Comprehensive Water Quality Assessment of Select Metropolitan Area Streams

CARNELIAN-MARINE OUTLET

December 2014

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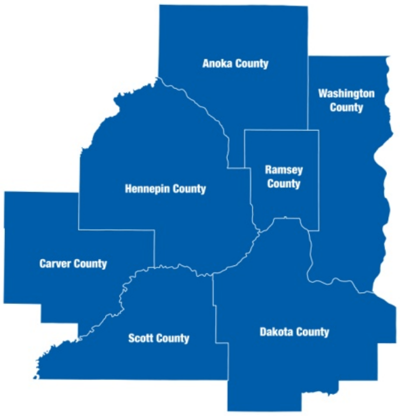

The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system, collects and treats wastewater, coordinates regional water resources, plans and helps fund regional parks, and administers federal funds that provide 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, *Carnelian-Marine Outlet,* is one in a series produced as part of the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams.* Located entirely in Washington County, the Carnelian-Marine Outlet 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 the Carnelian-Marine Outlet.

Cover Photo

The photo on the cover of this section depicts the boat launch at Big Marine Lake near Scandia, Minnesota. It was taken by the Carnelian-Marine St. Croix Watershed District.

Recommended Citations

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Introduction

Carnelian-Marine stream system is located in the eastern metropolitan area and is a tributary to the St. Croix River. It drains approximately 31 square miles of rural-residential, agricultural, and forested lands. The watershed lies entirely in Washington County and includes portions of the city of Scandia, and May and Stillwater townships.

This report:

- documents those characteristics of the Carnelian-Marine Outlet and its watershed most likely to influence stream flow and water quality.
- presents the results from assessments of flow and water quality.
- draws conclusions about possible effects of landscape features, climatological changes, and human activities on flow and water quality.
- compares the Carnelian-Marine Outlet 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 supported water quality monitoring of the Little Carnelian Lake Outlet from 1995 to 2009 as part of its Watershed Outlet Monitoring Program (WOMP). Monitoring was discontinued in 2009 and the station was removed. MCES partnered 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 been responsible for conducting continuous monitoring and collecting water quality samples upstream of Big Carnelian Lake at Ozark Road since 2000 (MPCA Station S004-461).

Monitoring Station Description

The monitoring station was located at the outlet of Little Carnelian Lake near Marine-on-St. Croix, Minnesota, about three miles upstream from the stream confluence with the St. Croix River, which is located just north of the city of Stillwater near the historic Boomsite. The stream flows from the outlet of Little Carnelian Lake and drains a large Washington County chain of lakes.

The monitoring station included continuous flow monitoring (ISCO Bubbler), baseflow grab sample collection, and a tipping bucket rain gauge (Texas Electronics). Composite samples for water chemistry analysis were not collected at this station because runoff events tended to be long and attenuated by the large lake volume, and therefore easily characterized by grab samples. The rain gauge at this monitoring station did collect rainfall data; however, supplemental winter precipitation data were obtained from the Minnesota Climatology Working

Group and the National Weather Service Cooperative Observer Program sites: Stillwater Station Number 218037, Stillwater Station Number 218039, and the New Richmond Station Number 475948.

Figure CM-1: Boat Launch on Big Carnelian Lake

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.

The Carnelian-Marine Outlet did not flow in 2007 and 2009. The monitoring site was discontinued after 2009.

Stream and Watershed Description

The Carnelian-Marine watershed lies entirely in Washington County, has a drainage area of approximately 31 square miles, and is located within Metropolitan Council Districts 11 and 12. The Carnelian-Marine Outlet stream drains a series of lakes, beginning with the headwater lake, Big Marine. The stream generally flows to the south-southeast from the city of Scandia with a channel length of 12.25 miles. It flows through seven major water bodies before entering the terminal lake, Little Carnelian. The Little Carnelian Lake outlet empties into a drainage pipe. The pipe discharges the flow to a rocky drainage channel near the intersection of Arcola Trail and Hwy 95, just north of the city of Stillwater. The channel discharges to the St. Croix River near the historic Boomsite.

In addition to the Carnelian-Marine Outlet stream, there are many other open water bodies within the watershed. Fish Lake (50 acres), Long Lake (45 acres), Big Marine Lake (1,799 acres), Mud Lake (62 acres), and Turtle Lake (32 acres) are in the northern part of the watershed. Bass Lake (26 acres), East and West Boot Lakes (47 and 50 acres, respectively), Big Carnelian Lake (457 acres), and Little Carnelian Lake (157 acres) are in the southern part of the Carnelian-Marine watershed.

The Carnelian-Marine watershed encompasses a total of 19,707 acres, of which 17,880 acres (90.7%) is upstream of the monitoring station (Figure CM-2; Table CM-1). The watershed is 16.9% agricultural land (15.8% within the monitored area) and 12.6% developed urban land (11.9% within the monitored area). The primary land covers in the watershed are forest, open water (including Big and Little Carnelian Lakes and Big Marine Lake), grasses/herbaceous, and wetlands. The urbanized land includes portions of the cities of Scandia and Hugo.

Based on the U. S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) 2009 Cropland Data Layer, of the agricultural land, 12% is planted in corn (13% monitored area) and 14% in soybeans (15% monitored area). According to a statewide estimate of potentially draintiled fields by University of Minnesota researchers, less than 0.1% of the agricultural land in the watershed is drain tiled (D. Mulla, University of Minnesota, personal communication, 2012).

Table CM-1: Carnelian-Marine Watershed Land Cover Classes[1]

Land Cover Class	Monitored		Unmonitored		Total	
	Acres	Percent	Acres	Percent	Acres	Percent
5-10% Impervious	332	1.9%	26	1.4%	358	1.9%
11-25% Impervious	1,267	7.1%	264	14.4%	1,531	7.8%
26-50% Impervious	236	1.3%	5	0.3%	241	1.2%
51-75% Impervious	5	<0.1%	3	0.1%	8	<0.1%
76-100% Impervious	298	1.7%	42	2.3%	340	1.7%
Agricultural Land	2,833	15.8%	501	27.4%	3,334	16.9%
Forest (all types)	4,222	23.6%	358	19.6%	4,580	23.2%
Open Water	2,648	14.8%	0	<0.1%	2,648	13.4%
Barren Land	9	<0.1%	0	<0.1%	9	<0.1%
Shrubland	7	<0.1%	0	<0.1%	7	<0.1%
Grasses/Herbaceous	3,491	19.5%	617	33.8%	4,108	20.8%
Wetlands (all types)	2,532	14.2%	12	0.6%	2,544	12.9%
Total	**17,880**	**100.0%**	**1,827**	**100.0%**	**19,707**	**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 Carnelian-Marine watershed was last glaciated during the Wisconsin Glaciation (approximately 20,000 years ago. As the glacier retreated it exposed the limestone, dolomite, sandstone, and shale bedrock. The glaciers deposited till that created the St. Croix moraine, most notably in the vicinity of Scandia and in the west-central portion of the watershed. Additionally, the majority of the lakes in the watershed were formed as the glaciers retreated. Kettle lakes − like Big Marine, Long, Big Carnelian, and Little Carnelian Lakes − were created as blocks of ice fell from the glaciers and were surrounded by glacier outwash (Patterson *et al.*, 1990). The ice melted and the lakes were formed.

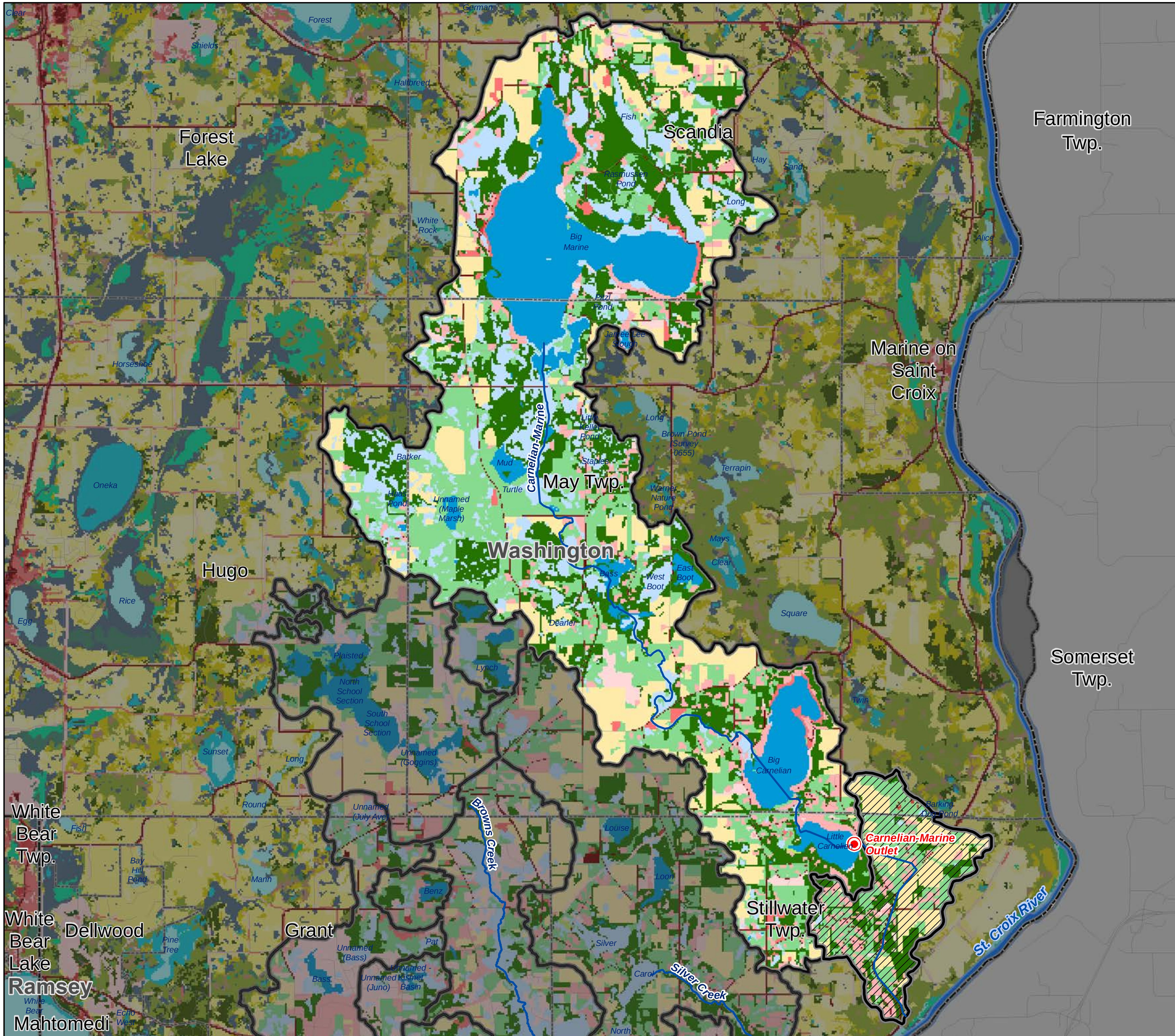
Nearly all of the soils in the Carnelian-Marine watershed are glacier outwash-associated loamy sands or silty loams. According to the U. S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) STATSGO soils data, 8% of these soils are characterized as Type A and 85% of these soils are B soils, which have low or moderately low runoff potentials, respectively (USDA, 2009). The Type A and B soils are primarily found in the lowest elevations of the watershed. The stream channel and lake beds are 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. For installation of infiltration practices, soil borings should be taken from the exact location of the proposed site location to assess level of soil filling or disturbance.

The watershed topography ranges from moderate in the upstream end to moderately steep upstream of the monitoring station, with the landscape punctuated by a series of lakes (Figure CM-3). From the monitoring station at the outlet to Little Carnelian Lake, outflow outlet is piped to the St. Croix River. The maximum watershed elevation is 1060.8 above mean sea level (MSL) and the minimum elevation is 830.1 MSL within the monitored area. Within the monitored area, 4% of the slopes are considered steep, and an additional 1% is 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 8.4 feet/mile.

Figure CM-2

MLCCS-NLCD Hybrid Land Cover

Carnelian-Marine Outlet



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
Carnelian-Marine

Land Cover Class	Monitored Acres	Percent	Unmonitored Acres	Percent	Total Acres	Percent
5-10% Impervious	332	1.9%	26	1.4%	358	1.8%
11-25% Impervious	1,267	7.1%	264	14.4%	1,531	7.8%
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Total	**17,880**	**100.0%**	**1,827**	**100.0%**	**19,707**	**100.0%**

0 0.5 1 1.5 2 2.5 3
Miles

The Carnelian-Marine watershed is relatively undeveloped, with agricultural lands, hobby farms, and rural-residential developments. There is one Minnesota Pollution Control Agency (MPCA) permitted point-source discharger within the watershed (Figure CM-4 and Table CM-2). The Carnelian Hills Community is the permit holder of a Class D domestic discharge facility. These facilities tend to be settling ponds with no mechanical wastewater treatment. There are no cooling, potable water, and dewatering facilities, or industrial stormwater or wastewater facilities in the watershed. The watershed has three registered feedlots with a total of 140 animal units (AUs) within the monitored part of the watershed, and an additional two feedlots with a total of 209 AUs in the unmonitored part of the watershed. No feedlots within the monitored part of the watershed have over 100 AUs, and only one feedlot in the unmonitored part of the watershed has over 100 AUs, with 120 AUs (Figure CM-4).

Table CM-2: Permitted Domestic Wastewater Treatment Facilities Discharging to the Carnelian-Marine Stream

Permit #	Permit Holder	Design Flow (mgd)	Class[1]	Phosphorus removal	General Notes
MN0063665	Carnelian Hills Community - May Township	0.022	D	NA	NA

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

The rural-residential nature of the Carnelian-Marine 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).

The Carnelian-Marine St. Croix Watershed District (CMSCWD) has led and funded many watershed improvement projects in the catchment. The largest project occurred in early 1980s, when localized flooding was frequent in the northern part of the watershed. This motivated the Carnelian-Marine Watershed District to connect the Big Marine Lake drainage area with the St. Croix River via a 15,000-foot gravity pipe (Emmons & Olivier Resources, Inc., 2010). This project created the Carnelian-Marine Outlet structure that was the location of the MCES monitoring site. More recently, the CMSCWD has been involved in the installation of raingardens and other water improvement features to improve the quality of the waters in their district. To see a complete list of projects and plans, please see CMSCWD's website.

Figure CM-3

METROPOLITAN COUNCIL

Watershed Topography

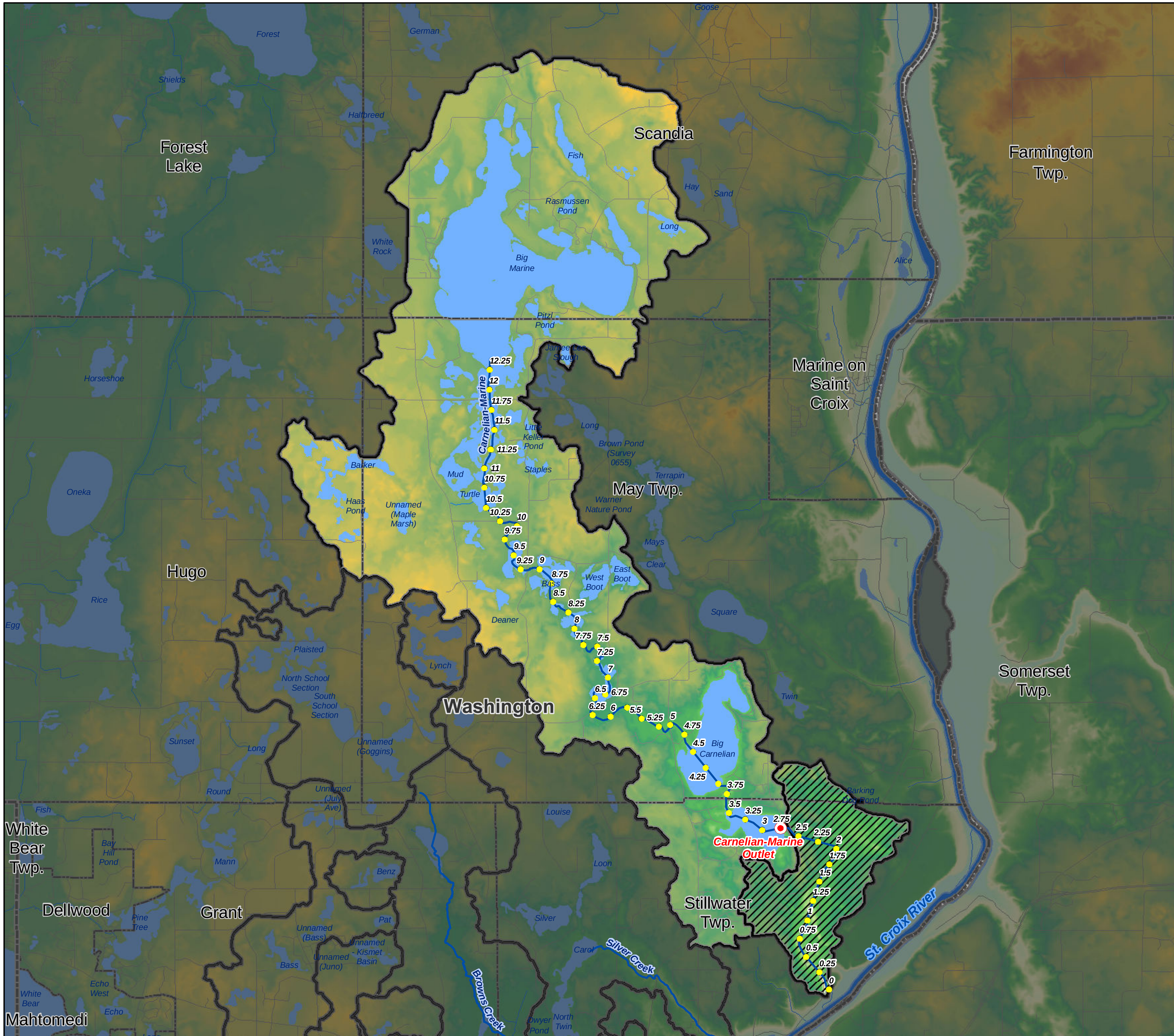
Carnelian-Marine Outlet

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

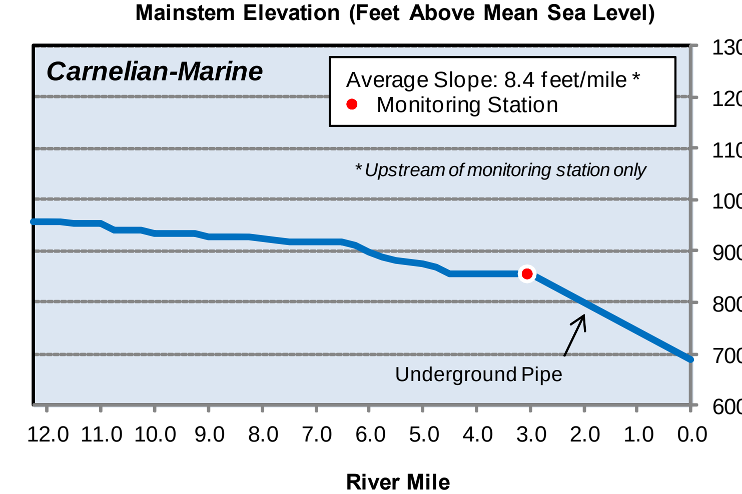
Elevation
Feet Above Mean Sea Level

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 2 2.5 3 3.5

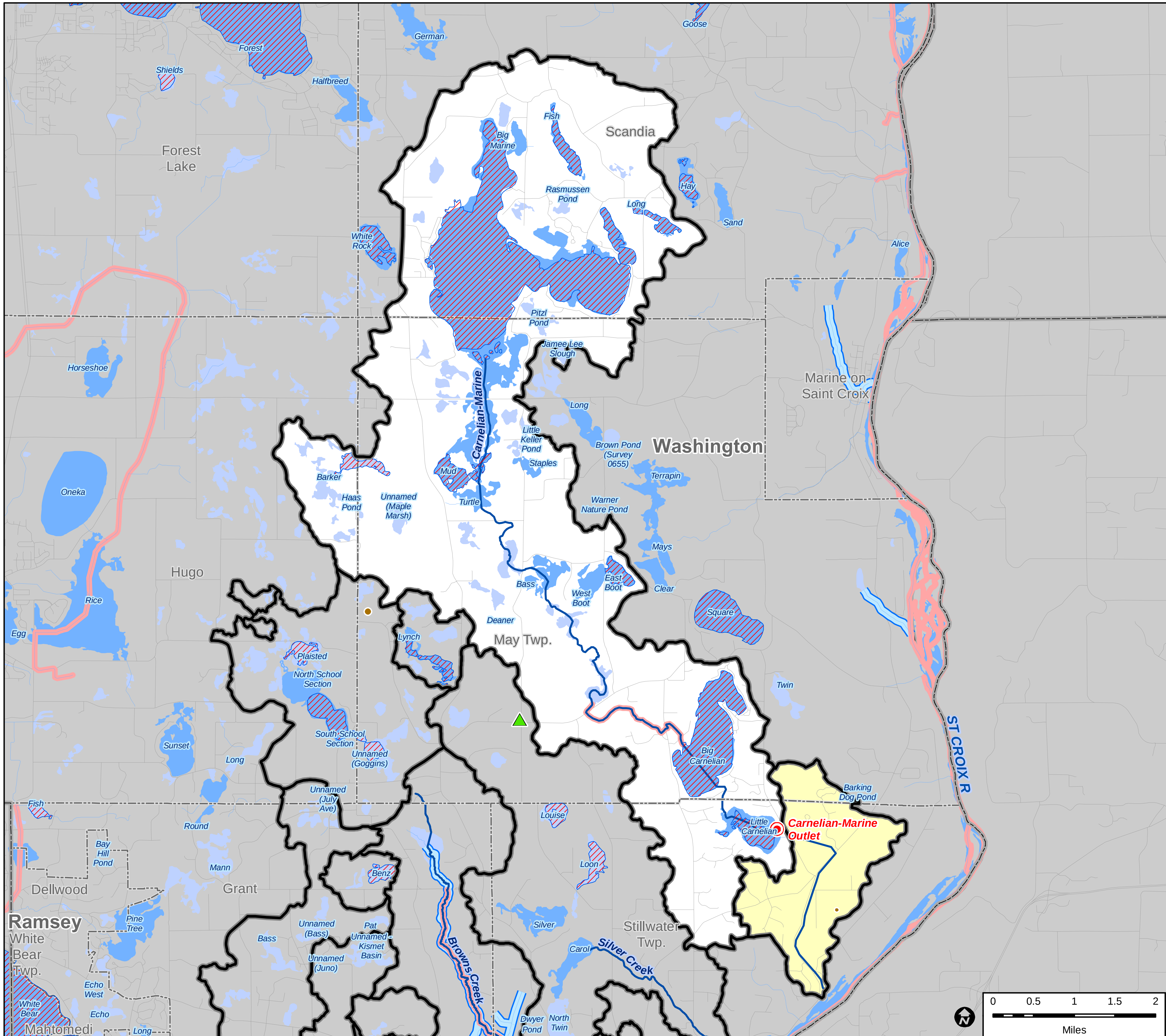
Miles

Figure CM-4

METROPOLITAN COUNCIL

Public and Impaired Waters and Potential Pollution Sources

Carnelian-Marine



- 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

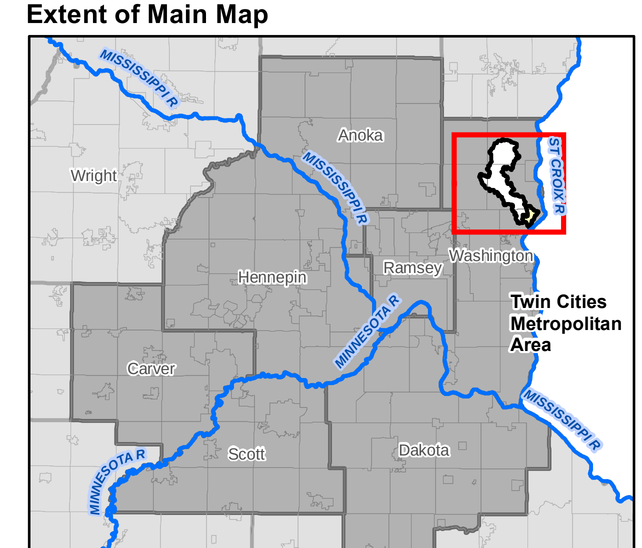
Feedlots with 100 or more animal units **

- 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 Boundaries
- City and Township Boundaries

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

Extent of Main Map



Water Quality Impairments

The Carnelian-Marine watershed contains one stream reach and nine lakes that are included on the MPCA 2014 303d (Impaired Waters) list (Tables CM-3 and CM-4, Figure CM-4). The reach of the Carnelian-Marine stream from the unnamed lake to Big Carnelian Lake is impaired for aquatic recreation and aquatic life due to high levels of bacteria, turbidity, and low scores on the fish bioassessment. Barker Lake, East Boot Lake, Fish Lake, Jellums Lake, Long Lake, and Mud Lake are all impaired for aquatic recreation due to high levels of nutrients. Big Carnelian, Big Marine, and Little Carnelian Lakes are impaired for aquatic consumption due to mercury in fish tissue.

Table CM-3: Carnelian-Marine Watershed Impaired Stream Reaches as Identified on the MPCA 2014 Impaired Waters List

Reach Name	Reach Description	Reach ID	Affected Uses[1]	Approved Plan	Needs Plan[2]
Unnamed creek	Unnamed lake to Big Carnelian Lake	07030005-601	AQL, AQR	--	*E. coli*, T, F-IBI

[1] AQR = aquatic recreation; AQL = aquatic life; [2] T = turbidity; F-IBI = fisheries bioassessments

The U. S. Environmental Protection Agency (USEPA) approved the CMSCWD's multi-lake TMDL (Total Maximum Daily Load study) Implementation Plan in 2012 to address the nutrient impairments (Emmons & Olivier Resources Inc. et al., 2012). The majority of suggestions include fisheries management, private and public projects, and an educational outreach component. In 2007, the MPCA authored the statewide TMDL Implementation Plan to address mercury impairments. As of the writing of this report, CMSCWD has not yet addressed the stream impairment.

Table CM-4: Carnelian-Marine Watershed Impaired Lakes as Identified on the MPCA 2014 Impaired Waters List

Lake Name	Lake ID	Affected Use(s)[1]	Approved Plan[2]	Needs Plan[2]
Barker	82-0076-00	AQR	--	Nutrients
Big Carnelian	82-0049-00	AQC	HgF	--
Big Marine (Main Lake)	82-0052-04	AQC	HgF	--
East Boot	82-0034-00	AQR	Nutrients	--
Fish	82-0064-00	AQR	Nutrients	--
Jellums	82-0052-02	AQR	Nutrients	--
Little Carnelian	82-0014-00	AQC	HgF	--
Long	82-0068-00	AQR	Nutrients	--
Mud (Main Lake)	82-0026-02	AQR	Nutrients	--

[1] AQC = aquatic consumption; AQR = aquatic recreation; [2] HgF = mercury in fish tissue

Hydrology

MCES monitored flow at the Carnelian-Marine Outlet at Little Carnelian Lake in Stillwater Township, Minnesota, from 1996 to 2009. Flow measurements were collected at 15-minute intervals and converted to daily averages. The hydrograph of the Carnelian-Marine Outlet, which displays daily average flow, daily precipitation, and the flow associated with grab and composite samples, indicates the variations in flow rates from season to season and from year to year (Figure CM-5), and the effect of precipitation events on flow.

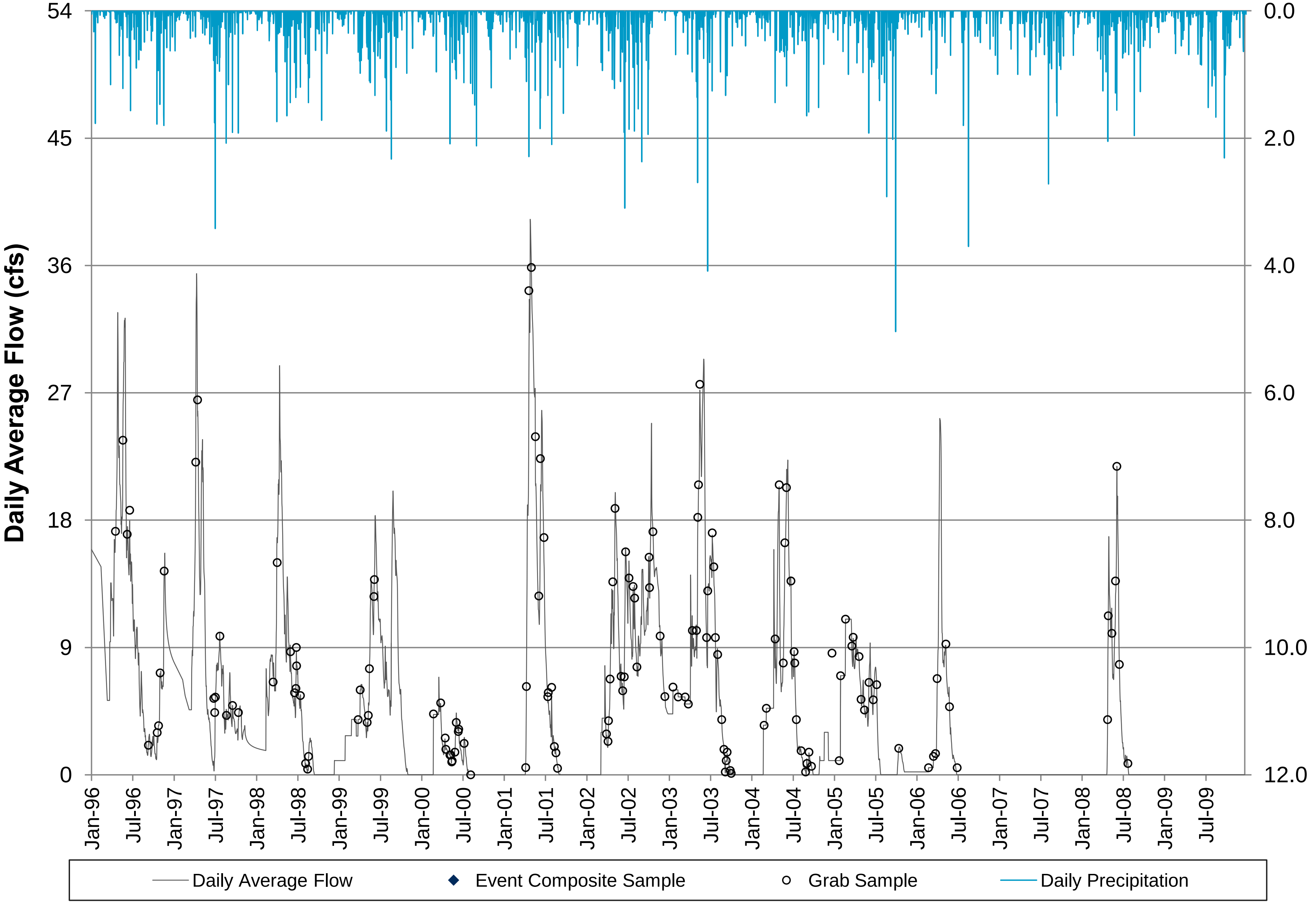
The MCES sampling program specifies collection of baseflow grab samples between events and event-based composites. The hydrograph indicates samples were collected during most events and that baseflow was also adequately sampled.

The Carnelian-Marine Outlet hydrograph is characteristic of a lake-fed stream system (Figure CM-5). Generally, the storm event daily average flows were less than 27 cubic feet per second (cfs); six spring rains or snowmelt driven events exceeded this level from 1996 to 2003. Of those events, the highest recorded daily average flow was 39.3 cfs, which occurred in 2001. The mean average daily flow was 4.8 cfs, and the median average daily flow was 1.7 cfs. Due to the dependence on lake levels and outflows, the Carnelian-Marine Outlet did not flow during prolonged dry periods, as seen in 2007-2009. Additionally, the flows were greatly reduced during the winter months and often did not flow at all. The lowest recorded average daily flow was 0 cfs.

Flow duration analysis of daily average flows indicates the upper 10^{th} percentile flows for period 1995-2009 ranged between approximately 14.8-39.3 cfs, while the lowest 10^{th} percentile flows were 0 cfs due to the lack of flow (see Figure CM-12 in the ***Flow and Load Duration Curves*** section of this report).

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 affect the stream as surface run off or overland flows. During the years 1996-2009, the average runoff ratio was 0.07, indicating an average of 93% of the precipitation either was stored in lake, wetland, or pond volumes, infiltrated the soils, evaporated off the surface, or was evapotranspirated by vegetation. As mentioned in the stream and watershed description, the Carnelian-Marine watershed soil types (Type A and B) facilitate high or moderately high infiltration. Given this characteristic and the recent regional trend of low lake levels, unless the precipitation input was very high, like rapid snowmelt events, very little water flowed out of the Carnelian-Marine Outlet.

Figure CM-5: Carnelian Marine Outlet Daily Average Flow, Sample Flow, and Precipitation, 1996-2009*



*Station was primarily dry during 2007-2009 and was discontinued after 2009; 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.

To assess the vulnerability of Carnelian-Marine watershed 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 the Carnelian-Marine stream system and the lakes along the flowpath were identified as potentially vulnerable, including Big Marine, Mud, Turtle, Bass, Big Carnelian, and Little Carnelian lakes. Several additional basins within the watershed were identified as vulnerable to groundwater withdrawals, including Barker Lake, East and West Boot Lakes, and Fish Lake, plus a number of surrounding smaller unnamed wetlands. This information reinforces and builds on the conclusions of a previous study funded by the CMSCWD and prepared by the Minnesota Geological Survey and the University of Minnesota. Alexander and others (2001) used piezometers, water chemical composition, and spatial analysis to show that the major lakes in the Carnelian-Marine watershed and the Carnelian-Marine stream all had varying degrees of groundwater contributions to their waters.

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 Carnelian-Marine Outlet (1996-2009). Figures CM-6 through CM-9 illustrate annual loads expressed as mass, as flow-weighted mean (FWM) concentration, as mass per unit of area (lb/ac), and as mass per unit of area per inch of precipitation (lb/ac/in), as well as 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 Carnelian-Marine Outlet loads and FWM concentrations with the other MCES-monitored metropolitan area tributaries.

The first charts in Figures CM-6 and CM-7 plot the annual flows from 1996-2012. The highest average annual flow, and thus the highest volume of flow, occurred during 1996 (approximately 10.6 cfs average annual flow); the lowest average annual flow, and lowest volume of flow, occurred in 2007 and 2009 (there was no average annual flow in either year). Over the full record, the mean and median average annual flows were 4.71 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 2007. The outlet only flowed for one event in 2008, so this data point should be used cautiously. The station was discontinued after 2009.

The annual mass loads for all of the analytes exhibit some year-to-year variation, but generally mirror the pattern in annual flows (Figure CM-6). Monitoring for TSS, TP, and TDP began in 1996. These pollutants are shown to have the highest loads in 1999. NO_3 and NH_3 monitoring began in 2001, and Cl monitoring began in 2002. These pollutants had a maximum annual load in 2002. Not including the 2008 load, every graph shows the lowest loads (when there was flow) occurred in 2006.

The annual FWM concentrations provide greater insight to the loading dynamics in the Carnelian-Marine watershed. Stream systems like the Carnelian-Marine stream, with in-line lakes, are expected to have fairly consistent annual FWM concentrations, as the lakes along the stream path can serve to settle out pollutants carried in the flows. Generally, the graphs shown in CM-8 follow this expectation. There were some occurrences with higher annual FWM concentrations. TSS had the peak FWM concentration in 1999, most likely due to a flushing storm event. The TP and TDP had peak FWM concentrations in 2000, most likely due to evapoconcentration, as this period coincided with the lowest non-zero recorded annual flows. FWM NO_3 and NH_3 concentrations showed high intra-annual variability that seems to be independent of flows. The Cl FWM annual concentrations maintained relatively steady concentrations over the period of record.

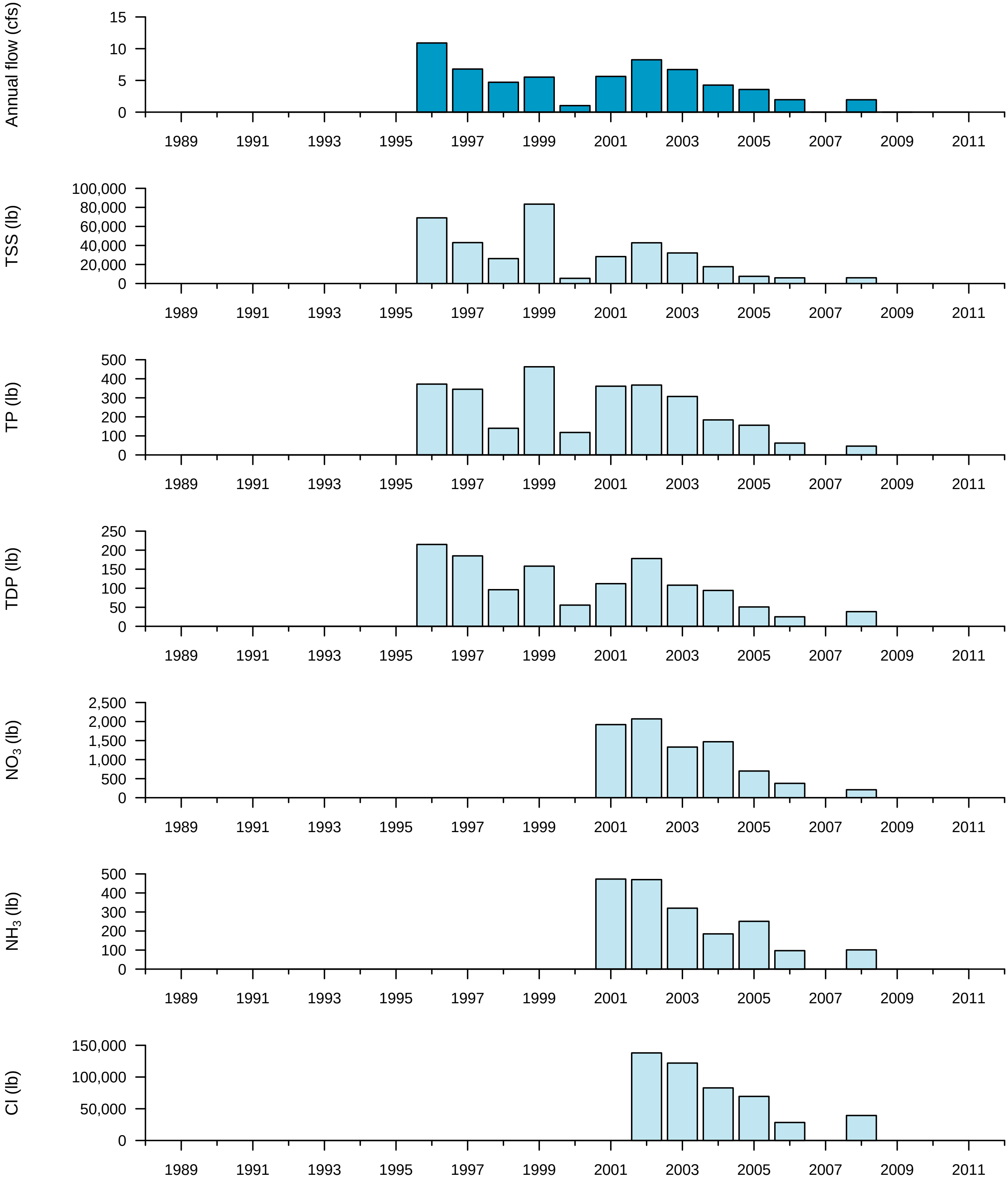
Figures CM-8 and CM-9 present the areal- and precipitation-weighted loads, respectively. These graphics are presented to assist local partners and watershed managers, and will not be discussed here.

The Flux32 loads and FWM concentrations were also compiled by month to allow analysis of time-based patterns in the loads in the Carnelian-Marine stream (Figure CM-10 and CM-11). The results for each month are expressed in two ways: the monthly results for the most recent year of collection (2009 for Carnelian-Marine) and the monthly average for 2000-2009 (with a bar indicating the maximum and minimum value for that month). Unfortunately, Carnelian-Marine Outlet did not flow during the final year of monitoring, leaving only the 10-year averages on the figures.

The Carnelian-Marine Outlet 10-year average loads of all pollutants demonstrate peak month loads in the late spring months of April and May (Figure CM-10). The loads decreased over the remaining months of the year, and did not show much variation in the mean values. Most likely, the spring snowmelt created high flow conditions causing Little Carnelian Lake to discharge excess water that transported pollutants. The lack of variation for the remainder of the year may be attributed to lower flow conditions and the settling nature of lake waters. As the Carnelian-Marine stream enters Little Carnelian Lake, the velocity of the water is greatly reduced. This allows the suspended particulates, primarily associated with TSS and TP, to settle out of the water column. The internal nutrient cycling in a lake utilizes and produces some dissolved and particulate pollutants, but most often they become entrained in the lake waters and do not exit the lake until the next high flow condition.

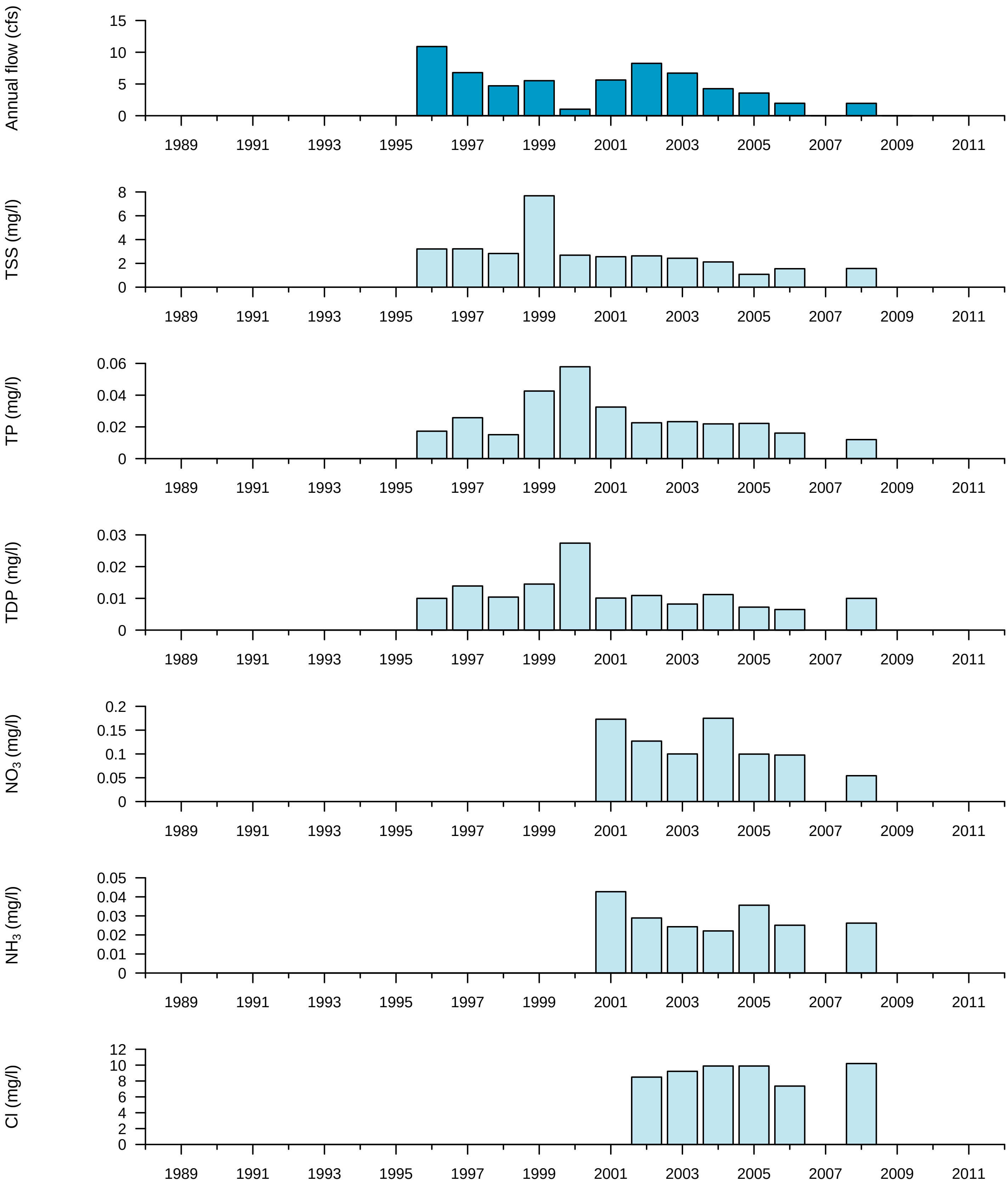
The FWM monthly average concentrations confirm the loads were more driven by flows than concentrations. All of the pollutants demonstrate inter-annual variation in concentrations, but the months with peak concentrations did not align with the months of greatest loading (Figure CM-11). The TSS FWM monthly average is greatest in August, and may be attributed to algal cells transported from Little Carnelian during late summer/early fall storm events. Both TP and TDP showed peak FWM monthly average concentrations in February that declined and had little variation for the remainder of the year. The variation in the NO_3 FWM 10-year average concentration was most likely due to in-lake biological uptake. It is apparent that the highest 10-year average NH_3 FWM concentration occurred in March, and coincided with a decrease in Cl FWM concentration. A possible explanation for this could be the snowmelt flushing of terrestrial NH_3 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 outlet. The remainder of the year had low levels of NH_3 concentration. The March Cl decrease may be due to a dilution effect as the spring snowmelt enters the lake.

Figure CM−6: Carnelian Marine*
Annual Mass Load



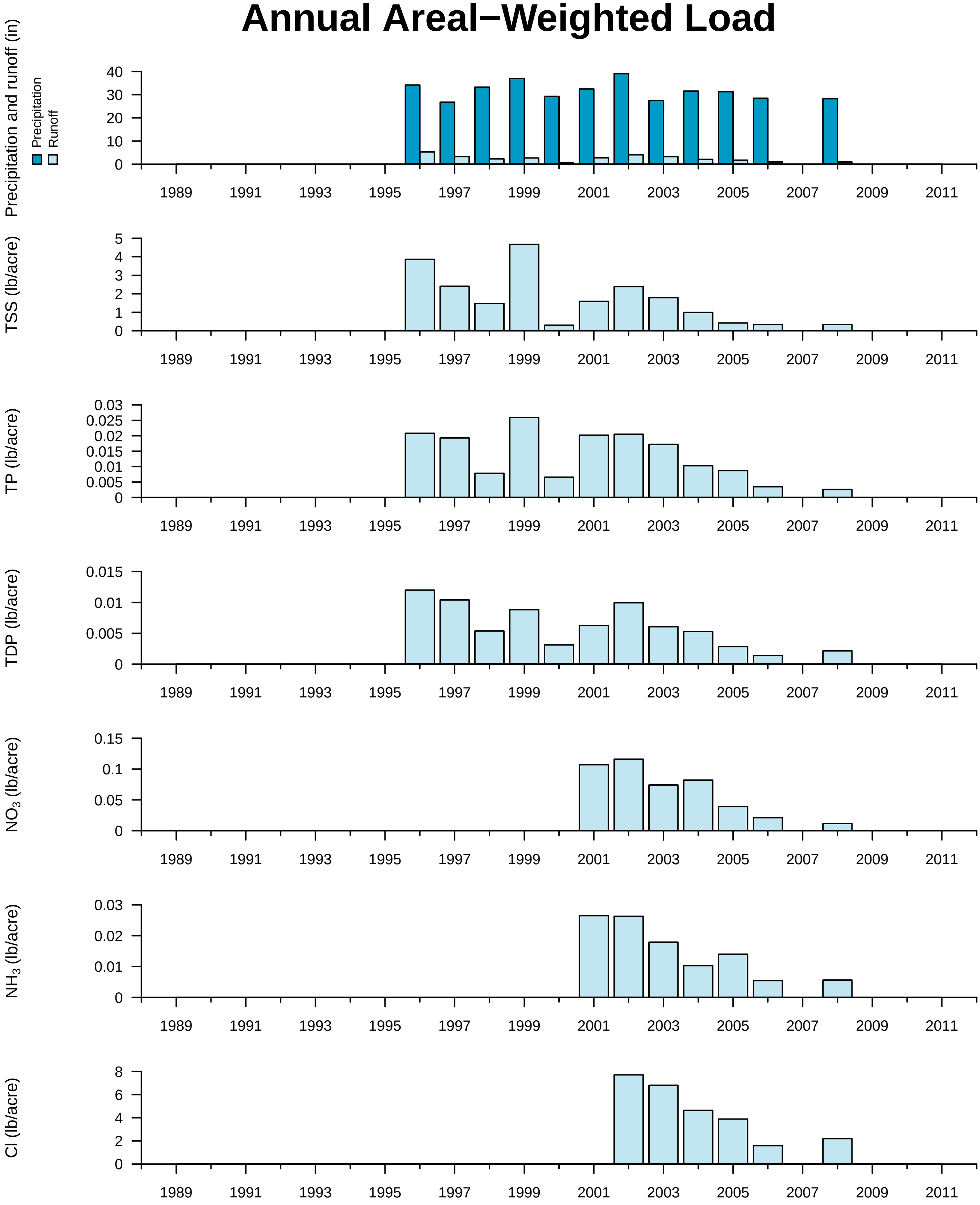
*TSS, TP, and TDP sampling began in 1996, NO3 and NH3 began in 2001, and Cl began in 2002.
No discharge from outlet in 2007 or 2009. Station was discontinued after 2009.
Loads were calculated by hand rather than in Flux32 so no confidence intervals exist.

Figure CM−7: Carnelian Marine*
Annual Flow−Weighted Mean Concentration



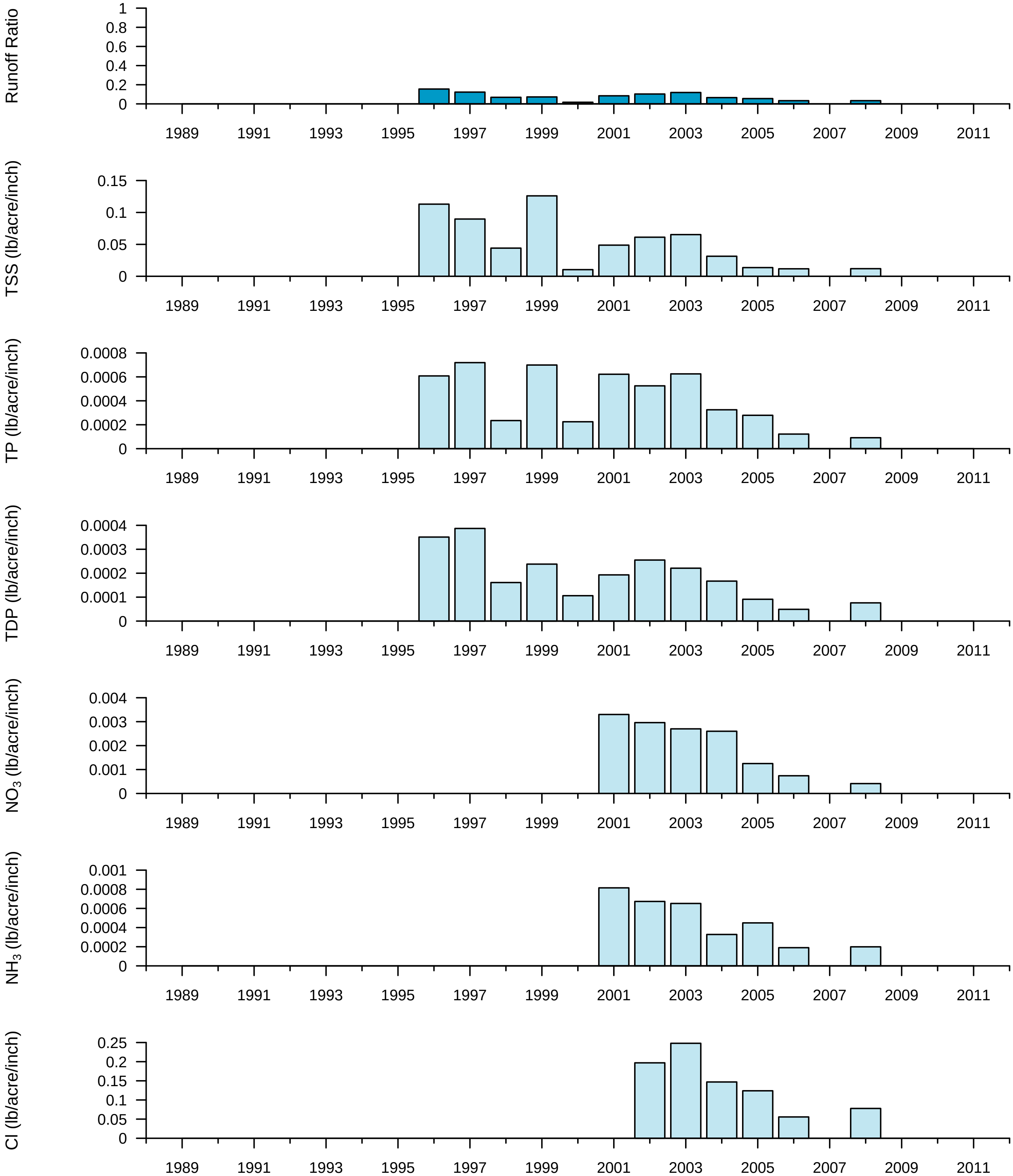
*TSS, TP, and TDP sampling began in 1996, NO3 and NH3 began in 2001, and Cl began in 2002.
No discharge from outlet in 2007 or 2009. Station was discontinued after 2009.

Figure CM−8: Carnelian Marine*
Annual Areal−Weighted Load



*TSS, TP, and TDP sampling began in 1996, NO3 and NH3 began in 2001, and Cl began in 2002.
No discharge from outlet in 2007 or 2009. Station was discontinued after 2009.

Figure CM−9: Carnelian Marine*
Annual Precipitation−Weighted Areal Load



*TSS, TP, and TDP sampling began in 1996, NO3 and NH3 began in 2001, and Cl began in 2002.
No discharge from outlet in 2007 or 2009. Station was discontinued after 2009.

Figure CM−10: Carnelian Marine Mass Load by Month

Most Recent Year (2009) of Data Compared to 2000−2009 Average

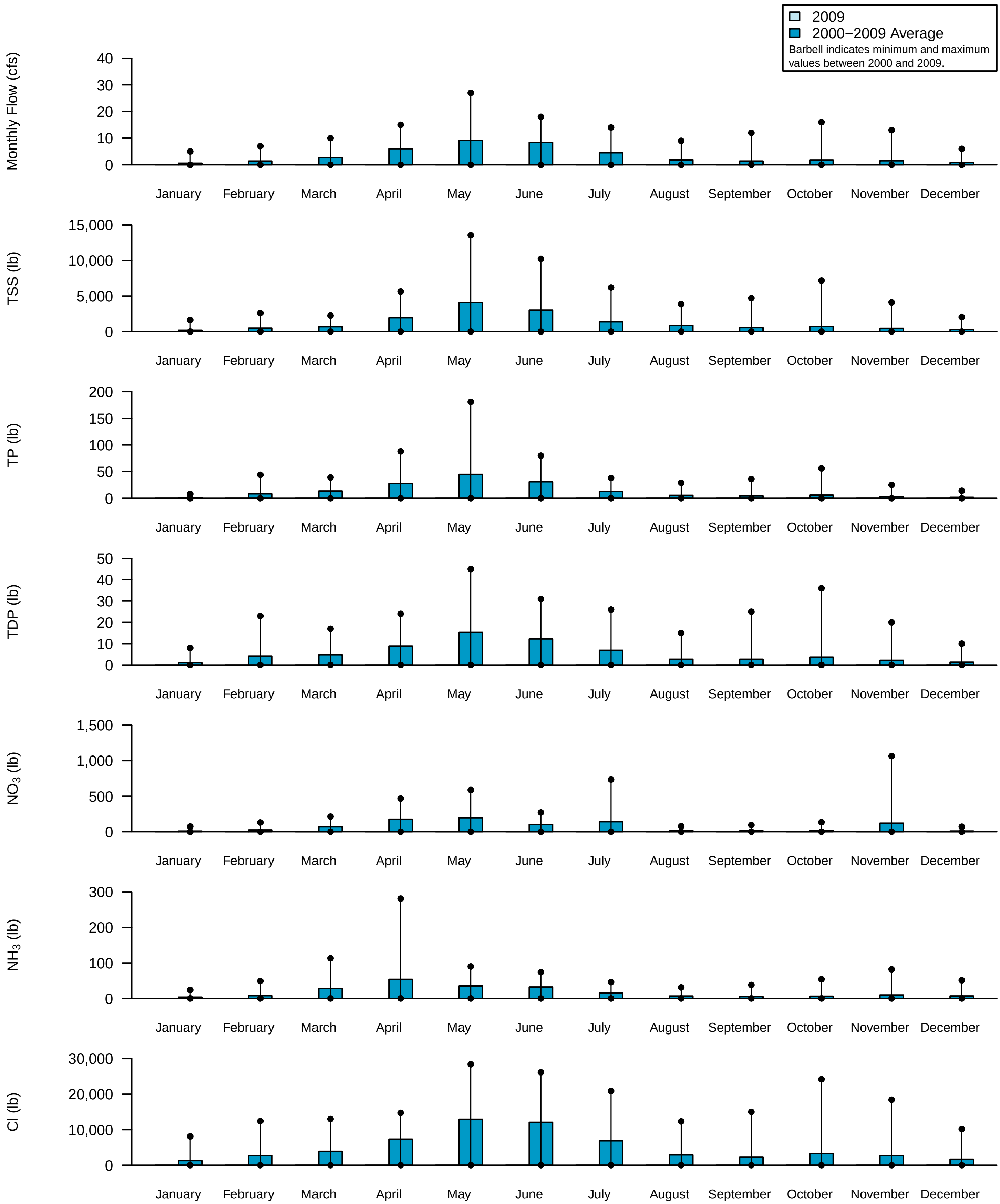
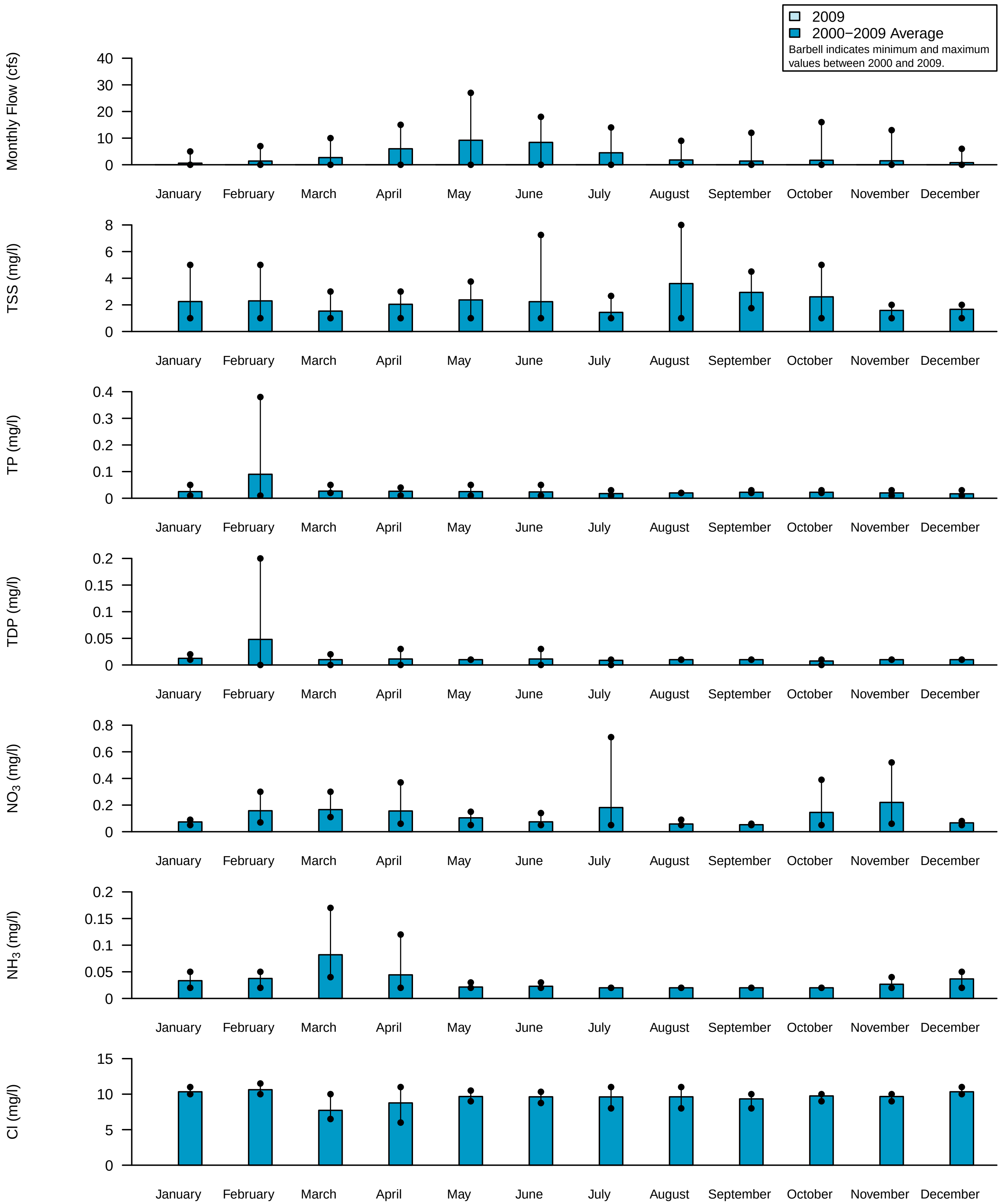


Figure CM−11: Carnelian Marine Flow−Weighted Mean Concentation by Month

Most Recent Year (2009) of Data Compared to 2000−2009 Average



Flow and Load Duration Curves

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

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

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

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

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

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

The 1995-2009 flow duration curve and load duration curves for TSS, TP, NO_3, and Cl for the Carnelian-Marine Outlet monitoring station (mile 3.0, at Little Carnelian Lake Outlet) is shown in Figure CM-12. 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 14.8-39.3 cfs, while the lowest 10^{th} percentile flows were 0 cfs due to the lack of flow. The lowest percentile flow above zero (0.0005 cfs) did not begin until the percentile rank of 36%. The flattened curve in the High Flow category indicates that when high flows occurred, they lasted for longer periods of time, usually attributed to lake overflows. The lack of a line in the Low Flow and much of the Dry Condition categories indicates that the Carnelian-Marine Outlet does not maintain flows throughout the year, which can be attributed to the low lake levels, reducing/restricting stream flow.

Table CM-5: Carnelian-Marine Stream Beneficial Use and River Nutrient Region (RNR) Classifications and Pollutant Draft Standards

Monitoring Station	Use Classification[1] for Domestic Consumption (Class 1) and Aquatic Life and Recreation (Class 2)	River Nutrient Region (RNR)[2] of Monitoring Station	Cl Draft Stnd[3] (mg/l)	TSS Draft Stnd[4] (mg/l)	TP Draft Stnd[5] (ug/l)	NO_3 DW Stnd[6] (mg/l)
Carnelian-Marine Outlet at Little Carnelian Lake (CM3.0)	2B	Central	230	30	100	10

[1] Minn. Rules 7050.0470 and 7050.0430.

[2] MPCA, 2010.

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

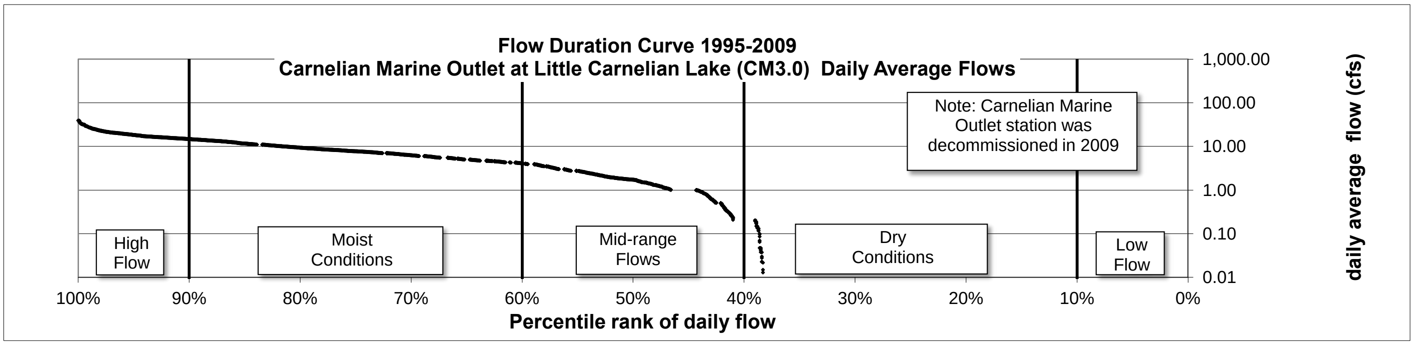
[4] MPCA, 2011a. Draft standard states TSS standard concentration for Class 2A and 2B water must not be exceeded more than 10% of the time over a multiyear data window, with an assessment period of April through September.

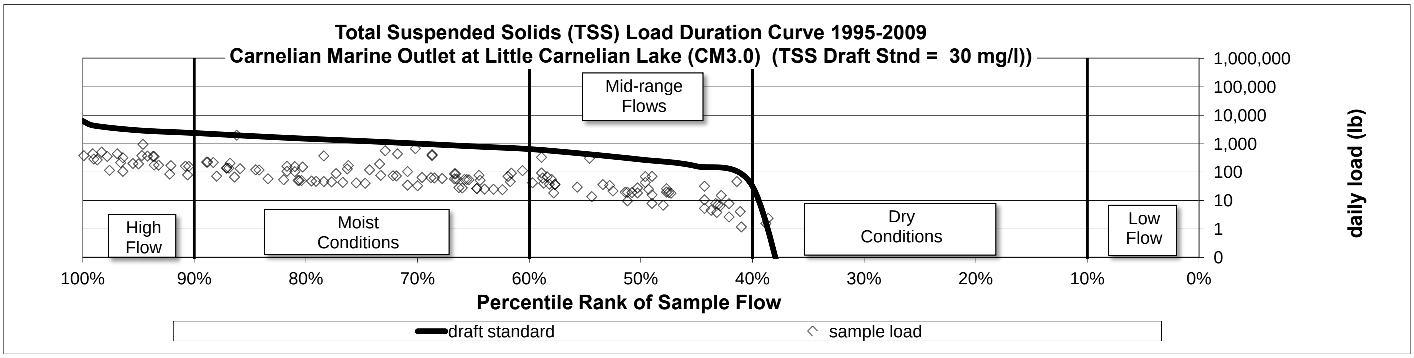
[5] MPCA, 2013. To violate the standard, concentration of causative variable (TP) must be exceeded, as well as one or more response variables: sestonic chlorophyll, BOD_5, DO flux, and/or pH.

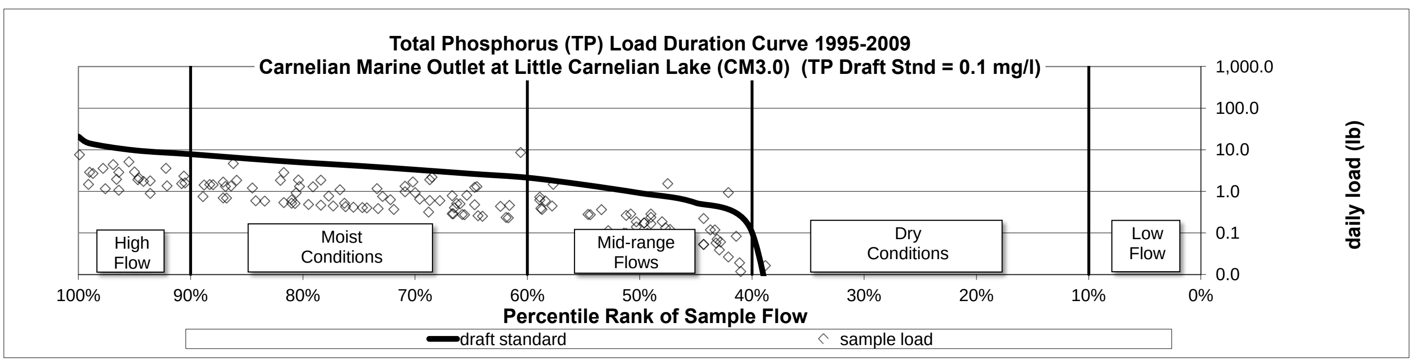
[6] MCES used the NO_3 drinking water standard of 10 mg/l pending results of USEPA toxicity tests and establishment of a draft NO_3 standard for rivers and streams.

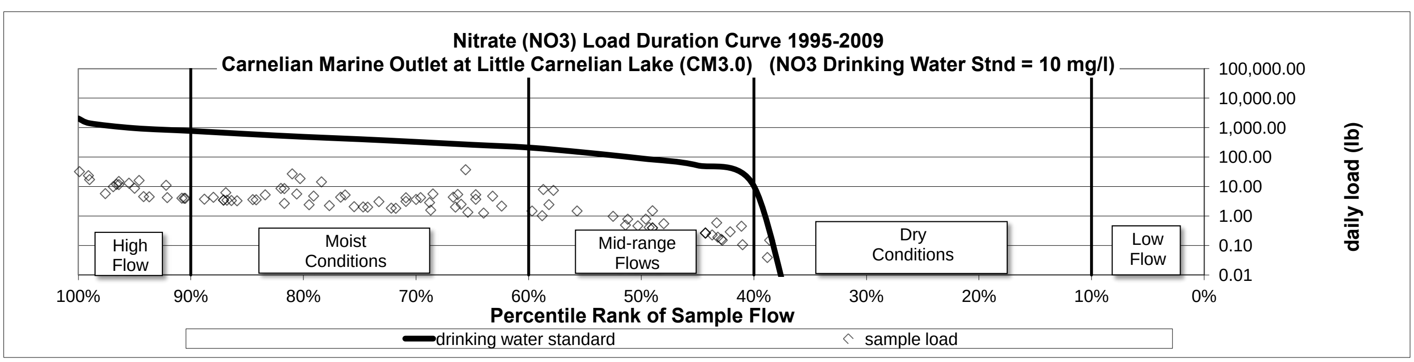
The load duration curves provide insight as to how flow conditions affect the stream loads compliance with state standards. As expected from lake outflows, the concentrations of pollutants were fairly consistent independent of flow rates. At all flow conditions, the Carnelian-Marine stream loads were at or below the loads dictated by the draft standards for TSS, TP, Cl, and the drinking water standard for NO_3. There were three TP points that fell above the draft standard line, but they were the exception, not the norm. They can be attributed to some natural variation in TP concentrations.

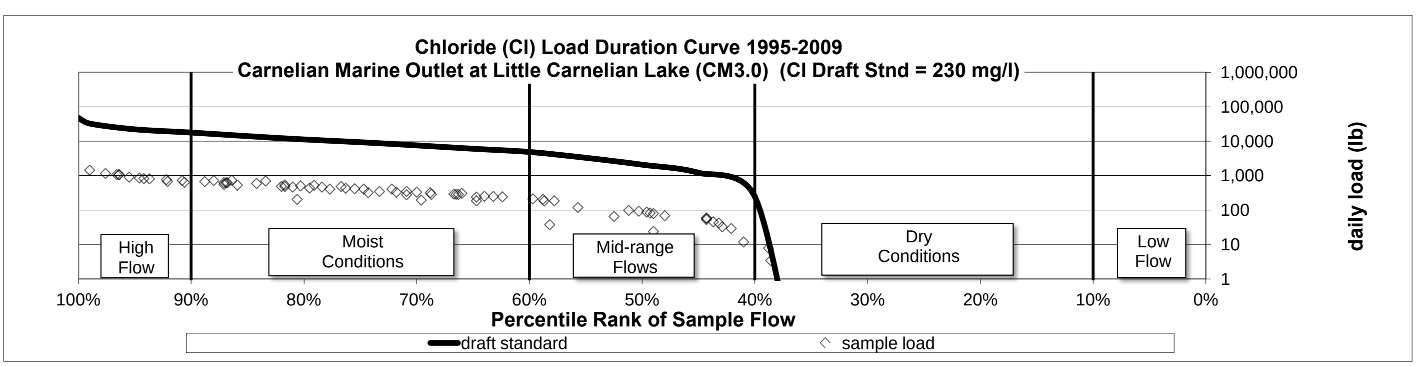
Figure CM-12: Carnelian Marine Outlet Flow and Load Duration Curves, 1995-2009











Aquatic Life Assessment via 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.

Due to the location of this site between the outflow of a lake and the gravity pipe, MCES and their collaborators did not collect macroinvertebrates. If more biological information for this watershed is needed, please see CMSCWD's website.

Trend Analysis

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

Due to a relatively short flow record for the monitored streams, MCES did not attempt to assess increases or decreases in flow. However other researchers have performed regional assessments of alterations in flow rate; their results can be used to form general assumptions about changes in flows in the metropolitan area streams.

Novotny and Stefan (2007) assessed flows from 36 USGS monitoring stations across Minnesota over periods of 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 likely have also contributed to increasing flow rates. For example, Schottler et al. (2013) found that agricultural watersheds with large land use changes have exhibited increases in seasonal and annual water yields, with most of the increase in flow rate due to changes in artificial drainage and loss of depressional storage. MCES staff plan to repeat the following trend analyses in 5-10 years. At that time, we anticipate sufficient data will have been collected for us to assess changes in flow rate, as well as to update the pollutant trends discussed below.

MCES staff assessed the available data for the Carnelian-Marine Outlet for potential trend analysis with QWTREND. Because the station had multiple years without flow, the data were not appropriate for analysis with QWTREND.

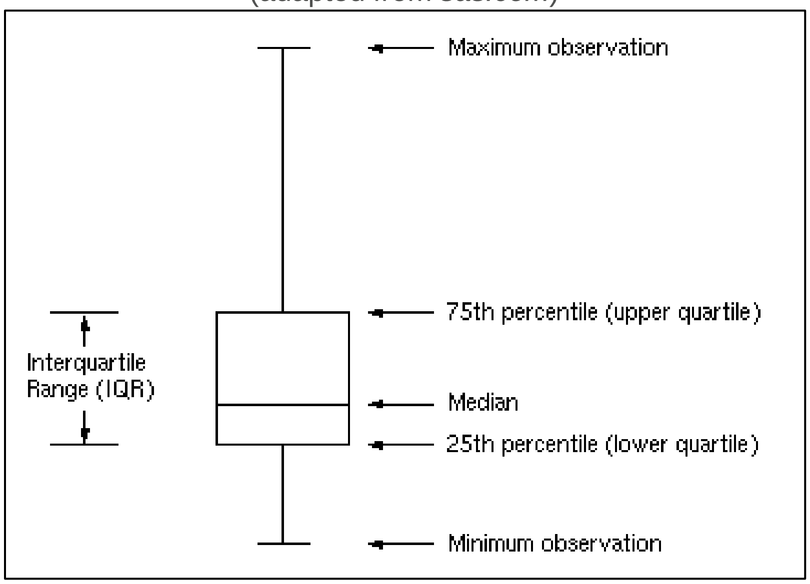
Comparison with Other Metro Area Streams

Chemistry

Box-and-whisker plots are used to summarize the comparison of the historical flow, TSS, TP, and NO3, and Cl data for Carnelian-Marine Outlet 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 CM-14 to Figure CM-17 and Table CM-6.

Figure CM-13 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 CM-13: General Schematic of a Box-and-Whisker Plot
(adapted from *sas.com*)



Comparisons for each chemical parameter for period 2003-2012 are shown using box-and-whisker plots of four metrics (annual flow-weighted mean (FWM) concentration, annual runoff ratio (volume/precipitation, which should be identical on each of the four parameter pages), total annual load, and annual areal yield), grouped on one page, with streams grouped by major receiving river and listed in order of upstream-to-downstream. In addition, the plot of FWM concentration includes the 2003-2012 FWM concentration for the three receiving rivers (Mississippi, St. Croix, and Minnesota), shown as a dashed line. The box-and-whisker plot for the Carnelian-Marine Outlet represents the data that were collected from 2003-2009.

Total Suspended Solids. The median annual FWM concentration for TSS in the Carnelian-Marine stream was the lowest of all of the St. Croix River tributaries (Figure CM-14). It was also lower than that in the St. Croix River (as measured at Stillwater, Minnesota; ~2 mg/l vs. 8.3 mg/l, respectively), indicating that the outflow of the Carnelian-Marine watershed served to dilute the TSS concentration in the St. Croix River when there was outflow. 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 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 the Carnelian-Marine Outlet was the lowest of all metropolitan area streams, with the exception of Silver Creek which has the same runoff ratio. These flows are influenced by wetlands and lakes on the stream channel, which causes the relatively lower runoff ratio. If the stream system was greatly influenced by spring flows (for example, Valley Creek, Browns Creek, or Eagle Creek) the runoff ratio would be much higher.

Total Phosphorus. Similar to TSS, the FWM TP concentration in the Carnelian-Marine Outlet was lower than the St. Croix River, and served to dilute the TP concentration in the river (Figure CM-15). The outflows from the Carnelian-Marine watershed and the other St. Croix River metropolitan area 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 Carnelian-Marine Outlet median TP annual yield was the lowest than all of the other metropolitan area tributaries.

Nitrate. The Carnelian-Marine Outlet median annual FWM NO_3 concentration of 0.1 mg/l was much lower than the drinking water standard (Table CM-5), and was the lowest concentration of all St. Croix tributaries (Figure CM-16). This concentration of NO_3 was lower than in the St. Croix River, and thus served to dilute the river. The median NO_3 annual yield was the lowest of all of the other MCES-monitored tributaries.

Chloride. The Cl annual median FWM concentration was lower than the other streams in the St. Croix watershed, but was greater than the concentration of the St. Croix River itself (Figure CM-17). This means that all of the monitored stations in the watershed were serving to pollute the St. Croix. Similarly, the Carnelian-Marine Outlet annual yield was the lowest value in the St. Croix watershed and the metropolitan area as a whole.

Macroinvertebrates

In other sections in this series (*Comprehensive Water Quality Assessment of Select Metropolitan Area Streams*), MCES created figures for area-wide comparisons of the macroinvertebrate M-IBI scores and the trends in water quality. However, since the Carnelian-Marine Outlet was not included in biomonitoring, it cannot be compared to the other metropolitan area streams. Please see the other reports in the series for further biomonitoring information.

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 Carnelian-Marine Outlet 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 study for the presentation of estimated changes for TSS, TP, and NO_3 in the other MCES-monitored streams.

Figure CM−14: Total Suspended Solids for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

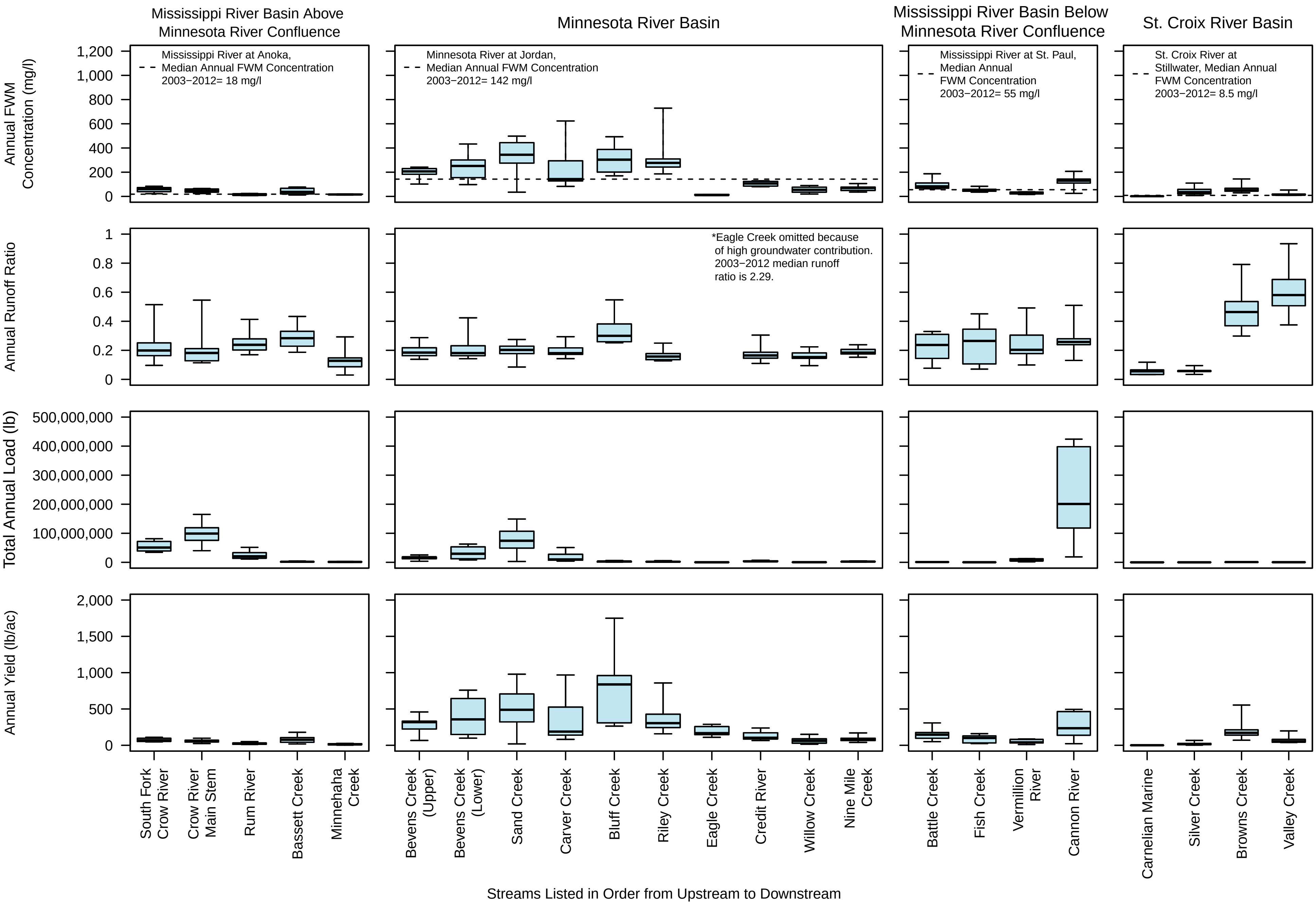


Figure CM−15: Total Phosphorus for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

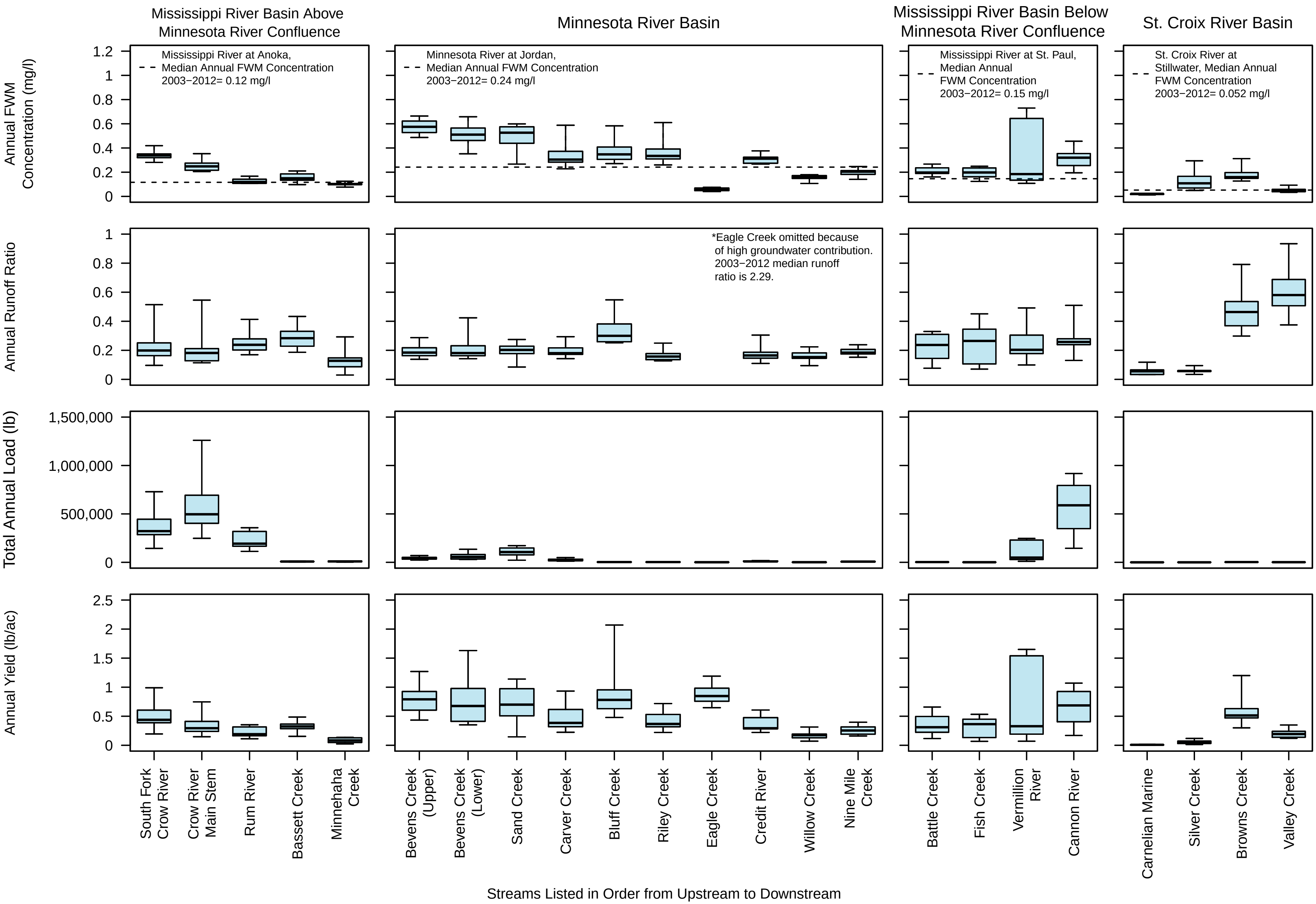


Figure CM−16: Nitrate for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

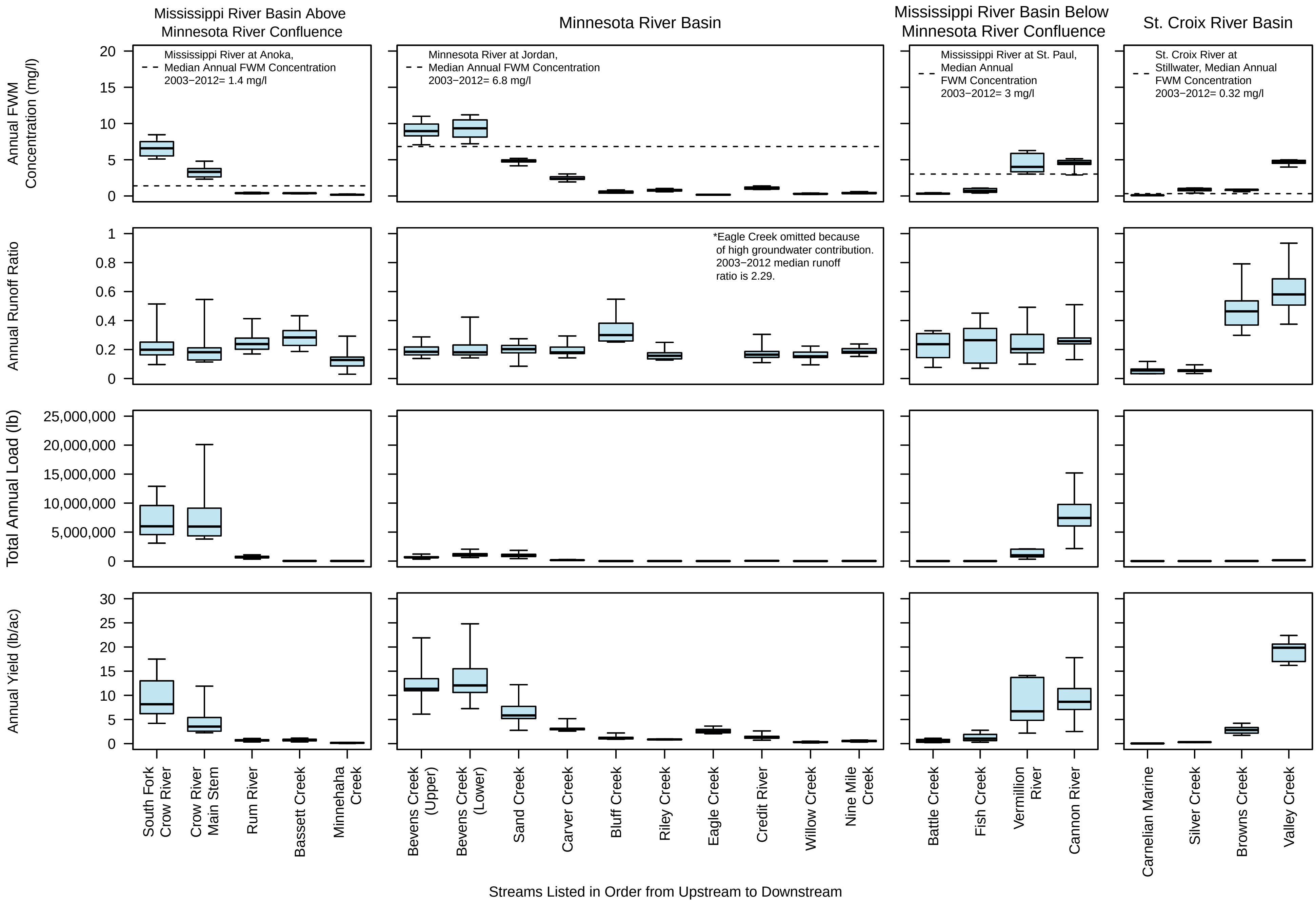


Figure CM−17: Chloride for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

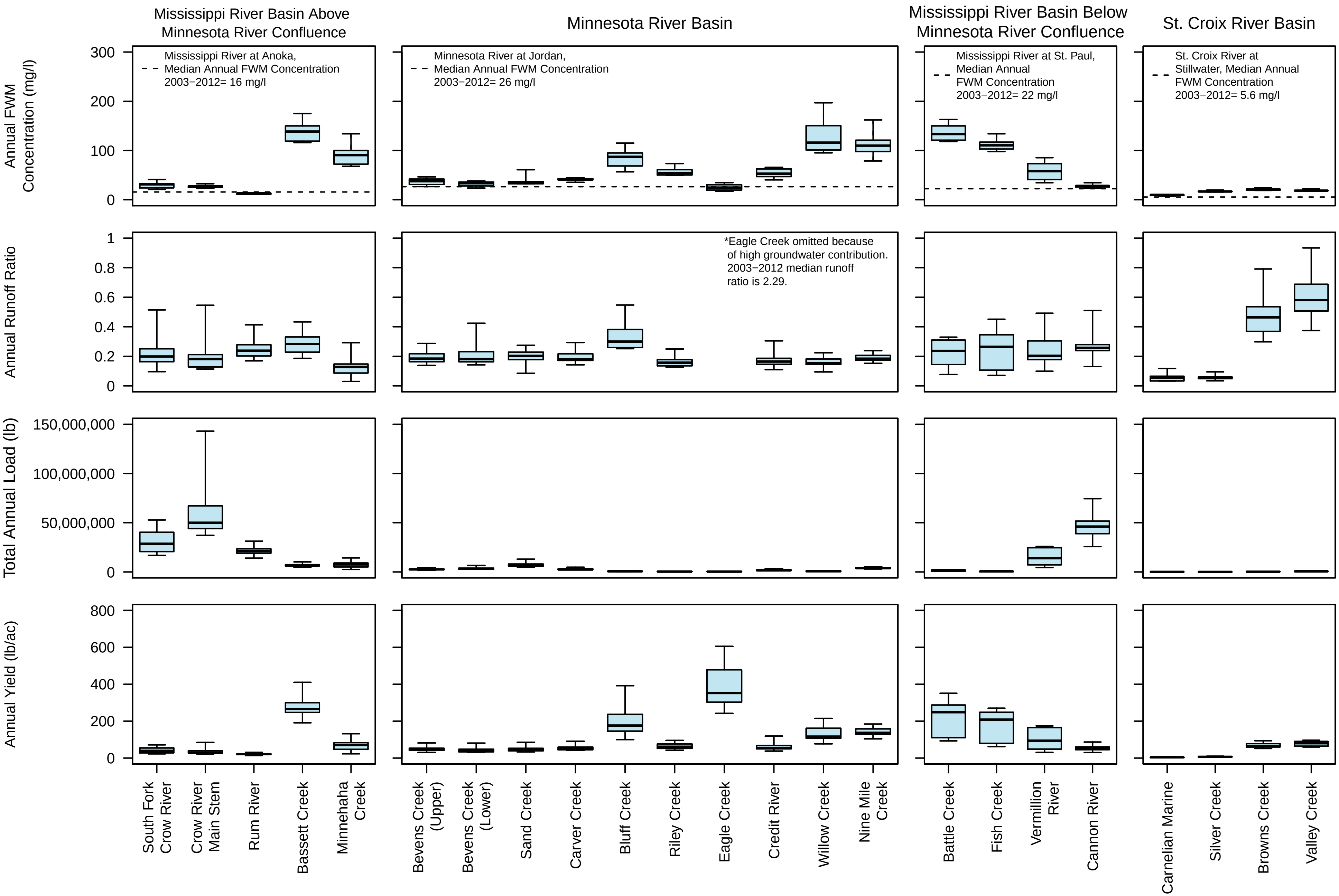


Table CM-6: Annual Median Concentrations, Loads, and Yields for MCES-Monitored Streams, 2003-2012

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

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

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

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

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

Conclusions

The Carnelian-Marine stream system is a tributary to the St. Croix River and drains portions of the city of Scandia, and May and Stillwater Townships. The watershed is primarily forested and grasslands, with pockets of agricultural areas and low density development. The northern and western edges of the watershed have the steepest topography, with the remainder of the watershed having rolling hills punctuated by lakes. The monitoring station was located at the outlet of Little Carnelian Marine Lake, near Stillwater, Minnesota. Downstream of the monitoring station, the stream enters a drainage gravity pipe that conveys the water to the St. Croix River. The monitoring at this site was discontinued in 2009 due to a consistent lack of flow.

The water quality in the Carnelian-Marine Outlet is affected by precipitation amount and intensity, and the management of in-line lakes along the Carnelian-Marine stream system. TSS and TP at the outlet (both FWM concentration and load) are very low, both in comparison to the St. Croix River and the other MCES-monitored metropolitan area tributaries. This is not surprising as sediment deposition occurs in locations of slowing water velocity (for example, stream water entering a lake) and TP is often associated with soils. The eight lakes along the Carnelian-Marine stream system provide an opportunity for sediment deposition. However, the lakes can be a source of algal sediments, and since the MCES monitoring site was at the outlet of Little Carnelian Lake, it is most likely the source of the measured TSS.

The NO_3 loads and concentrations are likely driven by agricultural activity and leaching of septic fields within the watershed. The concentration and loads at the Carnelian-Marine Outlet are lower than those in the St. Croix River (which is the lowest of the three major rivers of the metropolitan area), and the lowest of the other MCES-monitored metropolitan area tributaries.

The Cl loads and concentrations in the Carnelian-Marine Outlet were lower than the highly urbanized watersheds monitored by MCES, reflecting the low level of development and road density in the watershed and thus the relatively low input of Cl as road de-icer.

The climate pattern during the last years of monitoring had two of the lowest values of total annual precipitation since 2000. The lack of precipitation reduced the lake levels, decreased outflows from the Carnelian-Marine watershed, and greatly reduced the pollutant loads. The years that followed the station's retirement in 2009 had higher total precipitation amounts, which increased lake storage. The depth of Little Carnelian Lake increased five feet in the summer of 2012 from the winter lake depth in 2011 (MnDNR, 2013a). However, this increase in the lake depth does not approach the ordinary high-water depth, and the watershed has not had sustained discharges to the St. Croix River. Without the occurrence of large precipitation events, it is plausible that during some years the Carnelian-Marine watershed will not contribute any pollutant loads or flow to the St. Croix River.

Recommendations

This section presents recommendations for monitoring and assessment of the Carnelian-Marine Outlet, 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 run-off 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. The following recommendations have been drafted from the results of this report and are intended to assist MCES and its partners in directing future assessment work:

- MCES should confirm the Carnelian-Marine Outlet watershed boundaries and determine if any corrections need to be made due to rerouted flows, landlocked basins, etc. Adjustments to the drainage boundaries should be discussed with CMSCWD and reported to the MnDNR.
- 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 Carnelian-Marine Outlet watershed. This information should be included in watershed and local surface water management plan updates.
- In the past, MCES staff have participated in technical advisory committee meetings convened by the CMSCWD. This partnership should continue as the watershed district updates its water resource management plan and associated rules.

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