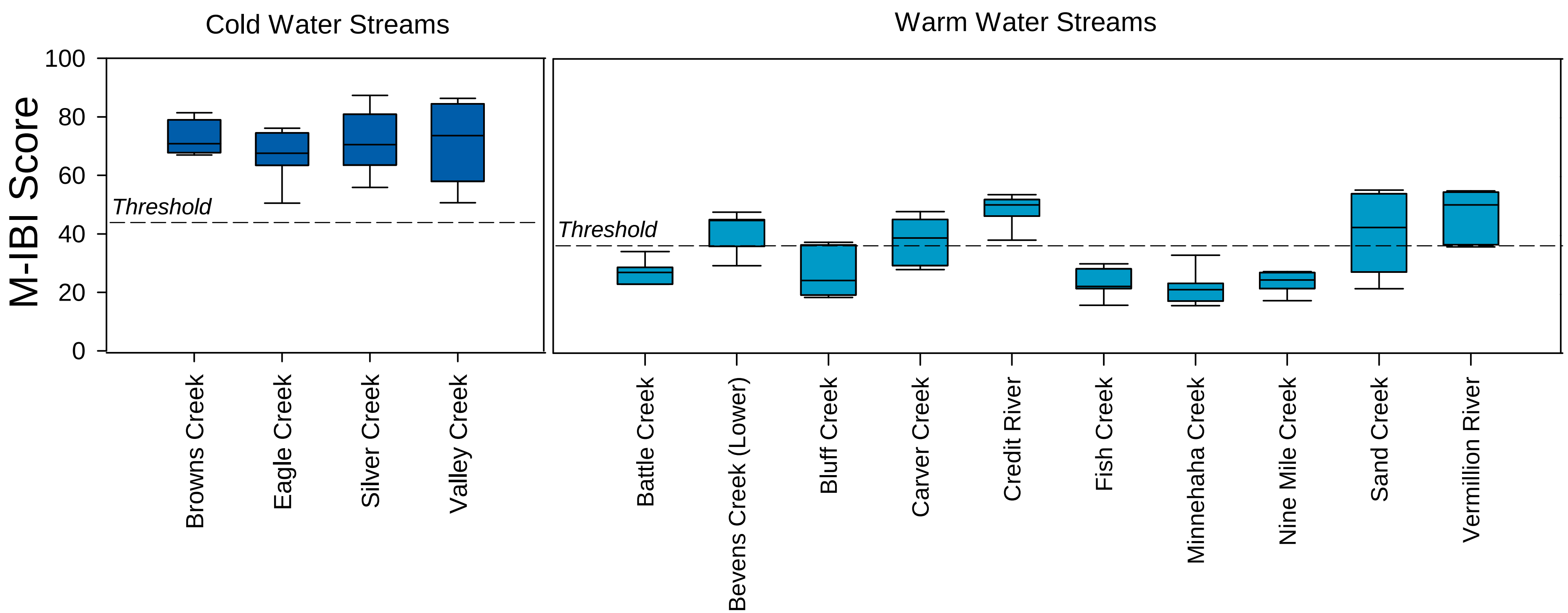
[2] FWM conc = annual flow-weighted mean concentration estimated using Flux32 (Walker, 1999).

[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 SI-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.

Conclusions

Silver Creek is a small tributary to the St. Croix River. The watershed lies entirely in Washington County, and contains runoff from portions of the cities of Stillwater and Grant, and May and Stillwater Townships. The watershed is a mix of agricultural lands, forest and grasslands, and small pockets of low-density, developed areas. There are no major point source contributions to Silver Creek. The watershed topography is fairly steep, culminating with a 50-foot drop, Fairy Falls, into a lower gorge which flows into the St. Croix River. The MCES monitoring station is located 0.1 miles upstream of the convergence with the St. Croix River, near Stillwater, Minnesota. Groundwater springs and seeps flow to the creek between the base of Fairy Falls and the monitoring site.

The water quality in Silver Creek is affected by several factors, including the frequency and intensity of precipitation events, land use activities, the soil infiltration capacity, the ground water quantity and quality, as well as the quality of water in impoundments like Carol Lake and Fairy Pond.

The TSS and phosphorus in Silver Creek (both FWM concentration and annual yield) are low both in comparison with the St. Croix River tributaries and the other MCES-monitored metropolitan area tributaries. The loads and concentrations are influenced by the intensity and duration of storm events. Large storm events flush TSS and phosphorus constituents from the riparian and near-stream areas. Monitoring data indicates the destruction of the beaver dam at the outlet of Fairy Pond in 2002 and subsequent release of water and sediment influenced water quality and pollutant loads that year.

The NO_3 and Cl loads and concentrations are likely driven by aquifer recharge and groundwater quality. Past and current agricultural and septic system discharges may have contaminated the groundwater in the watershed. Applied fertilizers can leach NO_3 from cropland into the regional aquifer. Cl sources can be attributed to road salts, leaking septic systems, or the use of water softeners. The Silver Creek NO_3 and Cl concentrations are similar to the neighboring catchment of Browns Creek (which has similar soils and geology, but greater urban development), but the Silver Creek median annual yields are lower by an order of magnitude. This demonstrates the difference in the amount of groundwater and surface water that contributes to each streams' flow.

The results from the biological monitoring suggest that Silver 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 those collected in 2002 and 2005. The most recent M-IBI scores were above the upper confidence level, indicating that stressors are most likely not negatively affecting the macroinvertebrate community. Overall, the monitoring stream reach habitat and water quality typically were able to sustain the needs for aquatic life.

Currently, Silver Creek is not a MnDNR-designated Class 2A Trout Stream, but if the geomorphology, stream flows, and water quality are adequately improved in the lower reach, the MnDNR's long-term goal is to establish a small population of heritage brook trout in the stream (CMSCWD, 2010). In recent years, the CMSCWD has implemented a large number of projects to improve the ecology and water quality in Silver Creek.

Recommendations

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

- As resources allow, MCES should provide CMSCWD and other local water managers with information about the heightened potential for surface waters to be impacted by groundwater changes in the Silver Creek watershed. This information should be included in watershed and local surface water management plan updates.

- MCES staff should communicate with CMSCWD staff to track alterations to and/or management of the outlet structure of Fairy Pond and other impoundments on the creek to aid in interpretation of changes in flow patterns observed from the monitoring station data.

- WCD and CMSCWD have occasionally collected samples from Silver Creek upstream of the MCES monitoring station. MCES staff should collaborate with WCD and CMSCWD staff to share data to aid in interpreting the Silver Creek WOMP station data.

- MCES and partners (especially CMSCWD, the National Park Service, and WCD) 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 future trend analysis.

- The CMSCWD has completed a number of implementation projects to improve the ecological conditions and water quality of Silver Creek. Due to the flashy nature of Silver Creek flows, the trend analysis software used by MCES (QWTREND) was not appropriate for estimation of trends in the creek. As MCES investigates additional techniques for estimating water quality and flow trends, the Silver Creek data should be re-evaluated.

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

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

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