Comprehensive Water Quality Assessment of Select Metropolitan Area Streams

WILLOW CREEK

METROPOLITAN COUNCIL

December 2014

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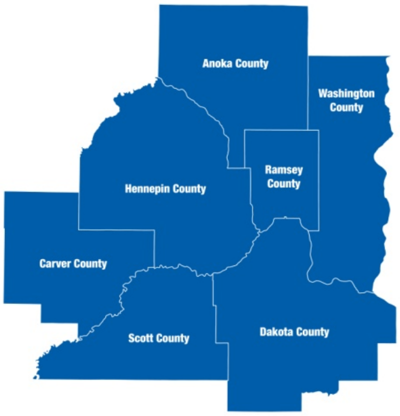

The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system, collects and treats wastewater, coordinates regional water resources, plans and helps fund regional parks, and administers federal funds that provide 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 partners conducted the stream monitoring work, while MCES staff performed the data analyses, compiled the results and prepared the report.

About This Section

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

Cover Photo

The photo on the cover of this section depicts the outlet of Sunset Pond in the Willow Creek watershed. It was taken by Metropolitan Council staff.

Recommended Citations

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Introduction

Willow Creek is located in the southern metropolitan area and is a tributary to the Minnesota River. It drains approximately 10 square miles of grassland, open water, bluff land, and urban areas (portions of the cities of Savage, Lakeville, Apple Valley, and Burnsville) in Scott, and Dakota Counties (Metropolitan Council Districts 4 and 15). The creek flows primarily through underground stormwater pipes. Most of the creek flows through Sunset Pond before entering an underground culvert which discharges to the Minnesota River near the Kraemer Quarry. The stations was discontinued in 2009.

Figure WI-1: Willow Creek Monitoring Station

This report:

- documents those characteristics of Willow Creek and its watershed most likely to influence stream flow and water quality.
- presents the results from assessments of flow and water quality data.
- presents statistical assessments of trends in stream chemistry concentrations.
- draws conclusions about possible effects of landscape features, climatological changes, and human activities on flow and water quality.

- compares Willow Creek flow and water quality with other streams within the metropolitan area monitored by Metropolitan Council Environmental Services (MCES).
- makes general recommendations for future monitoring and assessment activities, watershed management, and other potential actions to remediate any water quality or flow concerns.

MCES plans to update this report approximately every 5 years, in addition to issuing annual data summary reports.

Partnerships and Funding

MCES supported water quality monitoring of Willow Creek from 1999 - 2009. Partial funding for this site was provided by the Minnesota Legislature through a grant from the MPCA using Clean Water Land and Legacy Amendment funds. In the early years, MCES partnered with the Black Dog Watershed Management Organization to operate the monitoring station through the Organization's consulting engineering company. Later, MCES partnered with the Lower Minnesota River Watershed District (LMRWD). At that time, the Dakota County Soil and Water Conservation District (SWCD) maintained the monitoring station and completed the field work. MCES ended monitoring at this site in 2009 because of budgetary constraints.

Monitoring Station Description

The MCES monitoring station was located on Willow Creek in Burnsville, Minnesota, 1.0 mile upstream from the creek confluence with the Minnesota River. Willow Creek originates above the bluff of the Minnesota River Valley. The creek flows from Lee and Keller Lakes into Crystal Lake and from there it flows through Twin and Early Lakes into Sunset Pond. From the control structure at the outlet of Sunset Pond, the creek descends the bluff into the Lower Minnesota River Watershed. Below the bluff, Willow Creek is diverted into an underground box culvert that discharges on the south bank of the Minnesota River underneath the Burnsville Landfill.

The rating curve at this location is based upon a Manning's equation developed by the consulting engineer. Because the stream is situated in an underground box culvert, direct in-stream measurements to refine the Manning's equation within the confines of the box culvert were not feasible.

A rain gauge was present at this location for measurement of precipitation; however it was rarely used due to infrequent site visits for calibration. Precipitation data are available from the Minnesota Climatology Working Group, MSP Airport Station Number 215435. Daily precipitation totals from these 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 ensure the variability of rainfall within the watersheds was represented (Minnesota Climatology Working Group, 2013). This data is generated from Minnesota's HIDEN (High Spatial Density Precipitation Network) dataset. The gridded data was aerially-weighted based on the watershed boundaries.

Stream and Watershed Description

The Willow Creek watershed is a total of 6,437 acres, all upstream of the monitoring station. The watershed is almost completely urbanized, with 4,840 acres (75.2%) developed urban land in the monitored portion of the watershed and only 22 acres (0.3%) agricultural land (Figure WI-2). The watershed encompasses portions of the cities of Apple Valley, Lakeville, Burnsville, and a small portion of Savage. The most heavily urbanized area of the watershed is in the north-central portion around the I-35 split. Other primary land uses in the watershed are forest, grasses/herbaceous, open water, and wetlands. Table WI-1 shows the watershed area by land cover.

Table WI-1: Willow Creek Land Cover Classes[1]

Land Cover Class	Monitored	
	Acres	Percent
5-10% Impervious	298	4.6%
11-25% Impervious	92	1.4%
26-50% Impervious	3,482	54.1%
51-75% Impervious	415	6.4%
76-100% Impervious	552	8.6%
Agricultural Land	22	0.3%
Forest (all types)	320	5.0%
Open Water	463	7.2%
Shrub land	5	0.1%
Grasses/Herbaceous	556	8.6%
Wetlands (all types)	231	3.6%
Total	**6,437**	**100.0%**

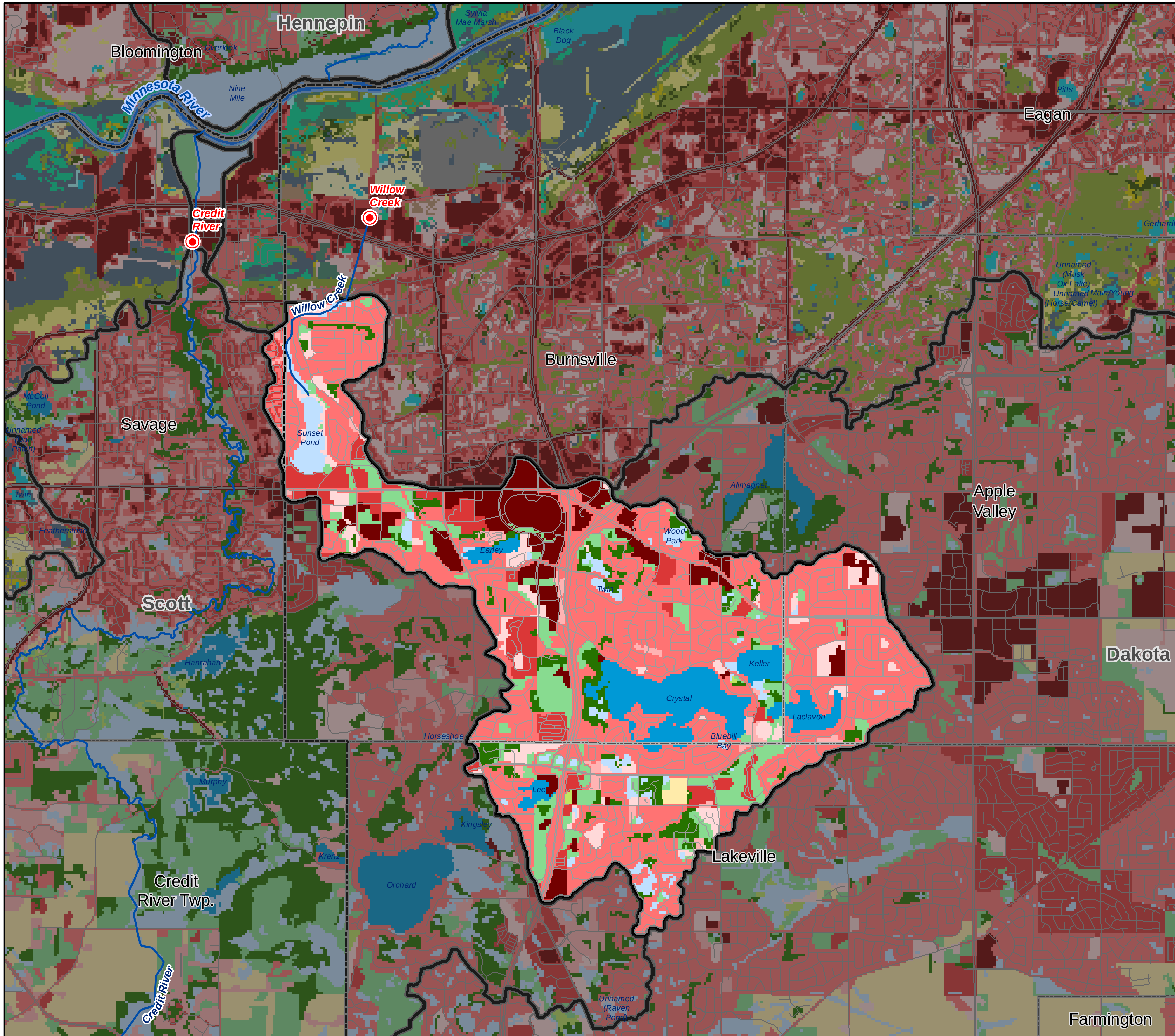
[1] Land cover spatial data file provided by MnDNR. The data is a composite of the 2008 MLCCS (Minnesota Land Cover Classification System), which covered primarily the 7-county metro area; and the 2001 NLCD (National Land Cover Data), which covered the outstate areas not included in the 2008 MLCCS.

The very upstream end of the watershed is relatively flat outwash plain, but the remainder of the watershed is hillier end moraine or older glacier drift (Figure WI-3). The maximum watershed elevation is 1195.9 MSL and the minimum elevation is 781.3 MSL within the monitored area. Within the monitored area 7.8% of the slopes are considered steep, and an additional 2.1% are considered very steep.

There are few point sources within the Willow Creek Watershed (Figure WI-4). The watershed contains two sites holding industrial stormwater permits, both in the monitored portion of the watershed. There are no cooling water, potable water, dewatering facilities, or industrial or domestic wastewater facilities in the watershed. There are no feedlots in the watershed.

Figure WI-2

MLCCS-NLCD Hybrid Land Cover
Willow 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						
Willow Creek						
	Monitored		**Unmonitored**		**Total**	
Land Cover Class	**Acres**	**Percent**	**Acres**	**Percent**	**Acres**	**Percent**
5-10% Impervious	298	4.6%				
11-25% Impervious	92	1.4%				
26-50% Impervious	3,482	54.1%				
51-75% Impervious	415	6.4%				
76-100% Impervious	552	8.6%				
Agricultural Land	22	0.3%		Not Applicable		
Forest (all types)	320	5.0%				
Open Water	463	7.2%				
Barren Land	0	0.0%				
Shrubland	5	0.1%				
Grasses/Herbaceous	556	8.6%				
Wetlands (all types)	231	3.6%				
Total	**6,437**	**100.0%**				

0 0.5 1 1.5 2
Miles

Figure WI-3

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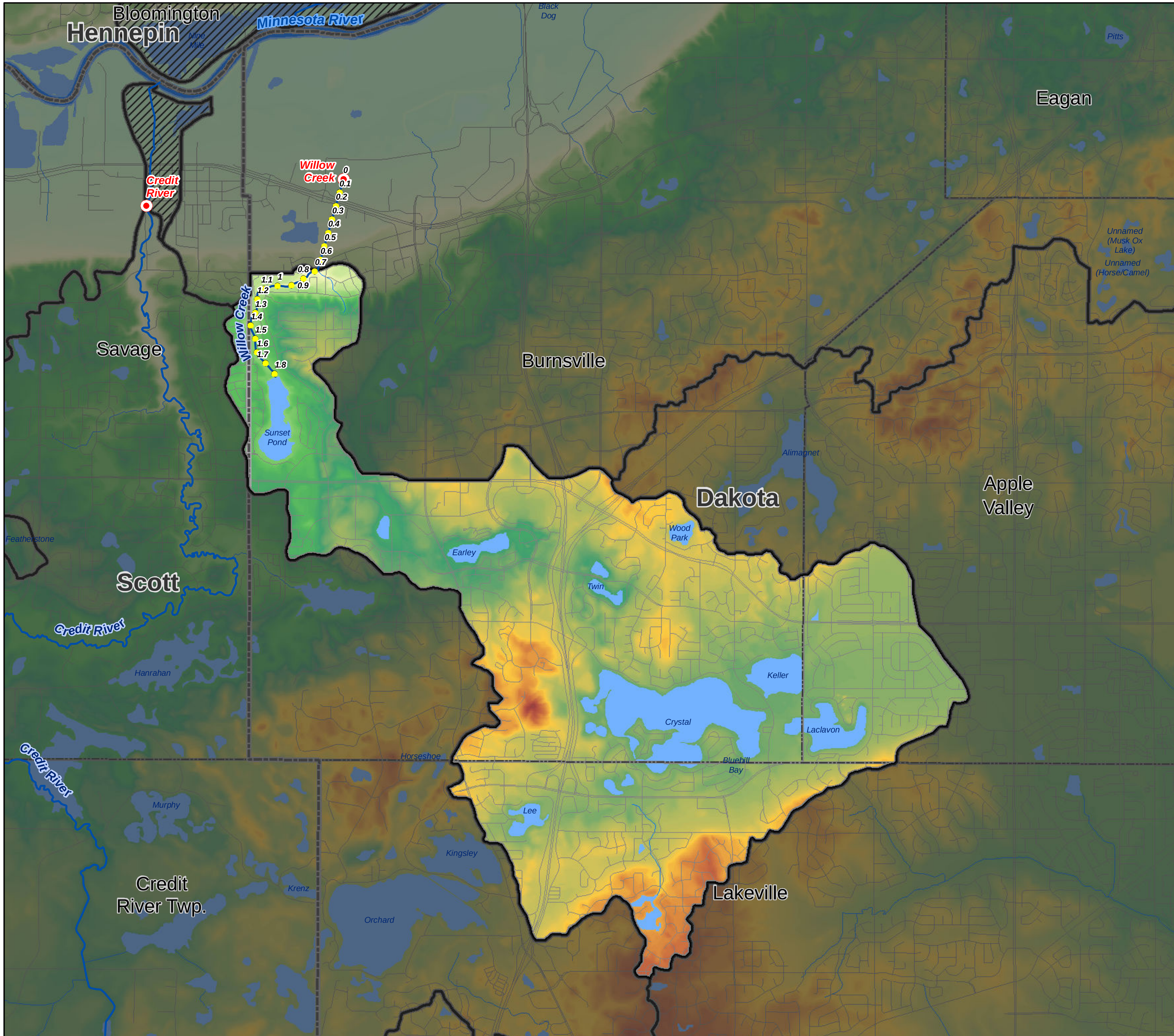
Watershed Topography
Willow Creek



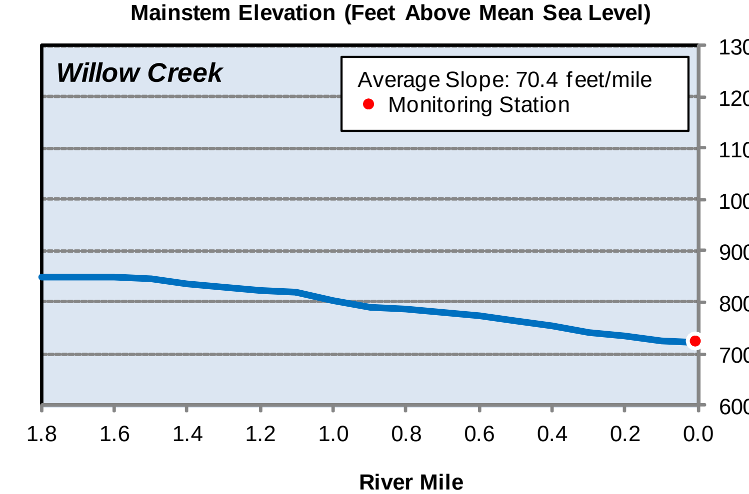
- MCES Stream Monitoring Sites
- USGS Flow Stations
- Stream Mile Markers
- Mainstems (Monitored and Unmonitored)
- Monitored Watershed Boundaries
- Unmonitored Watershed Areas
- Public Waters Inventory
- Other Rivers and Streams
- City and Township Boundaries
- County Boundary
- NCompass Street Centerlines,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

Water Quality Impairments

Four lakes within the Willow Creek watershed have been included on the MPCA's 2014 impaired waters list (Figure WI-4, Table WI-2). No Willow Creek stream reaches have been designated as impaired.

Table WI-2: Impaired Lakes in the Willow Creek Watershed as Identified on the MPCA 2014 Impaired Waters List

Lake Name	Lake ID	Affected Use(s)[1]	Approved Plan[2]	Needs Plan[2]
Crystal	19-0027-00	AQC, AQR	Nutrients,	HgF
Earley	19-0033-00	---	Nutrients	---
Keller	19-0025-00	AQR	Nutrients	---
Lac Lavon	19-0446-00	AQC	HgF	---
Lee	19-0029-00	AQR	Nutrients (lake was delisted in 2014)	---

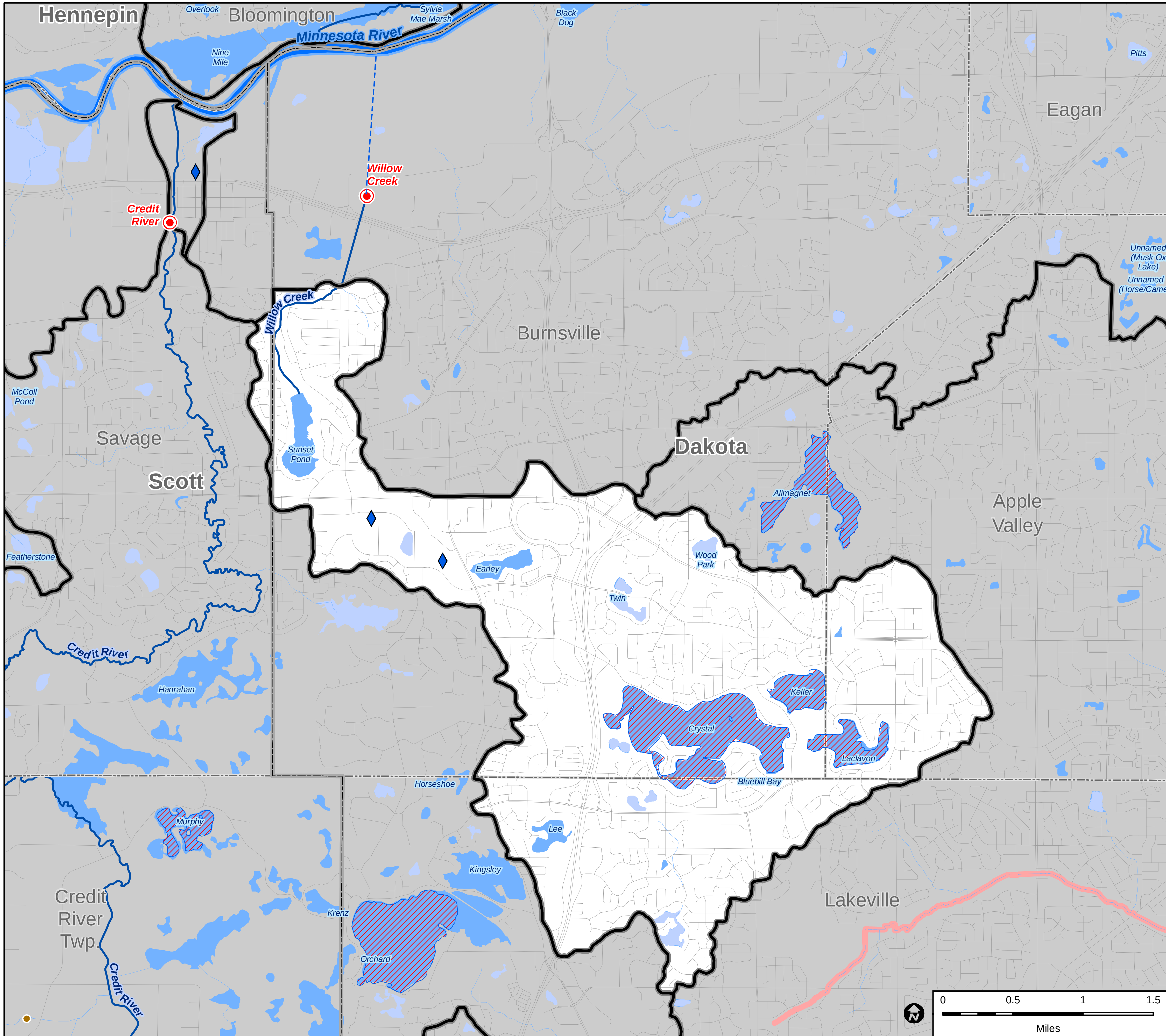
[1] AQC = Aquatic Consumption; AQR = Aquatic Recreation.

[2] HgF = Mercury in Fish Tissue.

Figure WI-4

Public and Impaired Waters and Potential Pollution Sources

Willow 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

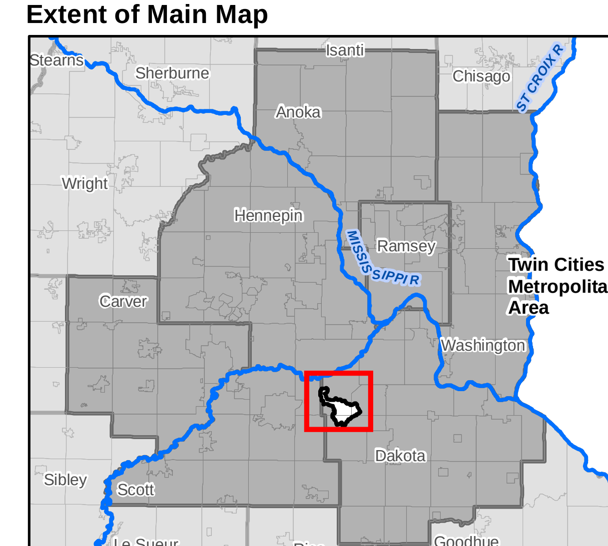
Feedlots with 100 or more animal units **

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



Hydrology

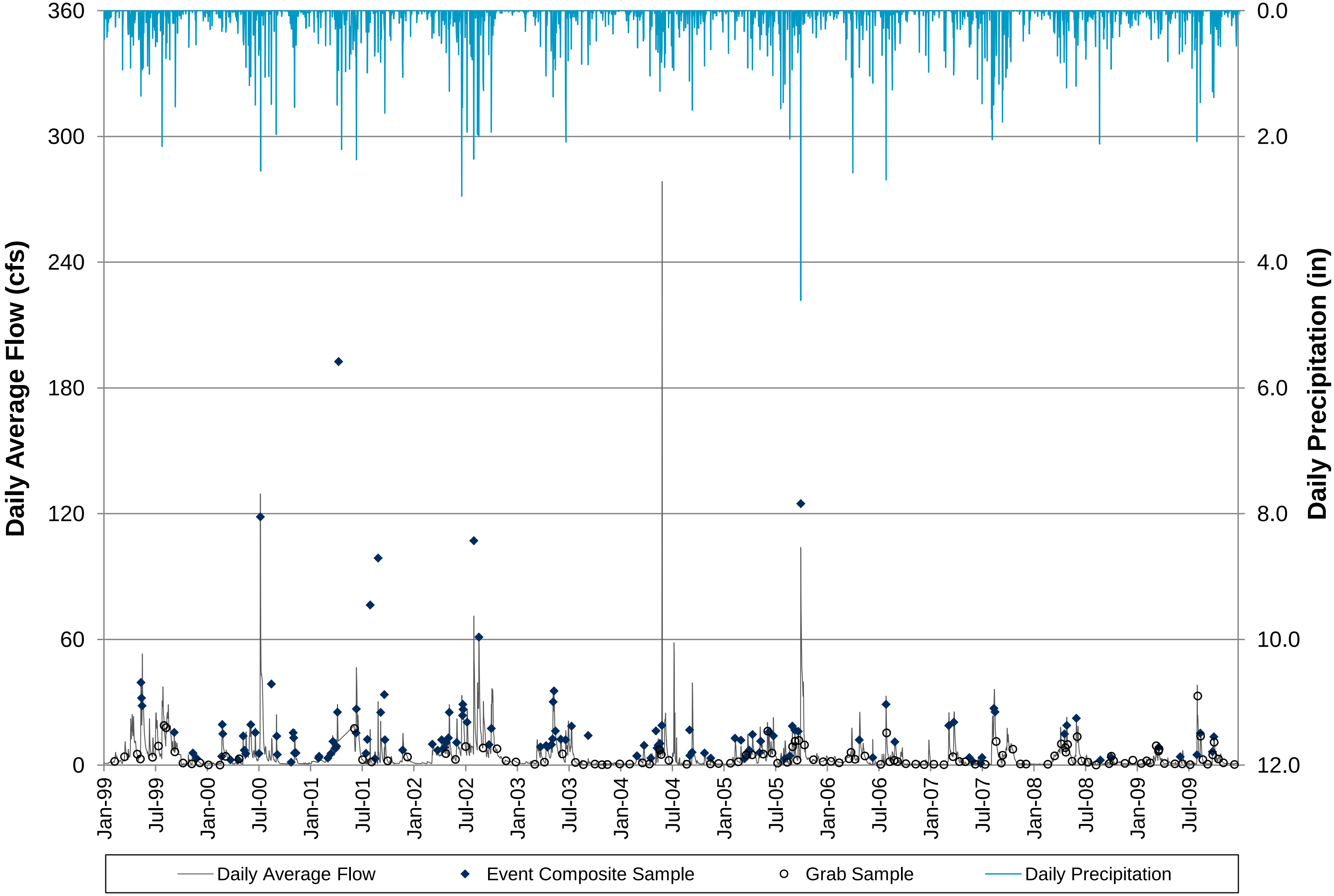
MCES monitored flow on Willow Creek near mile 1.0 from 1999 through 2009. Flow measurements were collected at 15-minute intervals and converted to daily averages. The hydrograph of Willow Creek, which displays daily average flow, daily precipitation, and the flow associated with grab and composite samples, indicates the variation in flow rates from season to season and from year to year (Figure WI-5), and the effect of precipitation events on flow.

The MCES sampling collects grab samples of base flows between events and composite samples of precipitation events. The hydrograph indicates samples were collected during most events and that baseflow was also adequately sampled.

Analysis of the duration of daily average flows indicates that the upper 10th percentile flows for the period 1999-2009 ranged between approximately 11.6-278.5 cubic feet per second, while the lowest 10th percentile flows ranged from 0.08-0.45 cfs (See Figure WI-12 in the ***Flow and Load Duration Curves*** section of this report.)

Additional annual flow/volume metrics are shown on Figures WI-6 to WI-9, along with the annual pollutant load parameters. The first graph on each sheet illustrates an annual flow metric consisting of 1) average annual flow (a measure of annual flow volume); 2) areal weighted flow; or 3) the fraction of annual precipitation converted to flow. Figure WI-6 indicates the highest average annual flow (and thus the highest volume of flow) during 1999-2009 occurred in 2002 (approximately 8.24 cfs average annual flow); the lowest occurred in 2009 (approximately 2.18 cfs average annual flow).

Figure WI-5: Willow Creek Daily Average Flow, Sample Flow, and Precipitation, 1999-2009*



*Monitoring station discontinued after 2009; precipitation record was acquired from NWS COOP station 215435-Minneapolis/St. Paul AP

Vulnerability of Stream to Groundwater Withdrawals

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

To assess the vulnerability of metro area waters to groundwater withdrawals, MCES staff examined spatial datasets of vulnerable stream segments and basins created as part of the 2010 regional groundwater analysis. Unfortunately, due to the location of the lower portion of the stream in an underground box culvert, Willow Creek was not included in this assessment. However, most of the basins within the watershed were identified as vulnerable to groundwater withdrawals, including Crystal Lake, Keller Lake, Early Lake, Sunset Pond, and Twin Lakes, plus a number of surrounding smaller unnamed wetlands.

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

Pollutant Loads

The U.S. Army Corps of Engineers program Flux32 (Walker, 1999) was used to convert daily average flow, coupled with grab and event-composite sample concentrations, into annual and monthly loads and flow-weighted mean concentrations. Loads were estimated for total suspended solids (TSS), total phosphorus (TP), total dissolved phosphorus (TDP), nitrate (NO_3), ammonia (NH_3), and chloride (Cl), for each year of monitored data in Willow Creek (1999-2009). Note that due to budgetary constraints monitoring of Willow Creek ended in 2009.

Figures WI-6 to WI-9 illustrate annual loads expressed as mass, as flow-weighted mean (FWM) concentration, as mass per unit of area (lb/ac), and as mass-per-unit of area-per inch of precipitation (lb/ac/in), as well as two hydrological metrics (annual average flow rate and fraction of annual precipitation as flow). A later section in this report (***Comparison with Other Metro Area Streams***) offers graphical comparison of the Willow Creek loads and FWM concentrations with the other MCES-monitored metropolitan area tributaries.

The flow metrics indicate year-to-year variation in annual flow rate that is likely driven by variation in annual precipitation amount as well as by variation in frequency of intense storm events. The fraction of annual precipitation delivered as flow is relatively stable between years; year-to-year variation is likely influenced by drought periods, by low soil moisture caused by dry periods, by increased capacity in upland storage areas during drought periods, and other factors.

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

The annual FWM concentrations for all parameters also fluctuate year-to-year and are likely influenced by annual precipitation and flow.

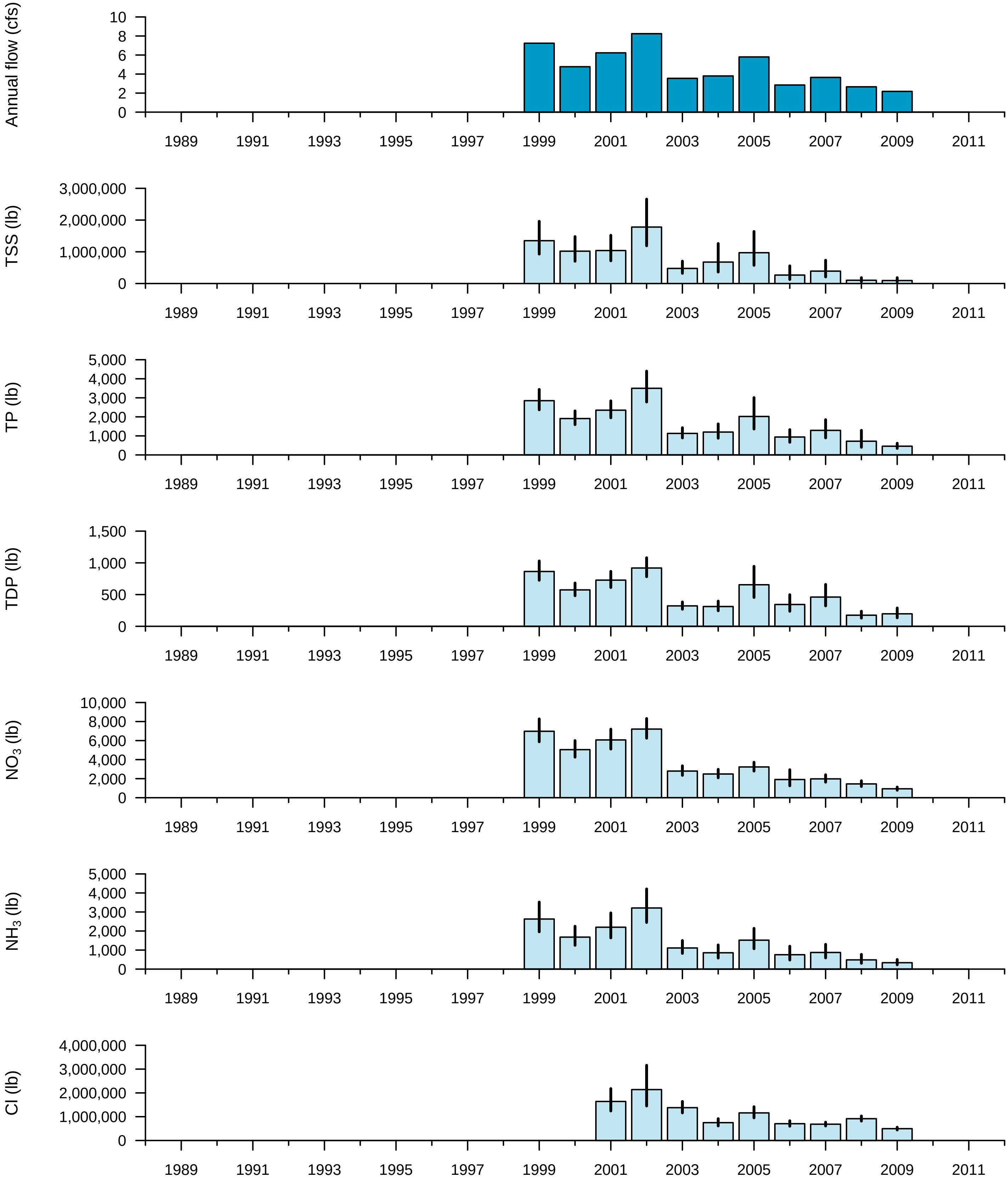
Figures WI-8 and WI-9 present the areal and precipitation-weighted loads, respectively. These graphics are presented to assist local partners and watershed managers, and will not be discussed here.

The Flux32 loads and FWM concentrations were also compiled by month to allow analysis of time based patterns in the loads in Willow Creek (Figure WI-10 and WI-11). The results for each month are expressed in two ways: the monthly results for the most recent year of data (2009 for Willow Creek) and the monthly average for 2000-2009 (with a bar indicating the maximum and minimum value for that month).

Over the 2000-2009 period, in the months of November through February average flows were low with a narrow range; flows increased significantly in March but still show a narrow range. The months of April through October generally show significant flows with a wide range between minimum and maximum values. Variations in flow from March through October are likely due to effects of snow melt and rain storms on impervious areas of the watershed. The magnitudes of the monthly mass loads in Willow Creek generally mimic those of the flows.

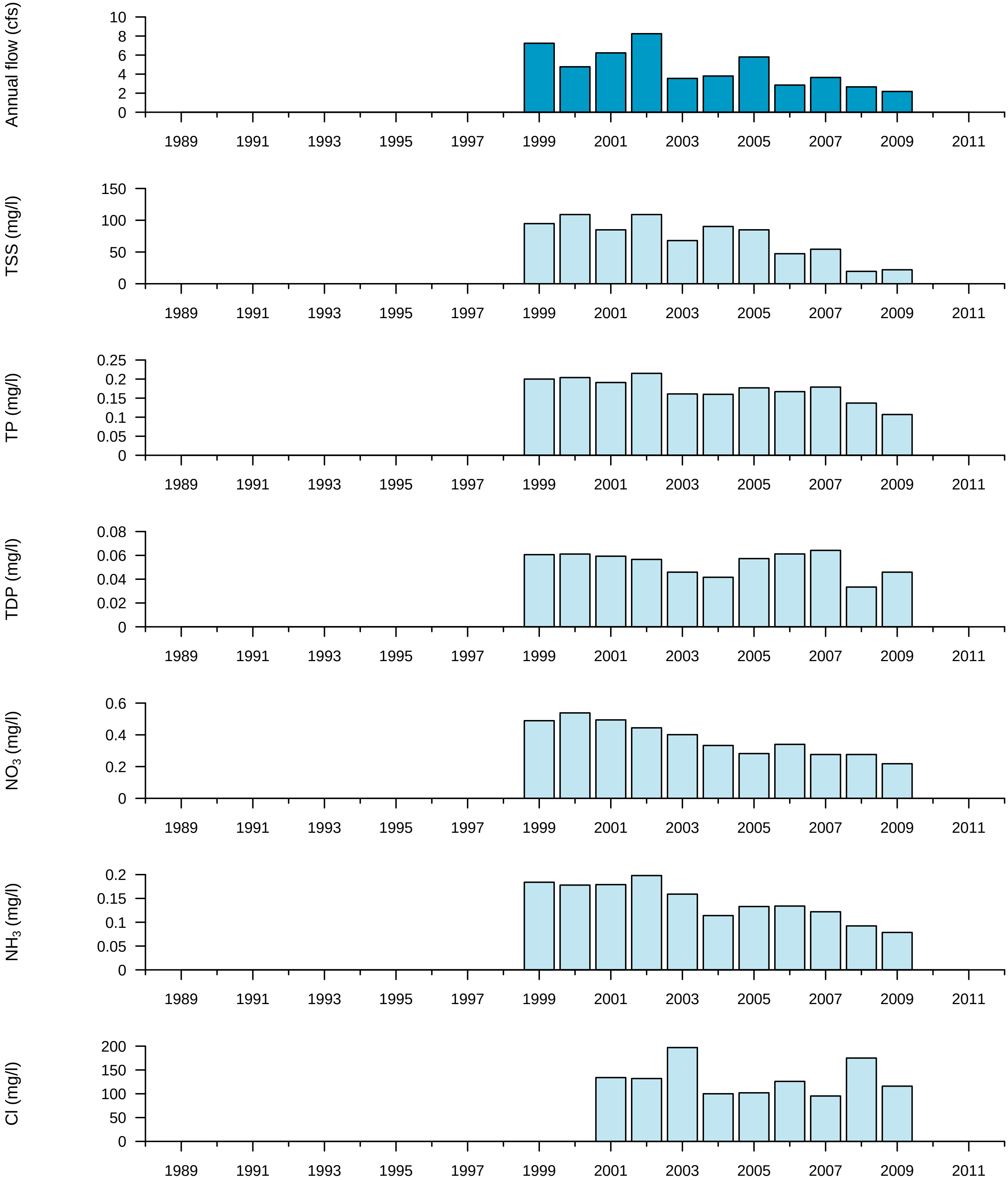
The monthly FWM concentrations also vary with flow, with the possible exceptions of dissolved constituents including TDP, NO_3, and Cl, which seem to show more uniformity from month to month.

Figure WI−6: Willow Creek*
Annual Mass Load



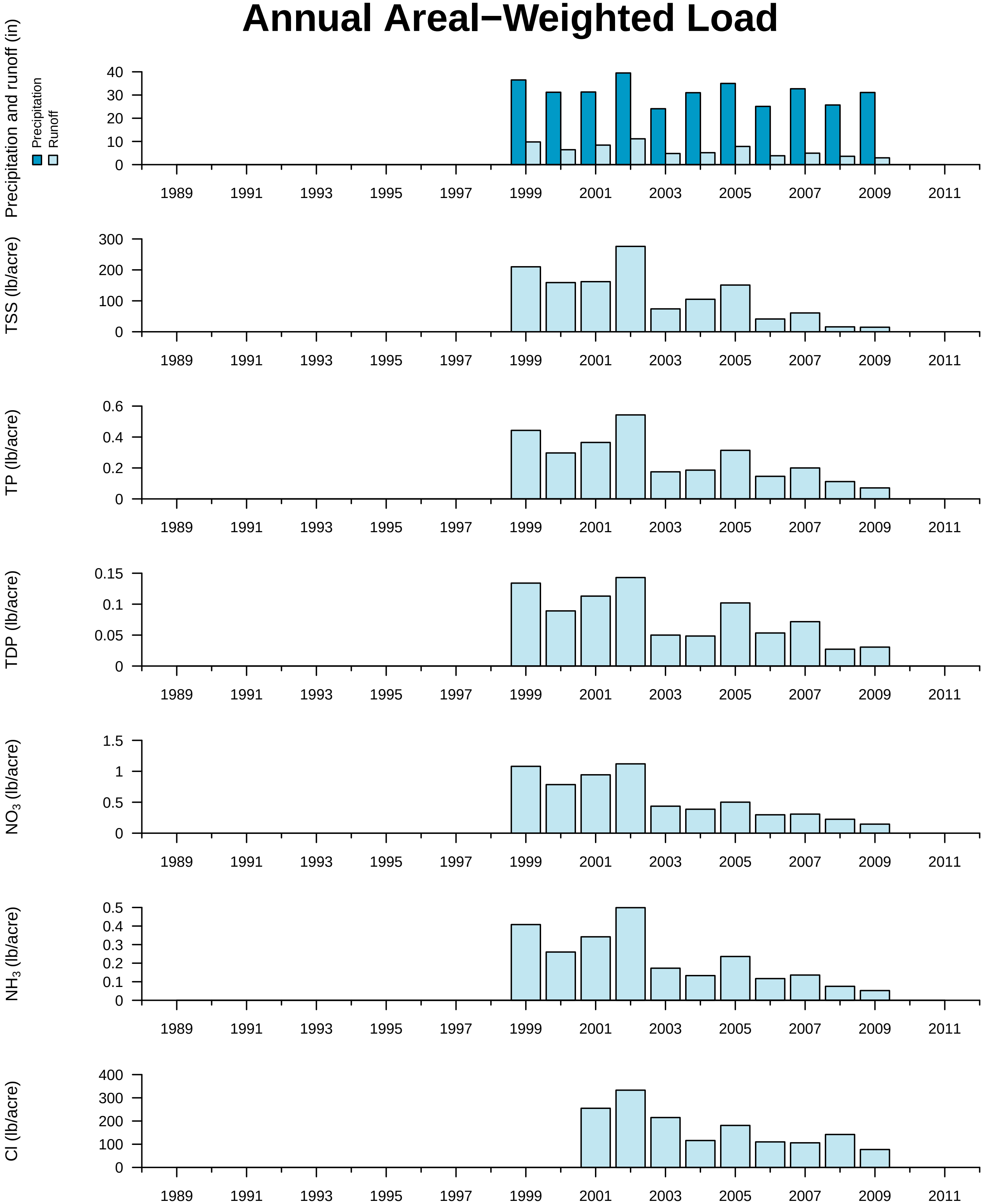
*TSS, TP, TDP, NO3, and NH3 sampling began in 1999, Cl began in 2001. Station was discontinued after 2009. Bars represent 95% confidence intervals as calculated in Flux32.

Figure WI−7: Willow Creek*
Annual Flow−Weighted Mean Concentration



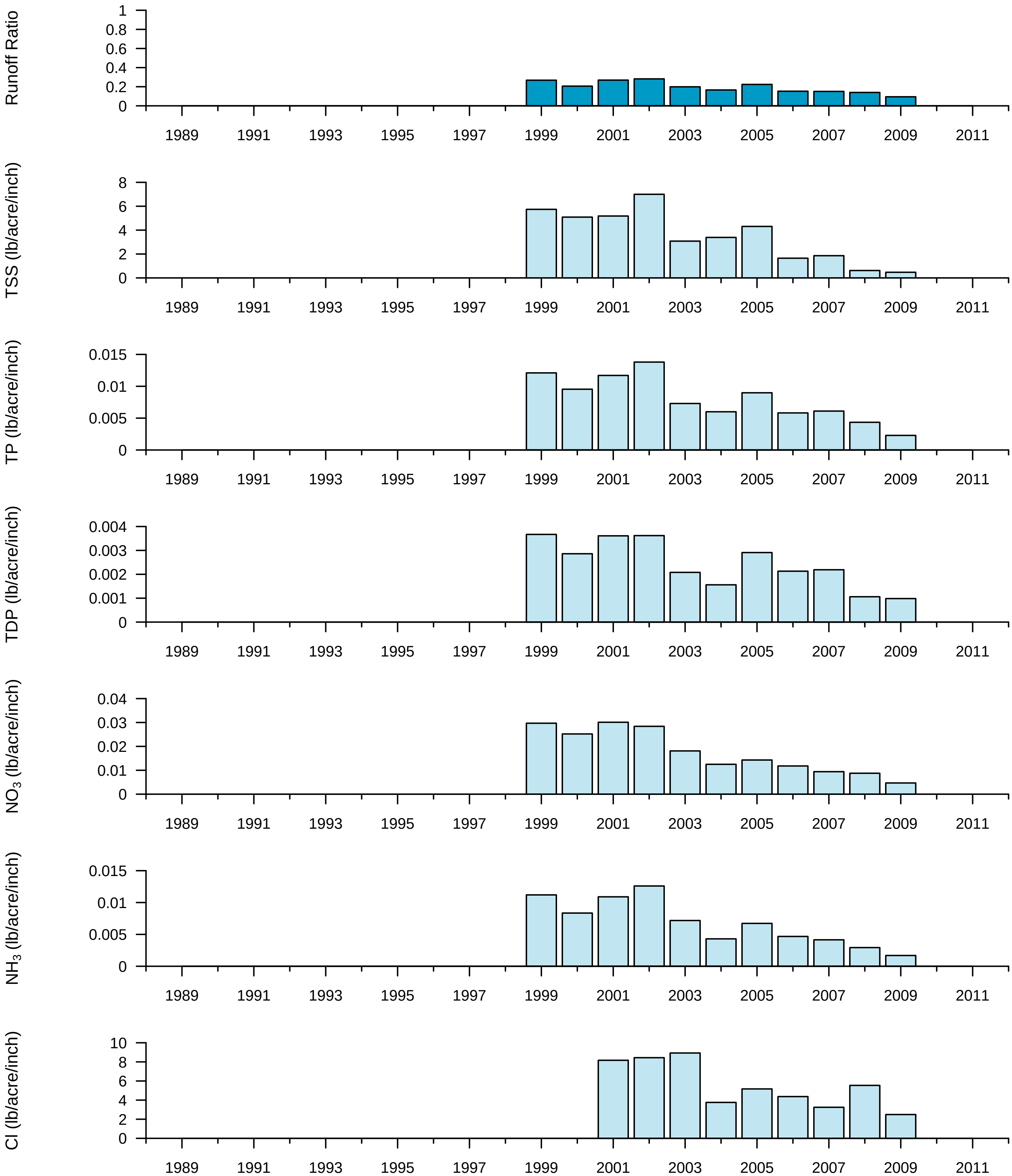
*TSS, TP, TDP, NO3, and NH3 sampling began in 1999, Cl began in 2001. Station was discontinued after 2009.

Figure WI−8: Willow Creek*
Annual Areal−Weighted Load



*TSS, TP, TDP, NO3, and NH3 sampling began in 1999, Cl began in 2001. Station was discontinued after 2009.

Figure WI−9: Willow Creek*
Annual Precipitation−Weighted Areal Load



*TSS, TP, TDP, NO3, and NH3 sampling began in 1999, Cl began in 2001. Station was discontinued after 2009.

Figure WI−10: Willow Creek
Mass Load by Month

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

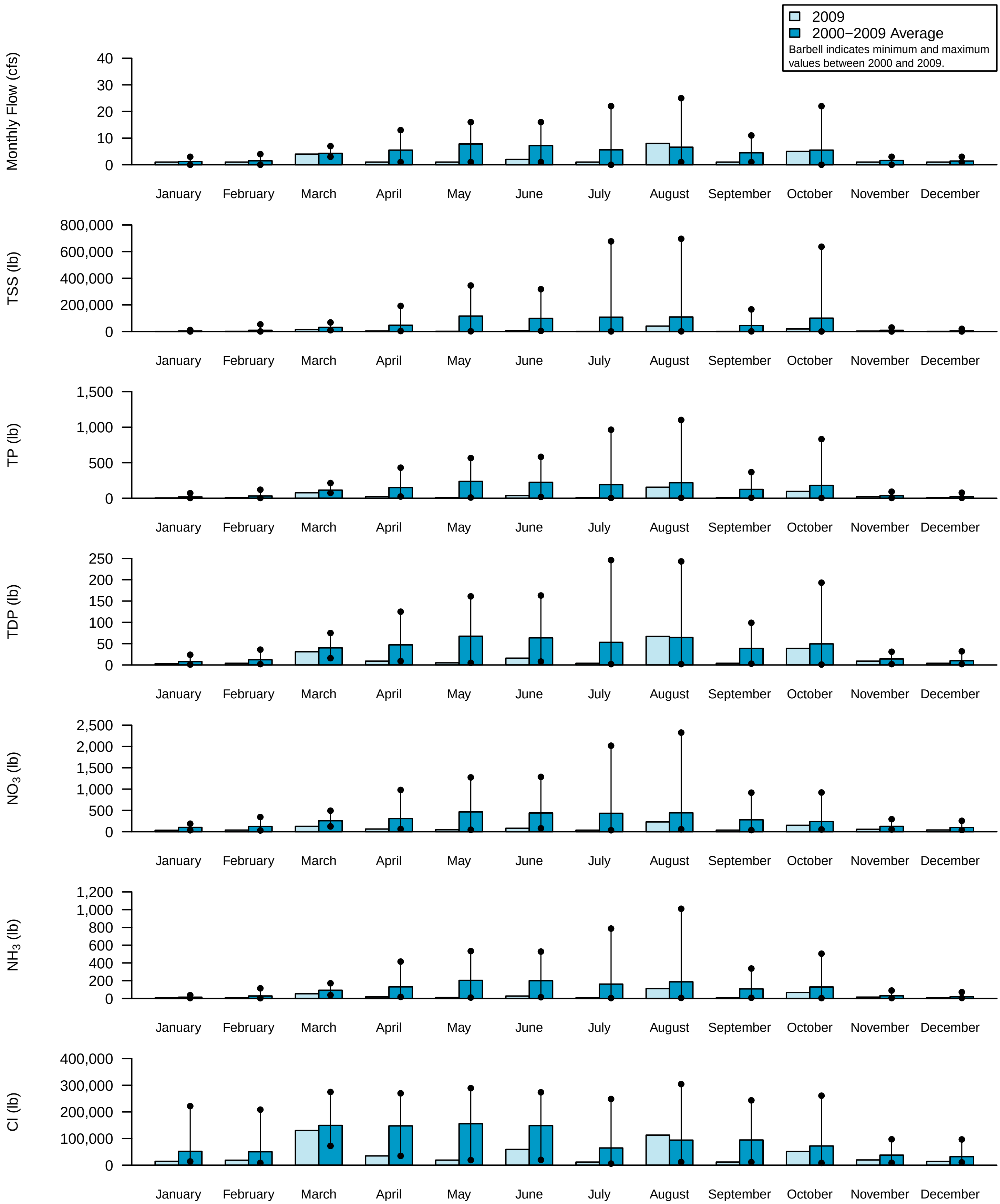
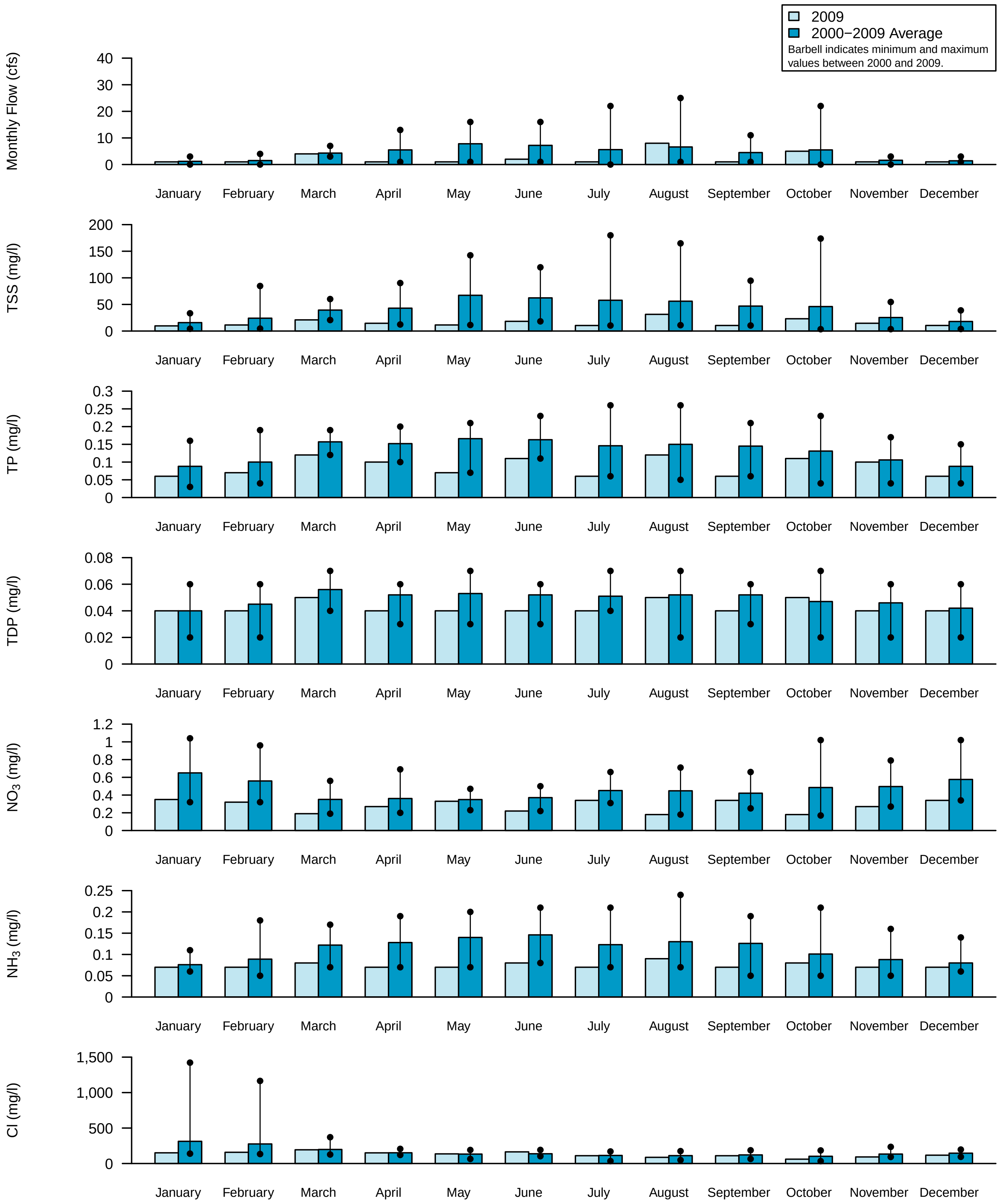


Figure WI−11: Willow Creek
Flow−Weighted Mean Concentation by Month

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 locations using U. S. Environmental Protection Agency (USEPA) recommendations, including:

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

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

MCES selected four parameters to assess using load duration curves: TSS, TP, NO3, and Cl. Each of the parameters was plotted using Willow Creek monitoring station daily average flows and sample data, along with the most appropriate MPCA draft numerical standard as listed in Table WI-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 standard, the water body must exceed the causative variable (TP concentration), as well as one or more response variables: sestonic (suspended) chlorophyll, biochemical oxygen demand ($BOD_{5)}$, dissolved oxygen (DO) flux, and/or pH (MPCA, 2013a). Thus for this report, the load duration curves are used as a general guide to identify flow regimes at which water quality violations may occur. The MPCA is responsible for identifying and listing those waters not meeting water quality standards; the results of this report in no way supersede MPCA's authority or process.

The 1999–2009 flow duration curve and load duration curves for TSS, TP, NO_3, and Cl for the Willow Creek monitoring station (mile 1.0, below Highway 13) are shown in Figure WI-12.

The TSS load duration curve shows that calculated loads equivalent to violations of the proposed 30 mg/l TSS standard occurred at all of the flow regimes, except low flow. However, most of the violations were at higher flows (the high flow and moist conditions regimes).

Similarly, for total phosphorus, there are exceedances of the draft nutrient standard concentration at all flow regimes, except low flow. Most exceedances are during the high flow and moist conditions regimes, but there are also a number of exceedances during mid-range flows, and a few during dry conditions.

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

The Willow Creek Cl load duration curve shows a few exceedances of the proposed standard during the moist conditions, mid-range flows, and dry conditions. The majority of exceedances seem to be at the moist conditions flow regime; which may indicate that the chloride is from road salt applied for deicing being washed off by snowmelt or spring rains. The high range of January and February Cl concentrations shown in Figure WI-11, seem to support this idea.

Table WI-3: Willow Creek Beneficial Use and River Nutrient Region (RNR) Classifications and Pollutant Draft Standards

Monitoring Station	Use Classification[1] for Domestic Consumption (Class 1) and Aquatic Life and Recreation (Class 2)	River Nutrient Region (RNR)[2] of Monitoring Station	Chloride Draft Stnd[3] (mg/l)	TSS Draft Stnd[4] (mg/l)	TP Draft Criteria[5] (ug/l)	Nitrate DW Stnd[6] (mg/l)
Willow Creek below Hwy 13 (WI1.0)	2B	Central	230	30	100	10

[1] Minn. Rules 7050.0470 and 7050.0430

[2] MPCA, 2010.

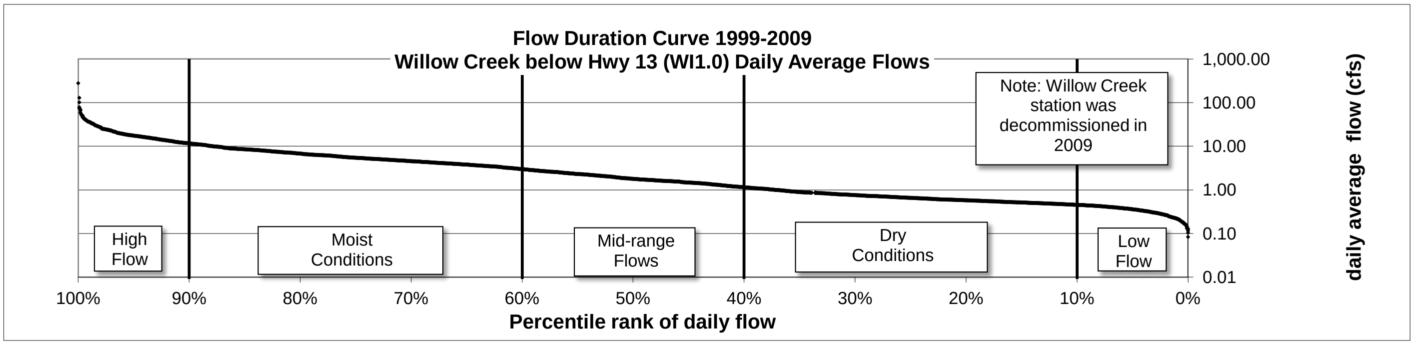
[3] Mark Tomasek, MPCA, personal communication, March 2013. MCES used 230 mg/l as the draft chloride standard pending results of EPA toxicity tests.

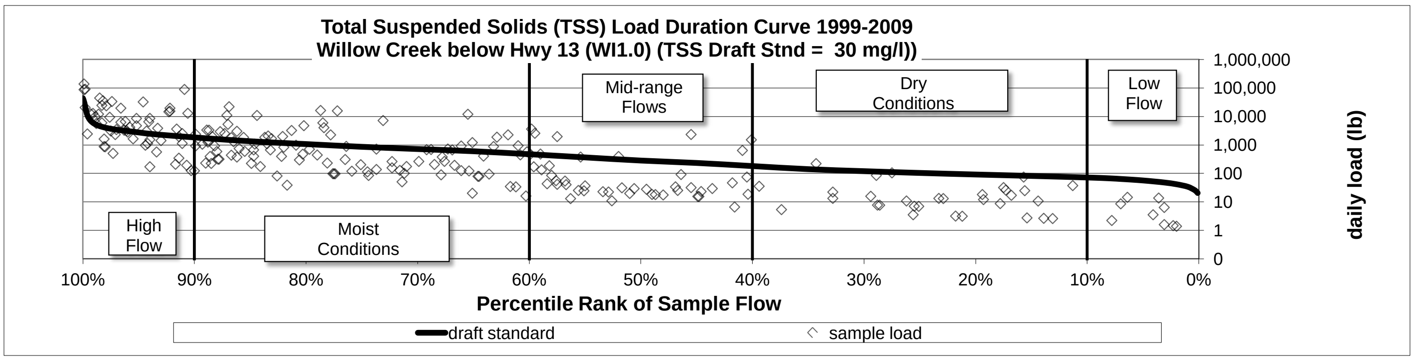
[4] MPCA, 2011. Draft standard states TSS standard concentration for Class 2A and 2B water must not be exceeded more than 10% of the time over a multiyear data window, with an assessment period of April through September.

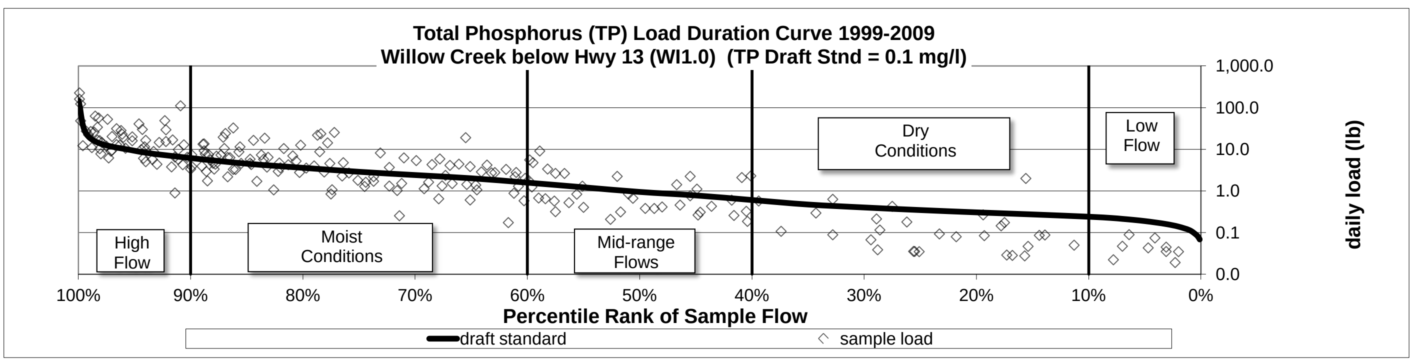
[5] MPCA, 2013a. To violate standard, concentration of causative variable (TP) must be exceeded, as well as one or more response variables: sestonic chlorophyll, BOD_5, DO flux, and/or pH.

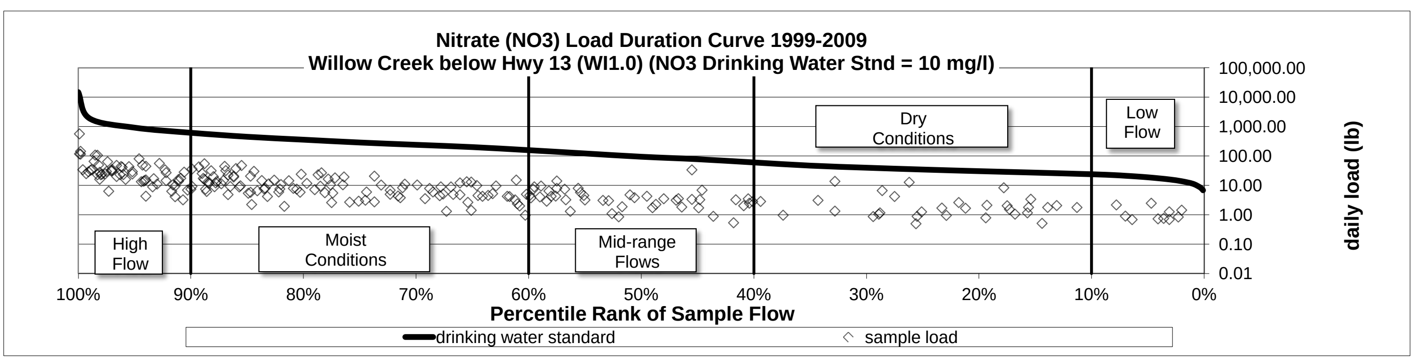
[6] MCES used the nitrate drinking water standard of 10 mg/l pending results of EPA toxicity tests and establishment of a draft nitrate standard for rivers and streams.

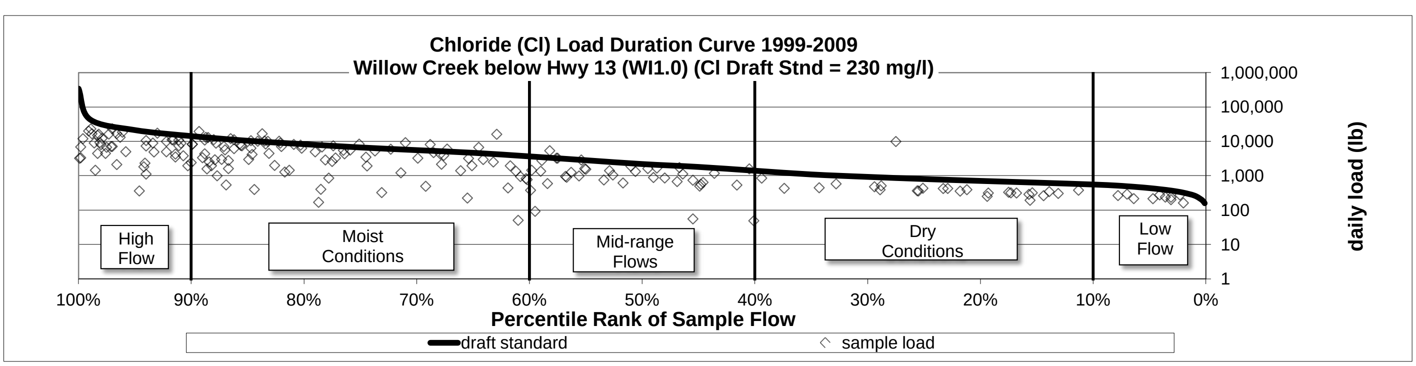
Figure WI-12: Willow Creek Flow and Load Duration Curves, 1999-2009











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 not collected any macroinvertebrate samples at the Willow Creek monitoring station.

Trend Analysis

Trend analysis was completed for the historical record of TP, NO3, and TSS using the U.S. Geological Survey (USGS) program QWTREND (Vecchia, 2003). QWTREND removes the variability of annual flow and seasonality from the statistical analysis, thus any trend identified should be independent of flow or seasonal variation.

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

Novotny and Stefan (2007) assessed flows from 36 USGS monitoring stations across Minnesota over a period of 10 to 90 years, finding that peak flow due to snowmelt was the only streamflow statistic that has not changed at a significant rate. Peak flows due to rainfall events in summer were found to be increasing, along with the number of days exhibiting higher flows. Both summer and winter baseflows were found to be increasing, as well. Novotny and Stefan hypothesized that increases in annual precipitation, larger number of intense precipitation events, and more days with precipitation are driving the increased flows.

Alterations in land use and land management 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 natural 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 trends for the period of 1999-2009 on Willow Creek for TSS, TP, and NO_3. The results are presented below.

Total Suspended Solids (TSS)

Two trends were identified for TSS flow-adjusted concentrations in Willow Creek during the assessed period of 1999 to 2009 (Figure WI-13, top panel). The assessment was performed using QWTREND without precedent 5-year flow setting. The trends identified were statistically significant (p=0.0025).

- Trend 1: 1999 to 2000, TSS flow-adjusted concentration increased from 8.7 mg/l to 22 mg/l (150%) at a rate of 6.4 mg/l/yr.

- Trend 2: 2001 to 2009, TSS flow-adjusted concentration decreased 22 mg/l to 6.1 mg/l (-72%) at a rate of -1.7 mg/l/yr.

The five-year trend in TSS flow-adjusted concentration in Willow Creek (2005-2009) was calculated to compare with other MCES-monitored streams, shown in the report section ***Comparison with Other Metro Area Streams***. TSS concentration decreased from 13.1 mg/l to 6.1 mg/l (-53%) at a rate of -1.4 mg/l/yr. Based on the QWTREND results, the water quality in Willow Creek in terms of TSS improved during 2005-2009.

Total Phosphorus

Based on the QWTREND analysis without precedent 5-year flow setting, no trends were reported for TP flow-adjusted concentrations in Willow Creek due to poor quality of statistical metrics.

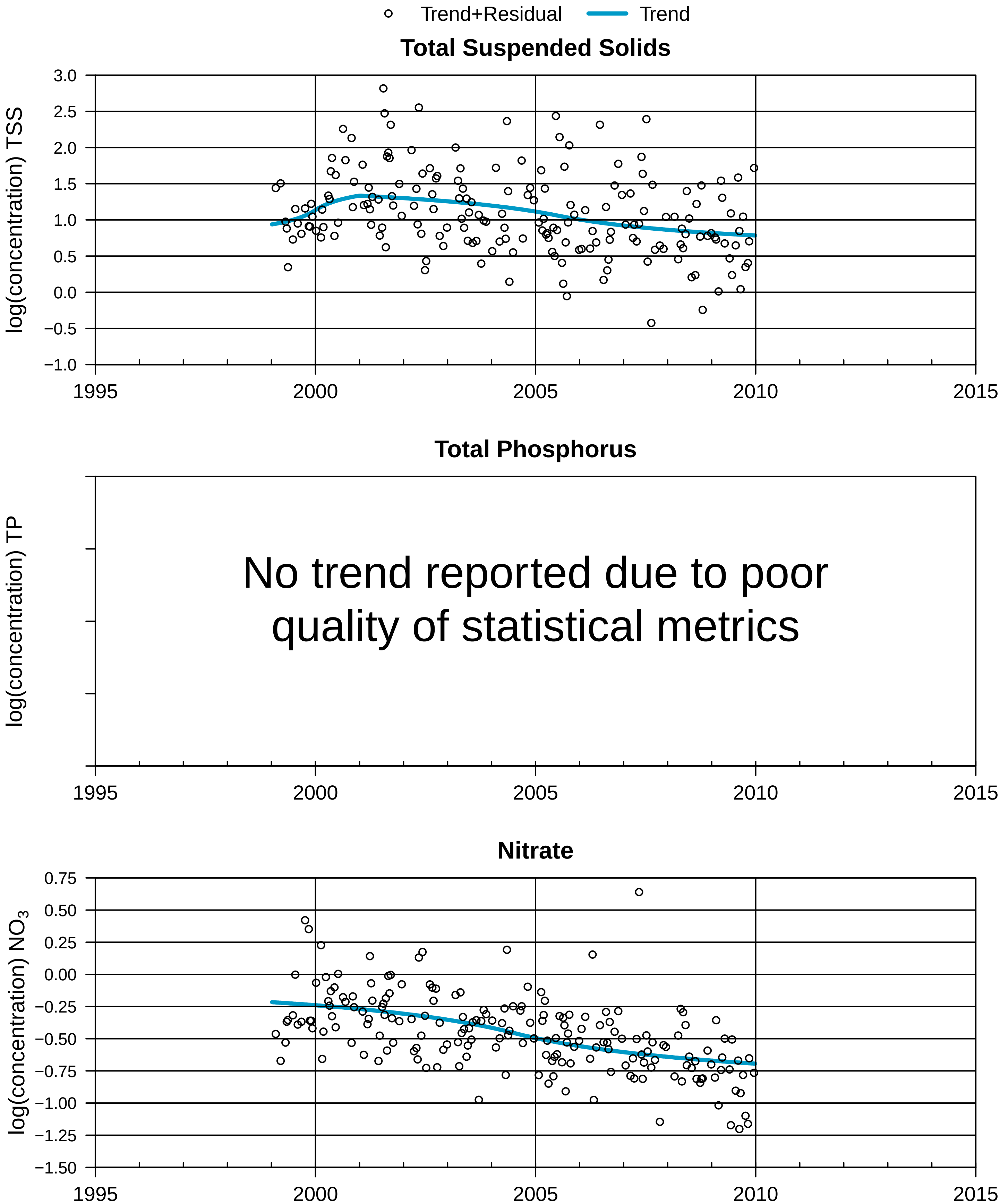
Nitrate

One downward trend was identified for NO_3 flow-adjusted concentrations in Willow Creek from 1999 to 2009 (Figure WI-13, bottom panel). The assessment was performed using QWTREND without precedent 5-year flow setting. The trend identified was statistically significant ($p=7.6x10^{-8}$).

- Trend 1: 1999 to 2009, NO3 flow-adjusted concentration decreased gradually from 0.61 mg/l to 0.20 mg/l (-67%) at a rate of -0.037 mg/l/yr.

The five-year trend in NO_3 flow-adjusted concentration in Willow Creek (2005-2009) was calculated to compare with other MCES-monitored streams, shown in the report section ***Comparison with Other Metro Area Streams***. NO_3 flow-adjusted concentration decreased from 0.32 mg/L to 0.20 mg/l (-37%) at a rate of -0.024 mg/l/yr. Based on the QWTREND results, water quality in Willow Creek in terms of NO_3 improved during 2005-2009.

Figure WI−13: Willow Creek Trends for TSS, TP and NO_3



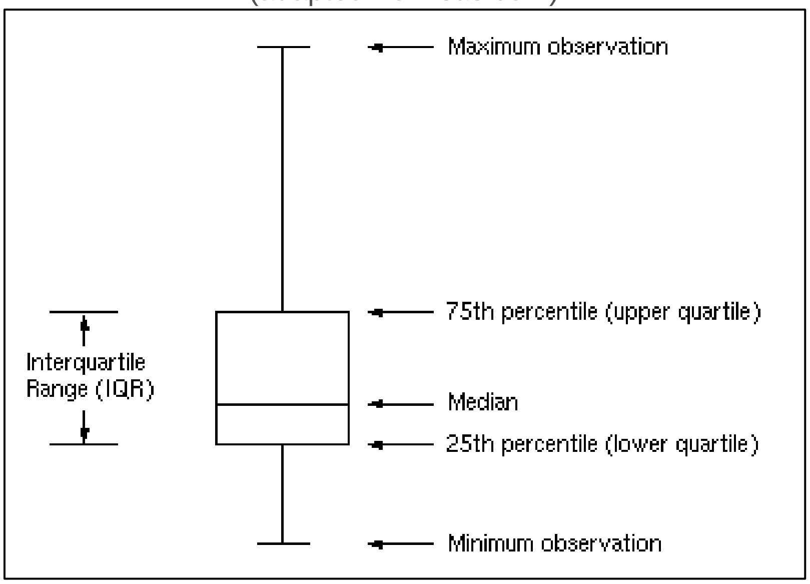
Comparison with Other Metro Area streams

Chemistry

Box-and-whisker plots are used to summarize the comparison of the historical flow, TSS, TP, and NO_3 and Cl data for Willow Creek with those of the other metropolitan area streams monitored by MCES and with the major receiving water (in this case the Minnesota River), the comparisons are shown in Figures WI-15 to WI-18.

Figure WI-14 shows the formatted legend of the format of 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 WI-14: General Schematic of a Box-and-Whisker Plot
(adapted from *sas.com*)



Comparisons for each chemical parameter for period 2003-2012, (1999-2009 for Willow Creek), 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 2002-2011 FWM concentration for the three receiving rivers (Mississippi, St. Croix, and Minnesota), shown as a dashed line. Generally speaking, the St. Croix River has the best water quality of the major rivers in the metro area, followed by the Mississippi River and then the Minnesota River.

Total Suspended Solids. The median annual FWM concentration for TSS in Willow Creek (54 mg/l) is lower than that of all other monitored metro area Minnesota River tributaries except Eagle Creek (Table WI-4; Figure WI-15). The median annual FWM concentration in Willow Creek is also lower than that of the Minnesota River as measured at Jordan Minnesota; (142 mg/l), indicating that Willow Creek has little impact on the TSS concentration in the Minnesota River.

Median annual runoff ratio for Willow Creek is similar to most of the other Minnesota River streams except Eagle Creek, which is dominated by shallow ground water inflows.

The Willow Creek median annual TSS load is also lower than that of all other monitored Minnesota River tributaries except Eagle Creek, and the median annual TSS yield (61 pounds/acre) is the lowest of the monitored Minnesota River tributaries.

Total Phosphorus. Similar to TSS, the Willow Creek median FWM TP concentration is the second lowest of the Minnesota River streams, with only Eagle Creek being lower (Figure WI-16). The median FWM TP concentration in Willow Creek is lower than the Minnesota River and thus serves to decrease the TP concentration in the river (0.161 mg/l vs. 0.24 mg/l) The Willow Creek annual TP load (1,130 pounds/year) is the second lowest (after Eagle Creek), and the median annual yield is the lowest of the monitored Minnesota River tributaries.

Nitrate. As with TSS and TP, the median annual FWM NO_3 concentration in Willow Creek is the second lowest of the Minnesota River tributaries, after Eagle Creek. It is also lower than that of the Minnesota River, and thus serves to dilute the river concentration (Figure WI-17). The median annual NO_3 load and yield in Willow Creek are the lowest of the monitored Minnesota River streams and among the lowest of all the monitored streams in the metro area.

Chloride. In contrast to the other constituents, the median annual FWM Cl concentration (116 mg/l) in Willow Creek is the highest of the metro area Minnesota River streams, and among the highest of all the monitored metro area streams (Figure WI-18). The FWM Cl concentration is also much higher than that of the Minnesota River (26 mg/l).The median annual CL load in Willow Creek (750,000 pounds/year) ranks near the low end of the Minnesota River tributaries, while the Cl yield ranks near the high end at 116 pounds/acre/year. The two most prevalent sources of Cl to streams are road surfaces (from chloride application as a de-icer) and WWTP effluent (from domestic water softeners).

Figure WI−15: Total Suspended Solids for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

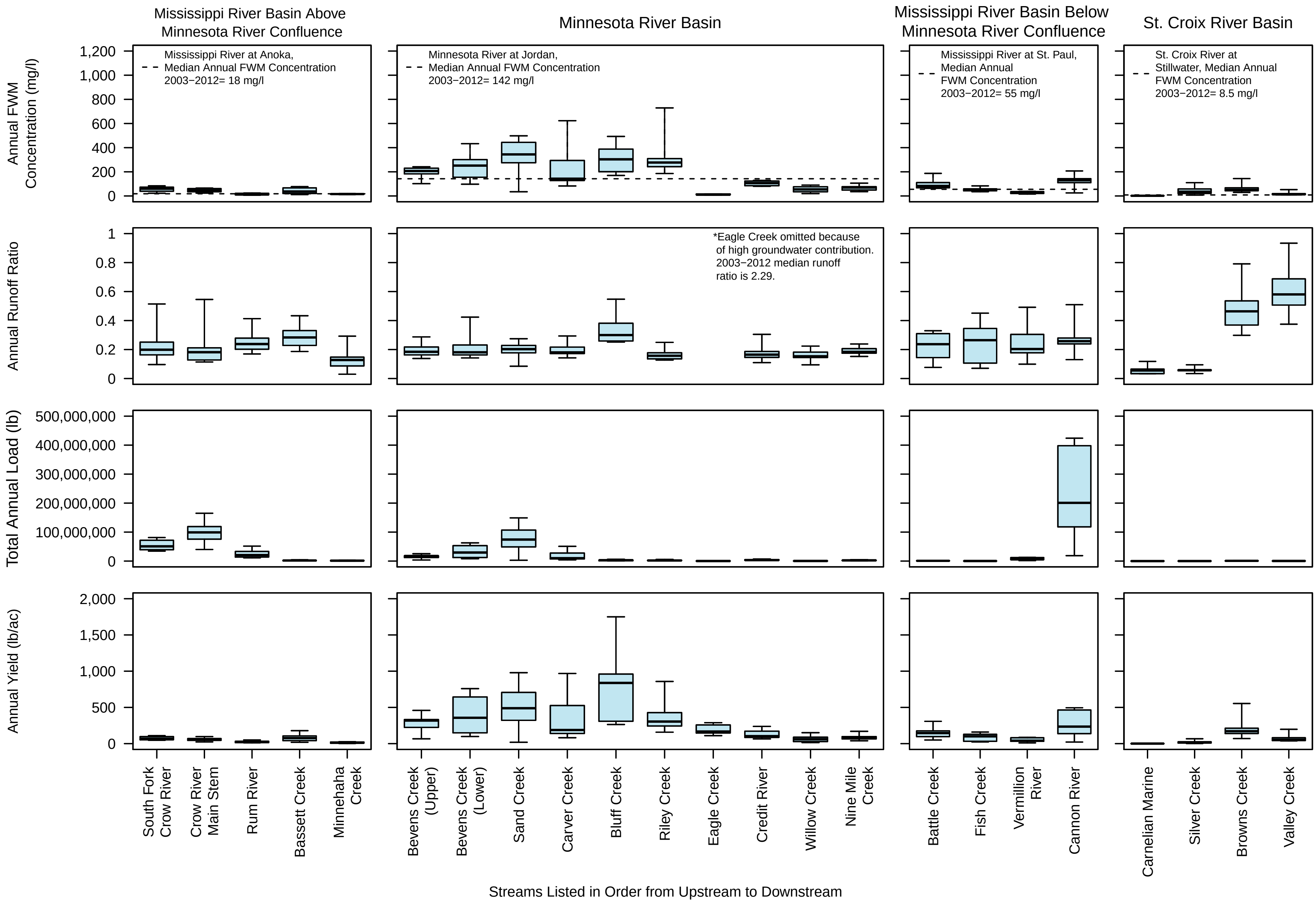


Figure WI−16: Total Phosphorus for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

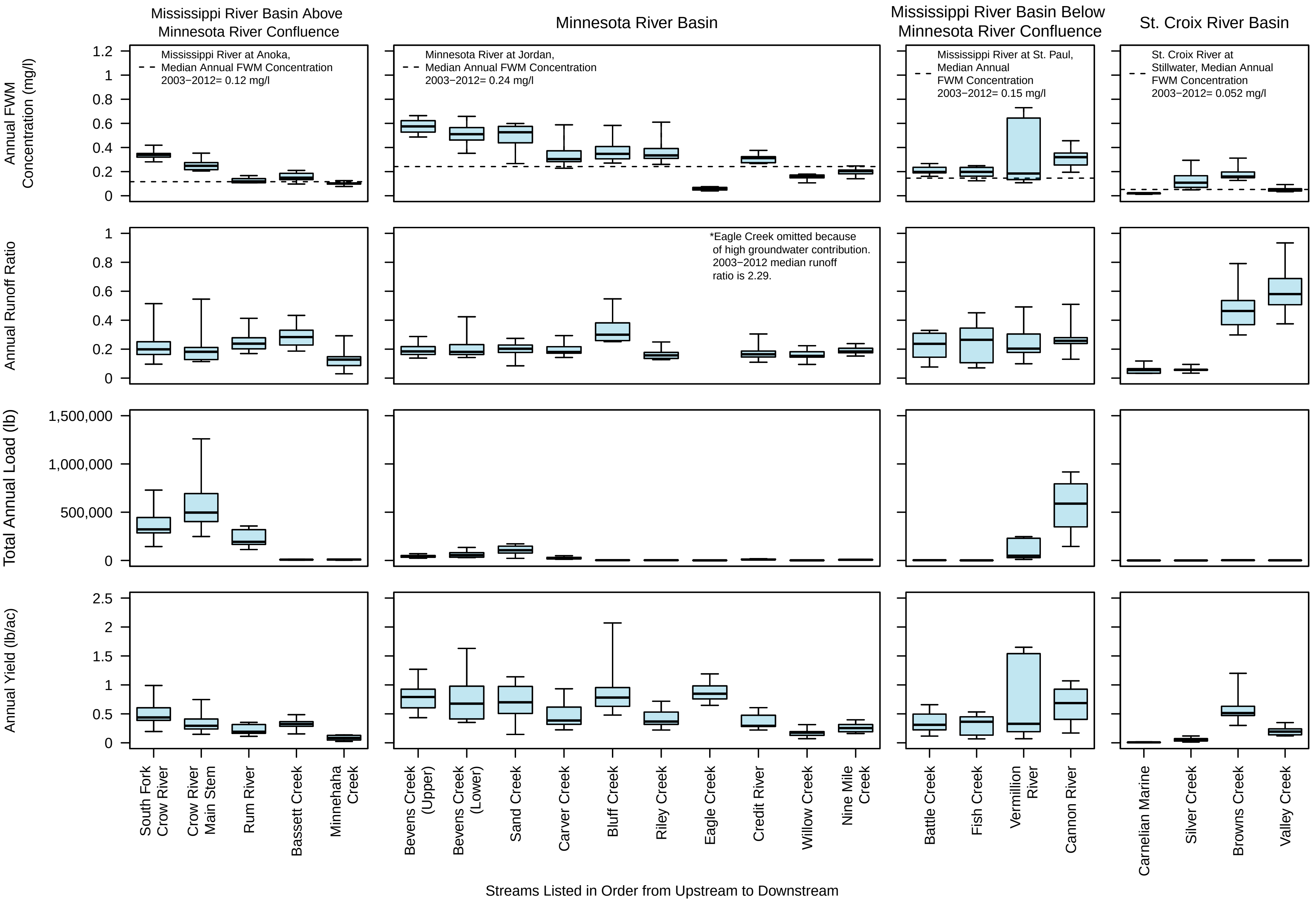


Figure WI−17: Nitrate for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

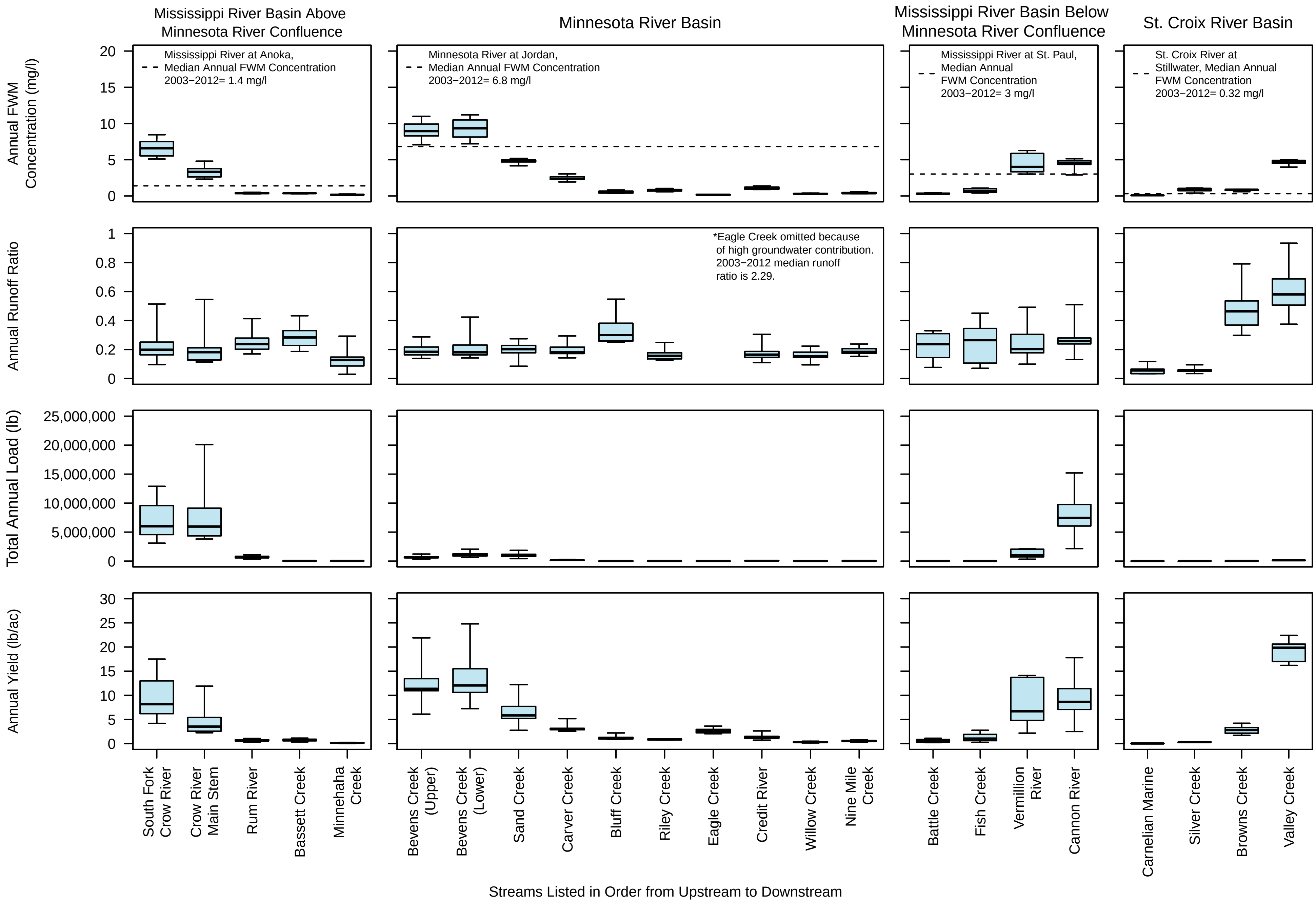


Figure WI−18: Chloride for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

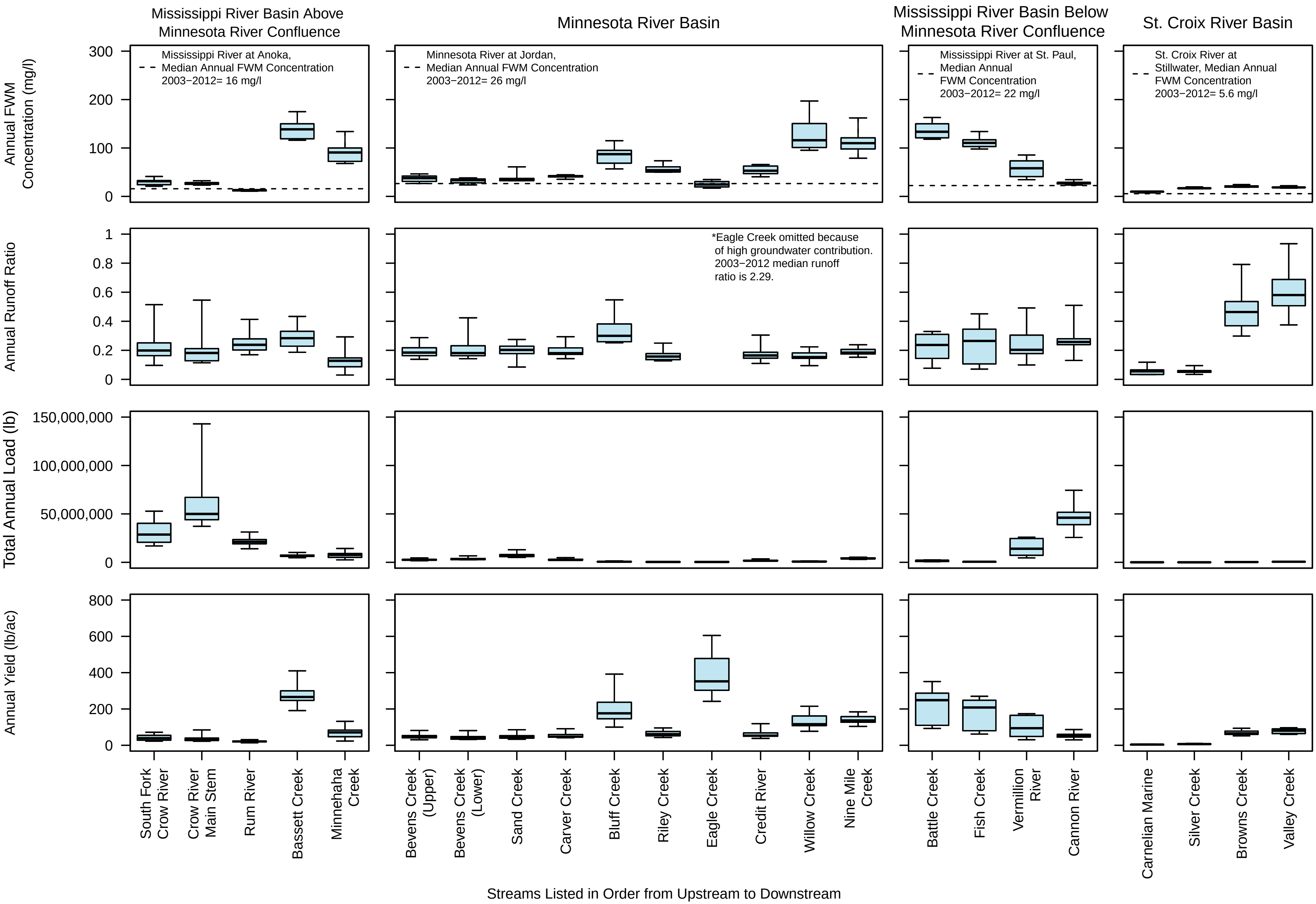


Table WI-4: Annual Median Concentrations, Loads, and Yields for MCES-Monitored Streams, 2003-2012

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

Metropolitan Area Trends Analysis

Statistical trend analysis for each MCES stream monitoring station was performed using QWTREND (Vecchia, 2003). Trend estimates were calculated for the last five years of available data (2008-2012 for most of the streams, but 2005-2009 for Willow Creek) to allow comparison of changes in water quality between streams. A similar approach was used in the 2013 MPCA nitrogen study (MPCA, 2013b) to compare QWTREND assessments in statewide streams and rivers.

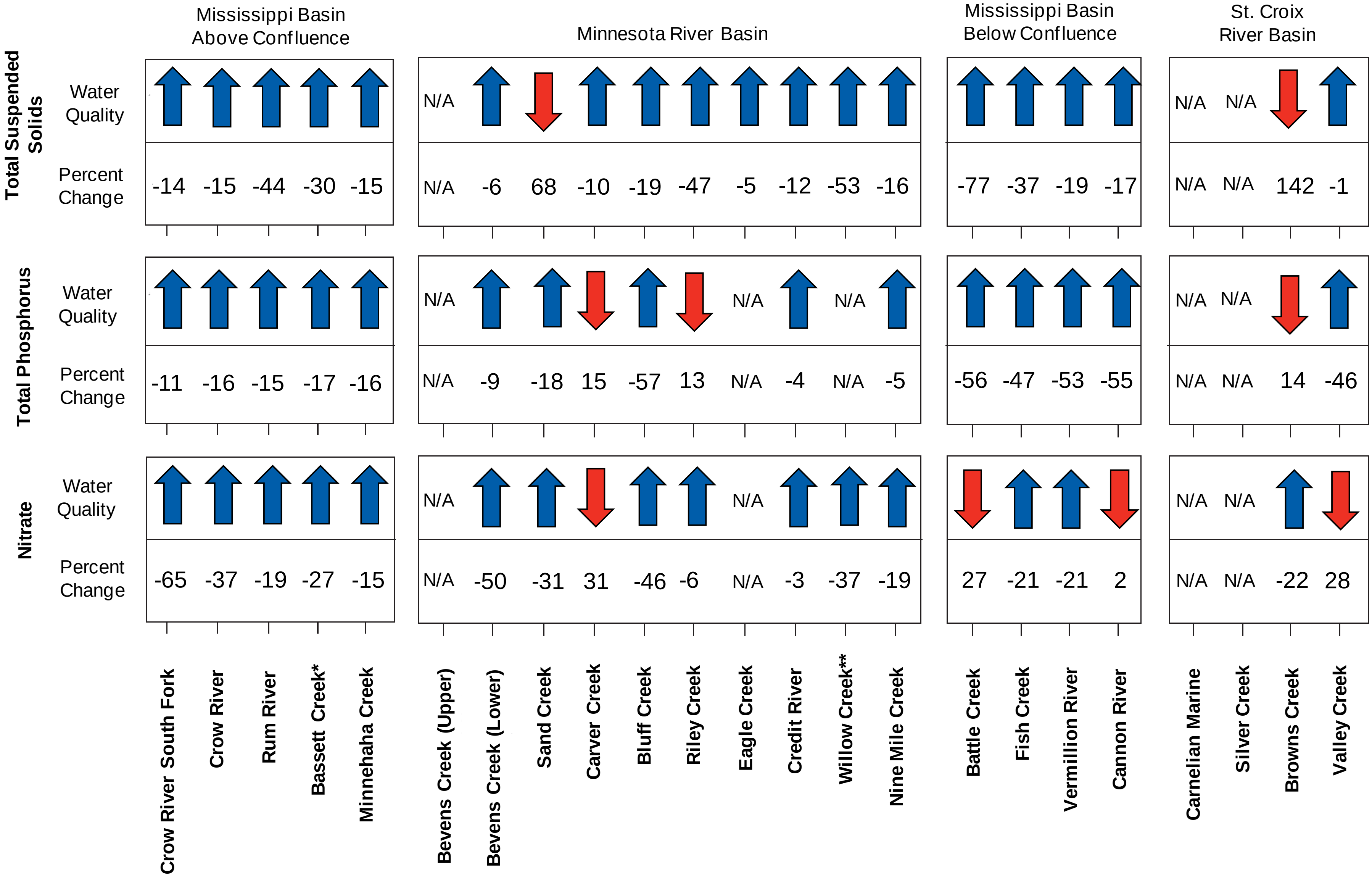
Estimated changes for TSS, TP, and NO_3 in MCES-monitored streams are presented below in two ways. First, tabulated results with directional arrows indicating improving (blue upward arrow) and declining (red downward arrow) water quality paired with percent change in flow-adjusted concentration estimated for 2008-2012 (Figure WI-19). Second, changes are shown by three seven-county metropolitan area maps (one each for TSS, TP, and NO_3 trends) with stream watersheds colored to represent improving and declining water quality (Figure WI-20). In both figures no trend was reported for those QWTREND analyses with poor quality of statistical metrics (for example, $p>0.05$).

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

The Minnesota River and its tributaries typically have had higher TSS concentrations than the Mississippi or St. Croix Rivers and associated tributaries. The trend analysis results indicate decreasing TSS flow-adjusted concentrations in all Minnesota River tributaries with the exception of Sand Creek. For the last five years of monitoring in Willow Creek, TSS and NO3 flow-adjusted concentrations decreased, resulting in improved water quality for those pollutants. No statistically significant trend was reported for TP flow-adjusted concentration in Willow Creek, due to the poor quality of the statistical metrics.

Figure WI-19: Regional Estimated Trends in Flow-Adjusted Stream Concentrations of TSS, TP, and NO_3, 2008-2012

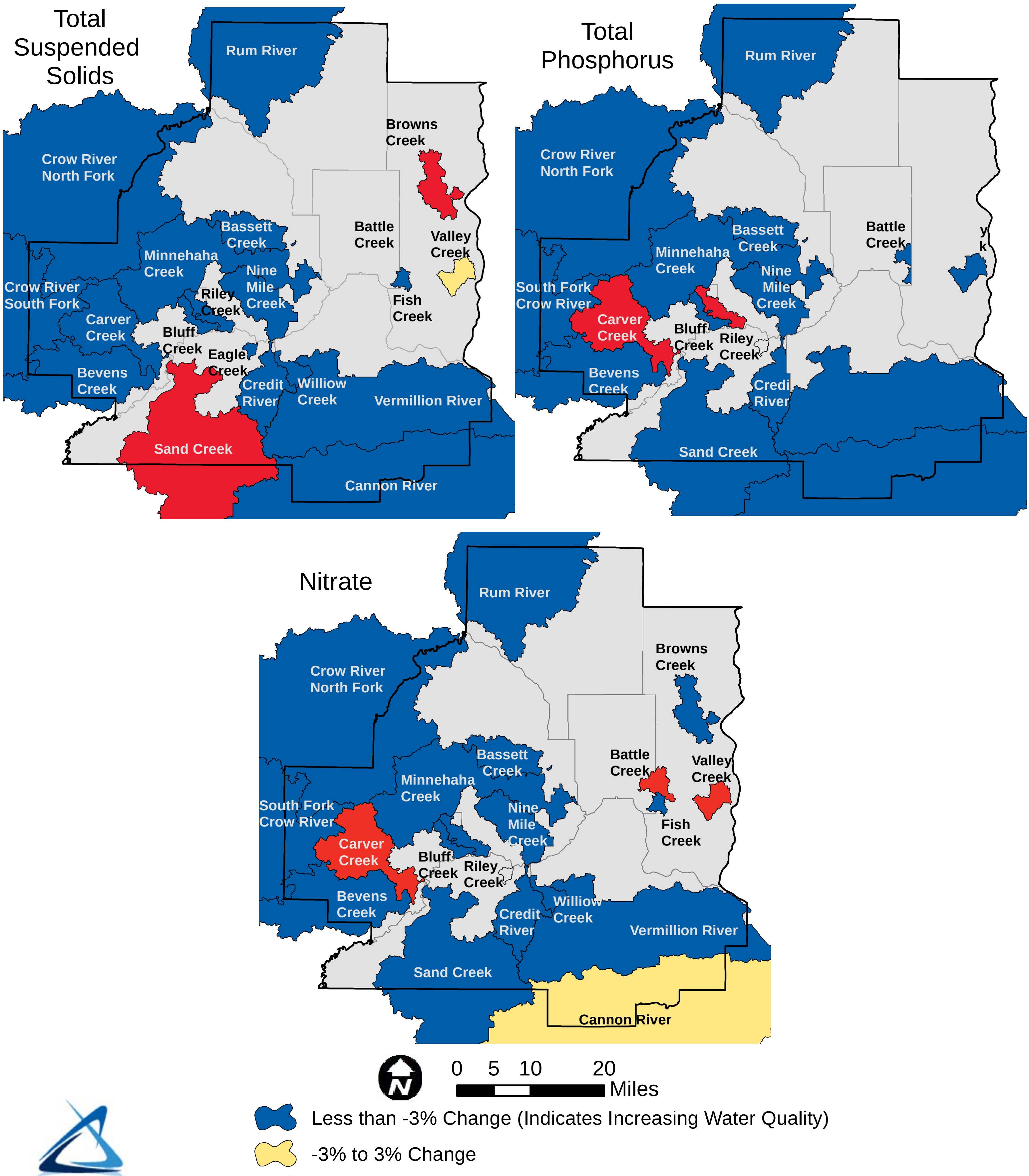
(Grouped by Major River Basin; As estimated by QWTrend)



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

Figure WI-20: Regional Maps of Estimated Trends in Flow-Adjusted Stream Concentrations of TSS, TP, and NO3, 2008-2012

(As estimated by QWTrend)



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Conclusions

Willow Creek is a tributary to the Minnesota River that drains parts of Dakota and Scott Counties, including portions of the cities of Savage, Lakeville, Apple Valley, and Burnsville (Metropolitan Council Districts 4 and 15). Land cover in the watershed is mostly developed, followed by grass land, open water, forested, and wetlands. The watershed generally slopes from south to north towards the Minnesota River. The stream flows through several lakes and Sunset Pond before it descends the Minnesota River bluff, and then enters a box culvert under the Burnsville landfill. There are two industrial stormwater permittees within the watershed. Nearly the entire watershed is located upstream of the monitoring station.

Willow Creek is essentially a small, suburban watershed. About 75 percent of the land cover in the watershed is development of varying density, and about 54 percent of this area has 26-50 per cent impervious cover.

TSS, TP, and NO_3 concentrations, loads, and yields are among the lowest of the MCES monitored Minnesota River tributaries. Conversely, Cl concentrations and yields are among the highest of the metro area Minnesota River streams, but the total Cl load ranks among the low to middle of these streams. This is likely due to the developed nature of the watershed coupled with its relatively small size (about 10 square miles).

Over the latest five year period for which data are available (2005-2009), trends in TSS and NO_3 flow-adjusted concentrations have decreased resulting in improved water quality for those pollutants. No significant trend for TP flow-adjusted concentrations were identified due to poor quality of statistical metrics.

Several lakes in the Willow Creek watershed have been designated as impaired. Keller Lake and Early Lake are impaired for excessive nutrients; Lac Lavon is impaired for mercury in fish tissue; Crystal Lake is impaired for excessive nutrients and mercury in fish tissue. Lee Lake was listed as impaired for excessive nutrients, but was de-listed in 2014. Willow Creek itself is not listed as impaired. Approved plans for addressing nutrient impairment have been completed for Crystal, Early, and Keller Lakes.

MCES has not conducted macroinvertebrate sampling or assessment for Willow Creek.

Recommendations

This section presents recommendations for monitoring and assessment of Willow Creek, as well as recommendations for partnerships to implement stream improvements. MCES recognizes that cities, counties, and local water management organizations are ideally suited to target and implement volume reduction, pollutant removal, and stream restoration projects within the watershed. It is beyond the scope of this document to suggest locations for implementation projects. Instead, MCES encourages the local water management organizations to use the results of this report to leverage funding and partnerships to target, prioritize, and implement improvement projects. MCES will repeat its analysis of water quality trends in 5 years, to assess potential changes in water quality.

The Willow Creek monitoring station was decommissioned during 2009 due to budget constraints, thus minimal recommendations are presented.

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 consider resuming water quality monitoring of Willow Creek, perhaps in partnership with the Eagan-Inver Grove Heights Watershed Management Organization (formerly the Black Dog WMO).
- The location of the stream in an underground box culvert would be favorable for winter monitoring (to prevent damage, monitoring equipment in most streams must be removed prior to winter freeze-up) which could further define the sources and timing of the Cl loading to the stream and the Minnesota River.
- MCES should continue to evaluate the effects of groundwater withdrawal on surface waters, including updating analyses with the best available data and linking results to predictive groundwater modeling and the comprehensive planning process.
- As resources allow, MCES should provide local water managers in the Willow Creek watershed with information about the heightened potential for surface waters to be impacted by groundwater changes in the watershed. This information should be included in watershed and local surface water management plan updates.

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