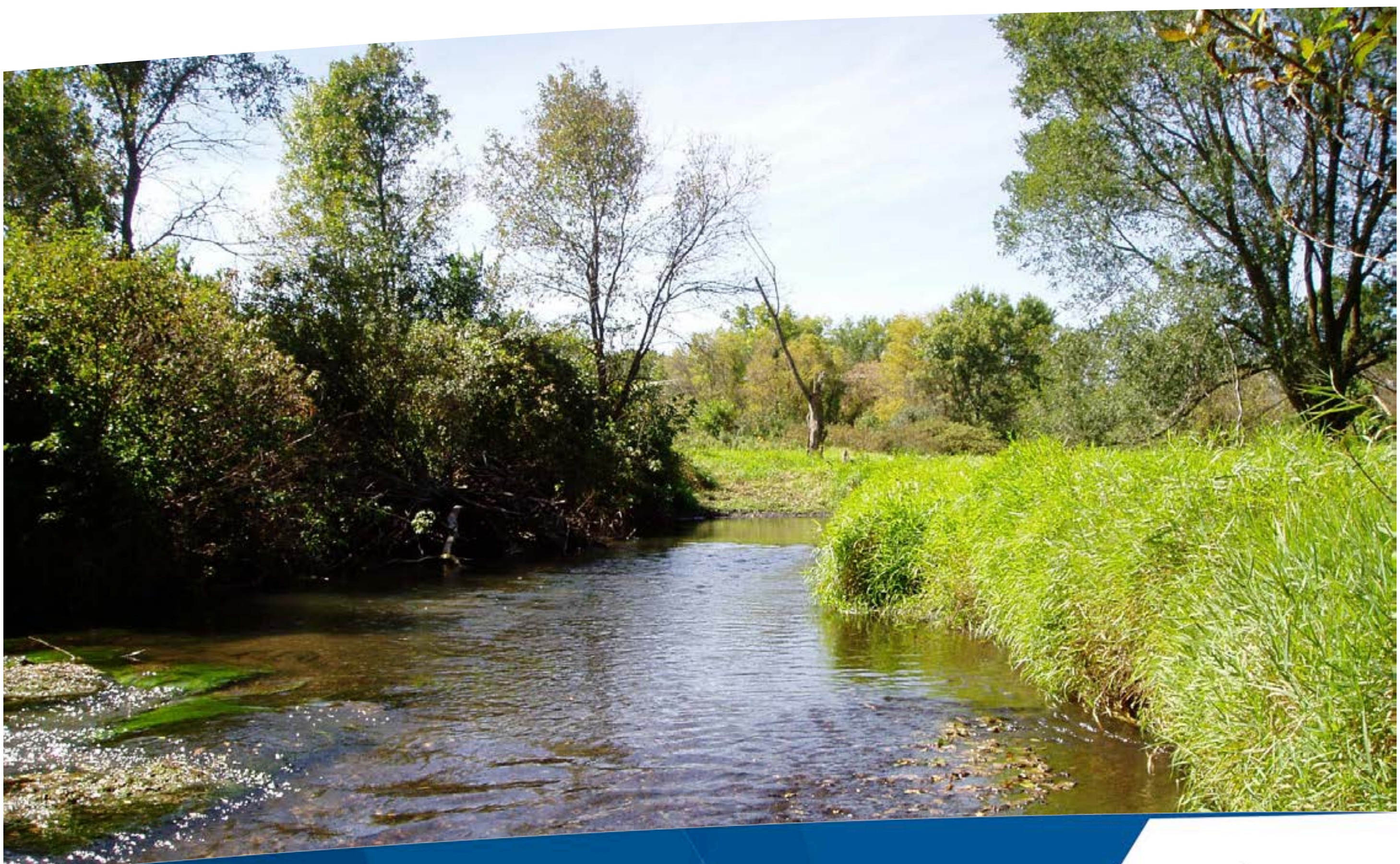
Comprehensive Water Quality Assessment of Select Metropolitan Area Streams

VERMILLION RIVER



METROPOLITAN COUNCIL

December 2014

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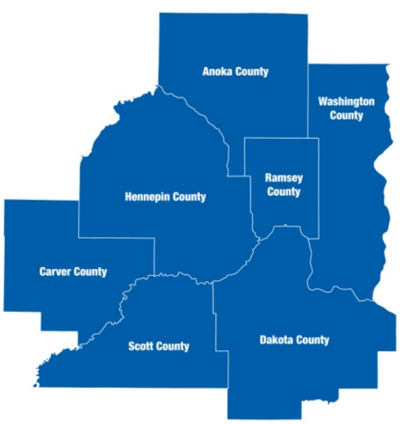

The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system, collects and treats wastewater, coordinates regional water resources, plans and helps fund regional parks, and administers federal funds that provide 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, *Vermillion River*, is one in a series produced as part of the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams.* Located in Dakota, Scott, and Goodhue counties, the Vermillion River is one of the eight Mississippi River tributaries examined. This section discusses a wide range of factors that have affected the condition and water quality of the Vermillion River.

Cover Photo

The photo on the cover of this section depicts the Vermillion River near mile 15.6. It was taken by Metropolitan Council staff.

Recommended Citations

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

Metropolitan Council. 2014. *Vermillion River*. In *Comprehensive water quality assessment of select metropolitan area streams*. St. Paul: Metropolitan Council.

Please use the following to cite the entire report:

Metropolitan Council. 2014. *Comprehensive water quality assessment of select metropolitan area streams*. St. Paul: Metropolitan Council.

Content

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Introduction

The Vermillion River is located in the southeast metropolitan area and is a tributary to the Mississippi River (Figure VR-1). It drains approximately 312 square miles of agricultural areas, forest, wetlands, grasses, and urban areas (cities of Elko New Market, Apple Valley, Lakeville, Farmington, and Hastings) through portions of Scott, Dakota, and Goodhue counties.

Figure VR-1: Vermillion River near the Empire Wastewater Treatment Plant, approximately 15 miles upstream of Hastings, Minnesota

This report:

- documents those characteristics of the Vermillion River and its watershed most likely to influence stream flow and water quality.
- presents the results from assessments of flow, water quality, and biological data.
- presents statistical assessments of trends in stream chemistry concentrations.
- draws conclusions about possible effects of landscape features, climatological changes, and human activities on flow and water quality.
- compares the Vermillion River 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, for potential MCES collaborations with local watershed management organizations, and other potential actions to remediate any water quality or flow concerns.

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

Partnerships and Funding

MCES has supported water quality monitoring of the Vermillion River immediately downstream of Highway 61 in the city of Hastings since 1995. MCES partners with the Dakota County Soil and Water Conservation District (SWCD) to operate the monitoring station as part of MCES's WOMP (Watershed Outlet Monitoring Program) program, which is funded solely by MCES.

The Vermillion River Watershed Joint Powers Organization (VRWJPO; formed 2002) is the local water management organization charged with development and implementation of policies, programs, and projects that protect and preserve water resources within the watershed. MCES staff serve on the Technical Advisory Group (TAG) for the VRWJPO. The VRWJPO works closely with other organizations, like MnDNR, the University of Minnesota, the Minnesota Outdoor Heritage Fund, and Trout Unlimited to perform projects that protect both the trout habitat in the river and the watershed's water resources (VRWJPO, 2011).

In addition to the work the VRWJPO accomplishes in the watershed, Friends of the Mississippi River (FMR), MnDNR, Dakota County SWCD, and MCES have worked collaboratively to improve the 400-acre MCES property at the Empire Wastewater Treatment Plant (WWTP) in Empire Township. Collaborative projects have included a natural resources management plan (FMR, *et al*., 2002), streambank stabilization and trout habitat restoration, restoration of a 50-acre wet meadow wetland, and removal of invasive species including buckthorn and purple loosestrife. During the WWTP expansion of 2004-2007, MCES used the natural resources plan to site a number of innovative stormwater practices within the plant process area, including three bioinfiltration basins, five pervious paver parking areas, vegetated swales to transport runoff, a green (vegetated) roof, and a prairie plant garden.

In 2002 MCES funded the SWCD to prepare a Vermillion River headwaters groundwater recharge area inventory and protection plan (Emmons and Olivier Resources, Inc., 2007). Goals of the plan included identification of groundwater recharge areas; identification of the relationship between recharge, river flow, and potential development impacts; prioritization of stormwater infiltration areas; and guidance for incorporation protection of groundwater recharge areas into community plans.

Monitoring Station Descriptions

The WOMP monitoring station was originally located on the north bank of the Vermillion River inside the ConAgra Mill near Highway 61 in Hastings, Minnesota, about two miles upstream from the Mississippi River floodplain, and is referred to as VR 2.0. In 2010 the station was moved to the south side of the river, almost directly across from the original location.

The flow monitoring station includes continuous stage monitoring (OTT PLS Pressure Transducer) and an automatic water sampler (Hach Sigma Sampler) which was used when composite samples were collected. The rating curve at this location is based on a relationship between a staff gauge and water level. An *in-situ* turbidity probe, previously deployed just upstream of the WOMP station during 2009-2011 by the VRWJPO, was installed at the station in 2012. During 2007-2012 only grab samples were collected from the station; no event composite samples have been collected since 2006 due to infrastructural and technical difficulties.

There is no rain gauge at this station; however, precipitation data are obtained from the Minnesota Climatology Working Group, Hastings Dam Station Number 213567. Daily precipitation totals from this station 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.

MCES also conducts grab sample monitoring at three locations in the upper watershed as part of its river monitoring program. Three sampling locations - VR20.6 (Vermillion River near Farmington), VR15.6 (Vermillion River near Empire), and VR 2.7 (Vermillion River near Hastings) – were established in the late 1970's to assess water quality effects of effluent discharge from the Empire WWTP. The Farmington and Empire stations are located upstream and downstream, respectively, of the original Empire WWTP effluent discharge pipe. These stations include auto-monitoring equipment (dissolved oxygen, specific conductance, and temperature) and manual collection of weekly or biweekly grab samples, which are analyzed for bacteria, nutrients chloride, oxygen demand, and suspended solids. The third river monitoring station (VR 2.7) is located 0.7 miles upstream of the WOMP station. Monitoring at this station is limited to auto-monitoring (dissolved oxygen, conductance, and temperature) and grab sampling for bacteria and ammonia. This report focuses on the data collected at the WOMP station (VR 2.0) and will include limited discussion of the upstream river monitoring sites.

Stream and Watershed Description

The Vermillion River flows through Scott, Dakota, and Goodhue counties and has a drainage area of approximately 312 square miles. The Vermillion River has several headwaters, for example the outlet of Lake Marion in the city of Lakeville and wetlands in New Market and Castle Rock townships. The river generally flows to the east for 43 miles until it flows over the Vermillion Falls (also known as the Hastings Dam) south of Highway 61, through the Vermillion River gorge, and under a railroad bridge, which MCES uses as the Mile 0.0 designation for the river. Downstream of the railroad bridge, the river splits, with one branch flowing north to the Mississippi River and the second branch flowing south, paralleling the Mississippi River within its floodplain for approximately 20 miles before joining the river near the city of Red Wing (VRWJPO, 2005).

The portion of the Vermillion River in Scott and Dakota counties lies within the seven-county metropolitan area and the Metropolitan Council's jurisdiction (Council Districts 4, 15, and 16). In 1988 and 2003 portions of the Vermillion River and its tributaries were designated as trout stream by the MnDNR [M.S. § 97C.005, Special Management Waters; (VRWJPO, 2005)].

In addition to the Vermillion River, there are many other open water bodies within the watershed. For example, Lake Alimagnet (104 acres), Long Lake (36 acres), Farquar Lake (64 acres), Lake Marion (530 acres), Potters Lake (8 acres), and Rice Lake (55 acres) are lakes in the Vermillion River watershed. For more information about lakes in the watershed, please see the Lake Finder website from the MnDNR (MnDNR, 2014).

Additionally, there are a number of tributaries that feed into the Vermillion River, including South, Middle, and North Creeks and the North and South Branches. The largest tributary, the

South Branch, enters the main stem of the Vermillion River near river mile 12, downstream of the former location of the Empire WWTP effluent outfall.

The Vermillion River watershed is a total of 199,474 acres, with 149,436 acres (74.9%) of the watershed upstream of the monitoring station. The entire watershed has 98,271 acres/49.3% (75,416 acres/50.5% monitored) agricultural land and 47,070 acres/23.6% (39,867 acres/26.7% monitored) developed urban land (Table VR-1; Figure VR-2). The urban area includes the cities of Farmington, Hampton, Coates, and Vermillion, the majority of Elko New Market and Hastings, and portions of Burnsville, Apple Valley, Lakeville, Rosemount and Red Wing.

Along with the 50,038 unmonitored acres in the Vermillion River watershed downstream of the monitoring station, a 23,427 acre section of land topographically drains to the Vermillion River, but is excluded from the watershed discussion for this study. This area is north of the mapped watershed, encompassing portions of Apple Valley, Eagan, Inver Grove Heights, Sunfish Lake, and Rosemount. It has been determined that the majority of surface water in this area is either infiltrated to groundwater, landlocked, or drains by overland flow directly to the Mississippi River (M. Zabel, VRWJPO, personal communication, 2015).

Based on the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) 2009 Cropland Data Layer of agricultural land in the watershed, 43% (42% within the monitored area) is planted in corn and 23% (23% within the monitored area) in soybeans. According to a statewide estimate of potentially draintiled fields by University of Minnesota researchers (D. Mulla, University of Minnesota, personal communication, 2012), 4% of the agricultural land in the monitored and total watershed is potentially draintiled.

The geologic history of a watershed dictates many soil and hydrologic properties and surface topography. The Vermillion River watershed was last glaciated during the Wisconsin Glaciation, which began approximately 75,000 years ago (Lusardi, 1997). Two separate lobes of the glacier advanced and retreated over the watershed. The Superior Lobe was first, and it formed the St. Croix moraine till and outwash plain in the northeast part of the watershed. The second lobe was the Des Moines Lobe which formed the Bemis moraine present in the western part of the watershed (Balaban and Hobbs, 1990). As the glaciers retreated they exposed the limestone, dolomite, sandstone, and shale bedrock. Additionally, sandy outwash was deposited, which is the present-day target of many quarries in the Vermillion River watershed.

Past studies (Almendinger and Mitton, 1995; Dakota County, 2003) indicate that the complicated geology of the watershed drives both shallow groundwater discharge to the river, as well as flow from the river to surficial groundwater. A buried valley of an ancient precursor to the Mississippi River cuts across the Vermillion River from northeast to southwest upstream of the city of Hastings, near the city of Vermillion. The depth-to-bedrock in the buried valley (which is filled with later glacial outwash) is greater than 500 feet, in contrast to a depth of less than 50 feet outside of the buried valley. The buried valley provides a conduit for river water to flow downward to surficial aquifers. See the ***Hydrology*** section for more information.

Table VR-1: Vermillion River Land Cover Classes[1]

Land Cover Class	Monitored		Unmonitored		Total	
	Acres	Percent	Acres	Percent	Acres	Percent
5-10% Impervious	7,076	4.7%	1,856	3.7%	8,932	4.5%
11-25% Impervious	5,726	3.8%	2,837	5.7%	8,562	4.3%
26-50% Impervious	20,573	13.8%	1,607	3.2%	22,180	11.1%
51-75% Impervious	4,148	2.8%	717	1.4%	4,866	2.4%
76-100% Impervious	2,343	1.6%	186	0.4%	2,529	1.3%
Agricultural Land	75,416	50.5%	22,855	45.7%	98,271	49.3%
Forest (all types)	8,399	5.6%	7,877	15.7%	16,275	8.2%
Open Water	984	0.7%	1,242	2.5%	2,225	1.1%
Barren Land	0	0.0%	2	0.0%	2	0.0%
Shrubland	280	0.2%	122	0.2%	402	0.2%
Grasses/Herbaceous	13,879	9.3%	4,286	8.6%	18,165	9.1%
Wetlands (all types)	10,611	7.1%	6,452	12.9%	17,064	8.6%
Total	**149,436**	**100.0%**	**50,038**	**100.0%**	**199,474**	**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.

According to the U. S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) STATSGO soils data, nearly all of the soils in the Vermillion River watershed are characterized as Type B soils, which have a moderate infiltration capacity. There are few, localized regions of soils with high infiltration capacities, or Type A soils, near Farmington and Empire, and the dual hydrologic soil group, Type B/D, along the Mississippi River and south of Hastings (VRWJPO, 2005). 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 consists of hummocky till in the far west, transitioning into rolling till along the south watershed border; the remainder of the watershed is relatively flat outwash and alluvium plane carrying the river over the Hastings Dam (Vermillion Falls) to the Minnesota River (Figure VR-3). The maximum watershed elevation is 1223.0 MSL and the minimum elevation is 752.5 MSL within the monitored area. Within the monitored area 2% of the slopes are considered steep, and an additional 1% is considered very steep (MnDNR, 2011).

Figure VR-2

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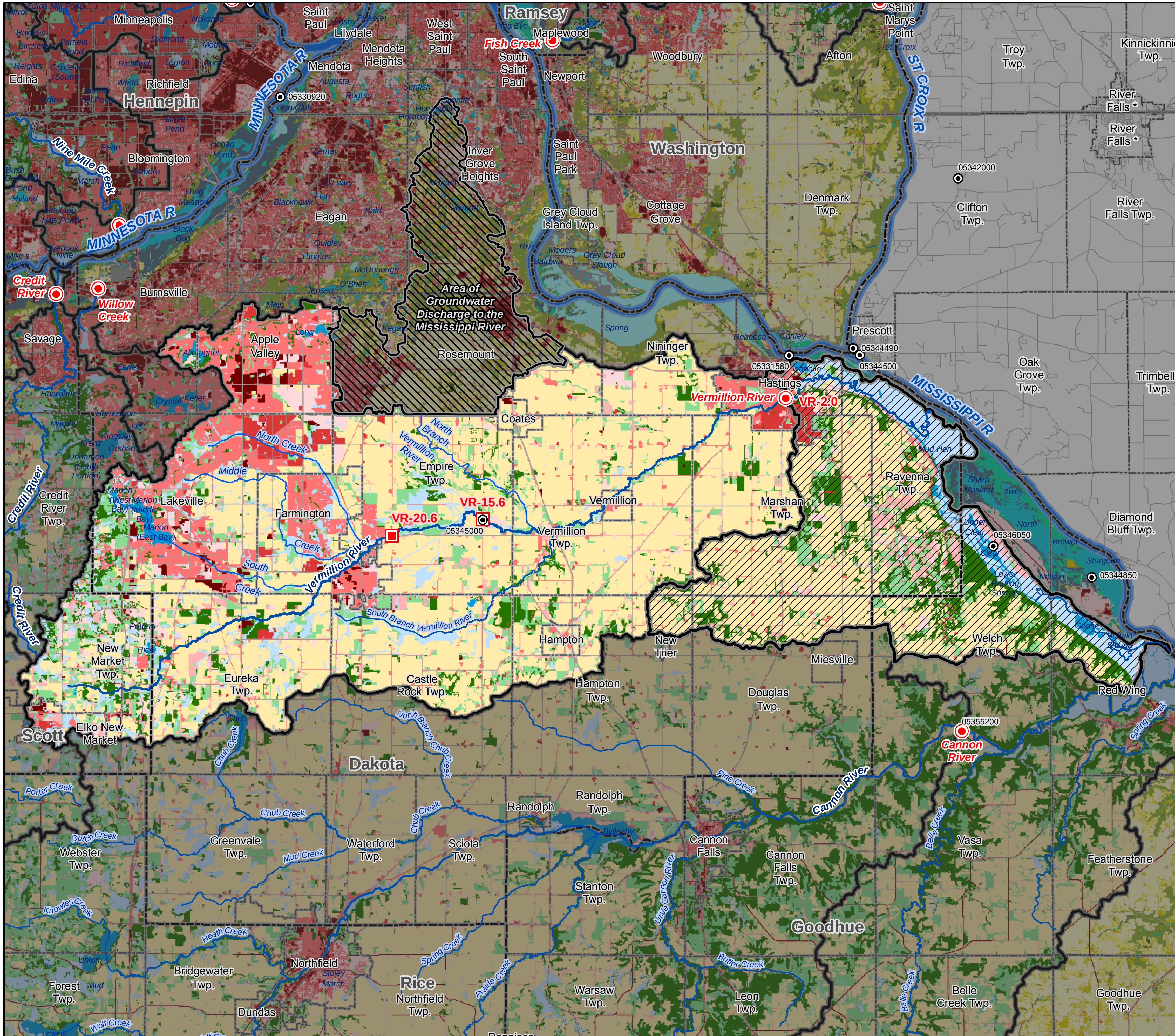
MLCCS-NLCD Hybrid Land Cover

Vermillion River



MCES River Monitoring Sites
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
Vermillion River

Land Cover Class	Monitored Acres	Percent	Unmonitored Acres	Percent	Total Acres	Percent
5-10% Impervious	7,076	4.7%	1,856	3.7%	8,932	4.5%
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Total	**149,436**	**100.0%**	**50,038**	**100.0%**	**199,474**	**100.0%**

0 2 4 6 8 10
Miles

The Vermillion River watershed contains four domestic wastewater treatment plants, including two Class A facilities - the Metropolitan Council's Empire WWTP and the Elko-New Market WWTP (Figure VR-4, Table VR-2). However in 2008 the Empire WWTP's outfall was diverted to the Mississippi River north of Hastings. Part of this diversion project included an expansion and upgrade of the Empire WWTP, with a biological phosphorus removal system added in 2006. The Elko-New Market WWTP was decommissioned in 2011, with the wastewater directed to the Empire WWTP. There are no WWTPs in the unmonitored part of the watershed. The watershed has four cooling, potable treatment and dewatering facilities, two industrial wastewater permit holders, and19 industrial stormwater permit holders within the monitored part of the watershed. There is one cooling, potable treatment and dewatering facility and three industrial stormwater permit holders in the unmonitored part.

The Vermillion River watershed has 87 registered feedlots with a total of 12,700 animal units (AUs) in the monitored part of the watershed, and an additional 35 registered feedlots with a total of 5,636 AUs in the unmonitored part. 44 of the feedlots in the monitored area have 100 AUs or more, and 20 feedlots in the unmonitored area have 100AUs or more. The largest feedlot in the watershed is a beef cattle farm with 995 AUs.

Table VR-2: Permitted Domestic Wastewater Treatment Facilities Discharging to the Vermillion River

Permit #[1]	Permit Holder	Design Flow (mgd)	Class[2]	Phosphorus Reduction History[3]	Other notes[3]
MN0045845	Met Council - Empire WWTP	29	~~A~~	P reduction initiated 06/2006	Effluent diverted from Vermillion River to Mississippi River starting 01/2008
MN0056219	Elko-New Market WWTP	0.362	A	P reduction initiated 03/2006	Facility ceased operation 12/2011
MN0021946	Hampton WWTP	0.101	D	NA	NA
MN0025101	Vermillion WWTP	0.054	C	NA	NA

[1] Facilities with design flow > 1 mgd shown in gray

[2] In general, Class A and B WWTPs use mechanical systems with activated sludge that continuously discharge. Class D are stabilization ponds that are allowed to discharge March 1-June 15 (spring discharge) and September 15-December 31 (fall discharge). See Minn. Rule. 9400.0500, Classification of Facilities, for more information.

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

Figure VR-3

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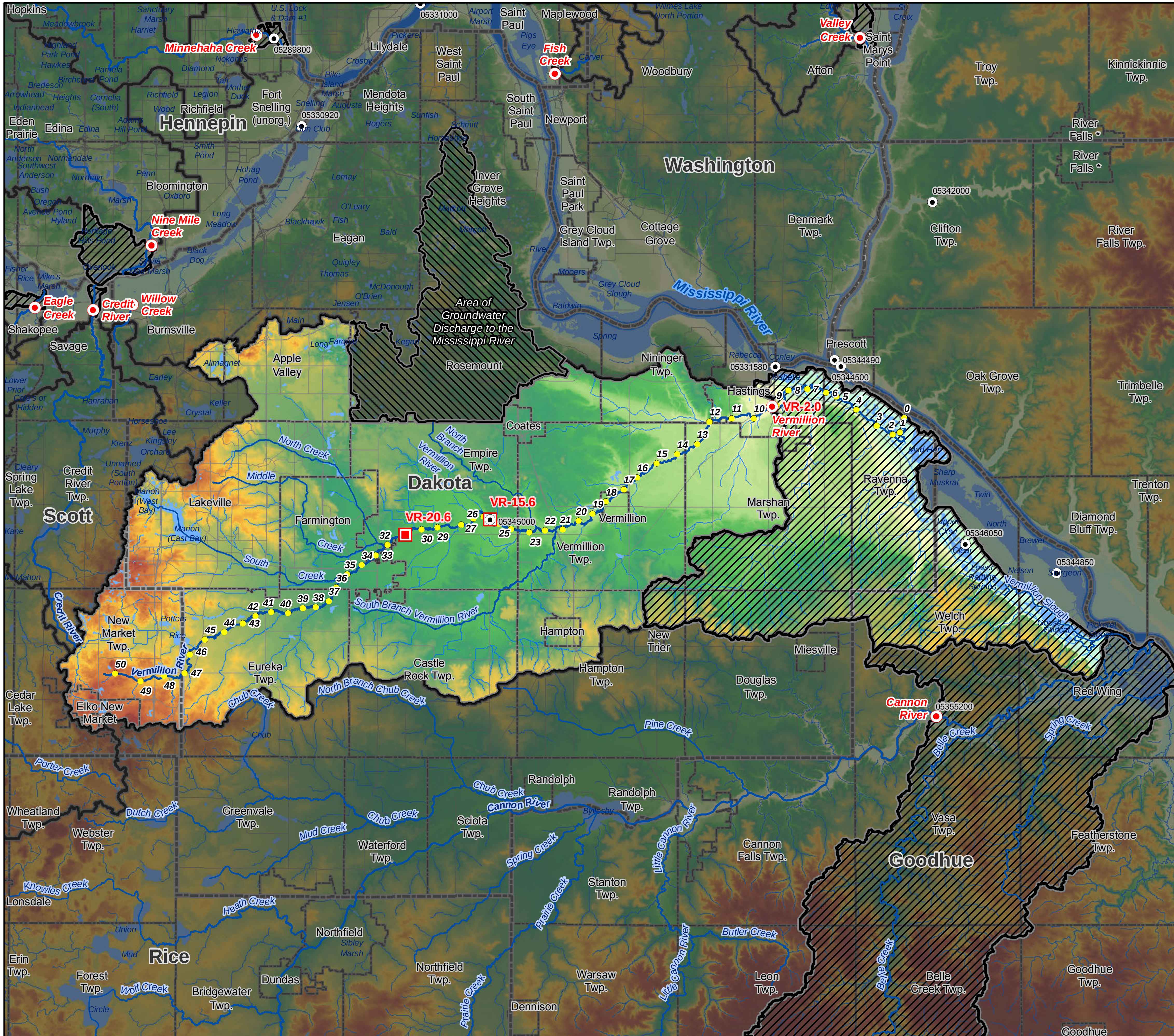
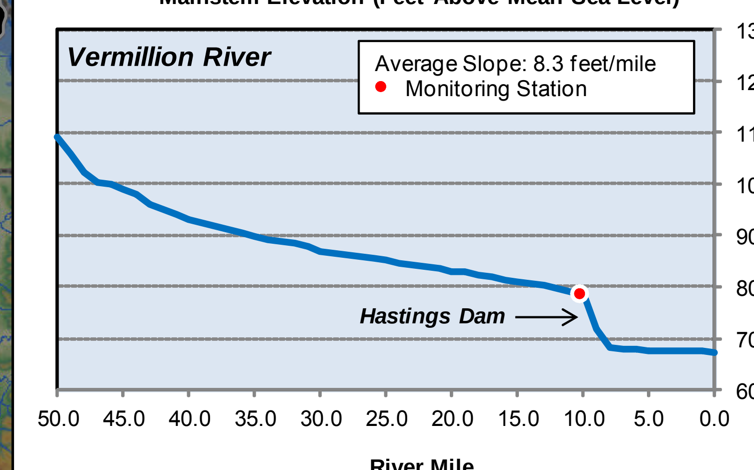
Watershed Topography
Vermillion River





- MCES River Monitoring Sites
- MCES Stream Monitoring Sites
- USGS Flow Stations
- Stream Mile Markers
- Mainstems (Monitored and Unmonitored)
- Unmonitored Watershed Areas
- Monitored Watershed Boundaries
- County Boundary
- City and Township Boundaries
- Highways and Other Major Roads
- Public Waters Inventory
- Other Rivers and Streams

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

0 2 4 6 8 10
Miles

Figure VR-4

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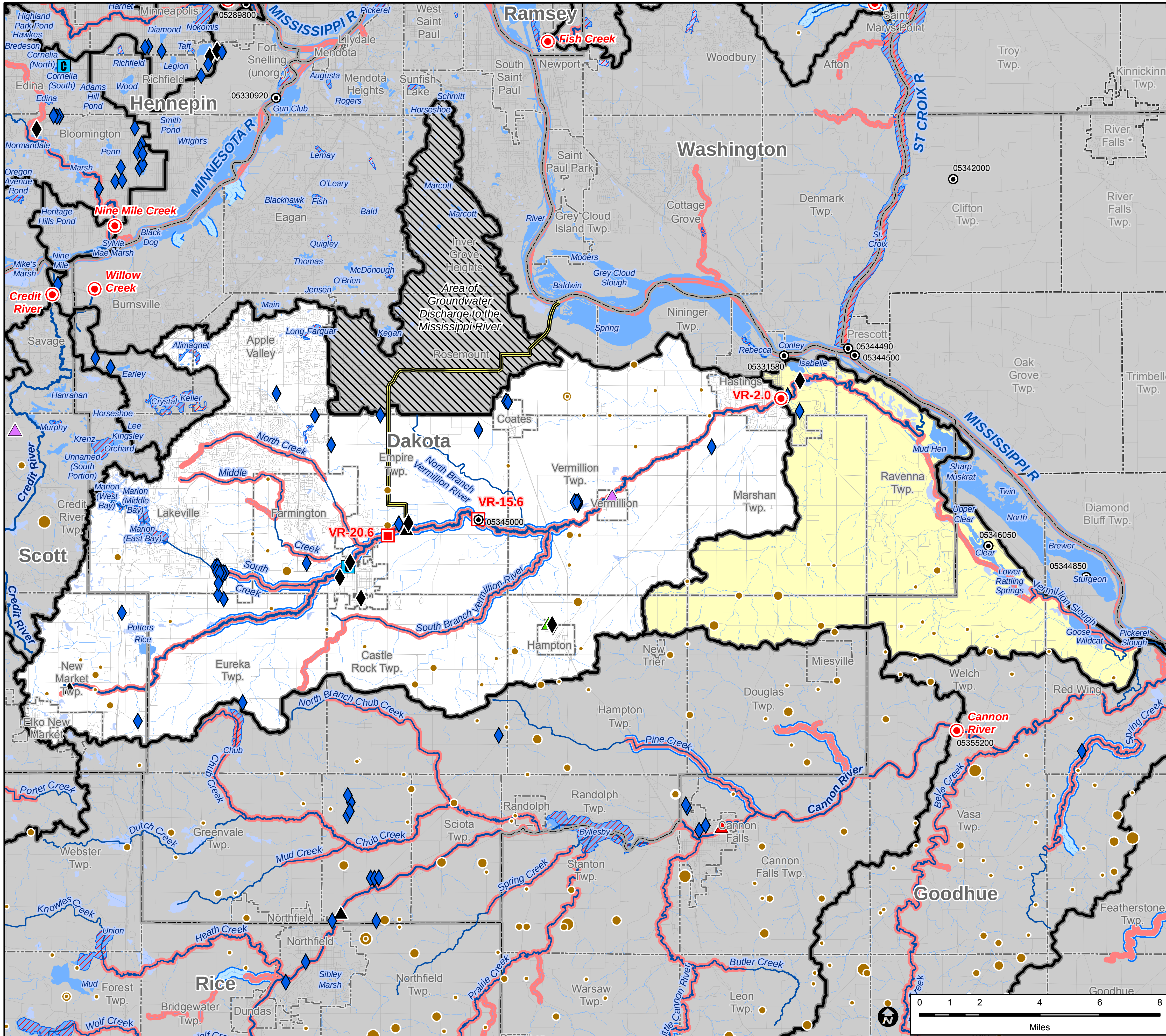
Public and Impaired Waters and Potential Pollution Sources
Vermillion River



MCES River Monitoring Sites

- MCES River Monitoring Sites
- 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
- Empire WWTP Effluent Diversion (1/2008)

Domestic Wastewater Discharges **

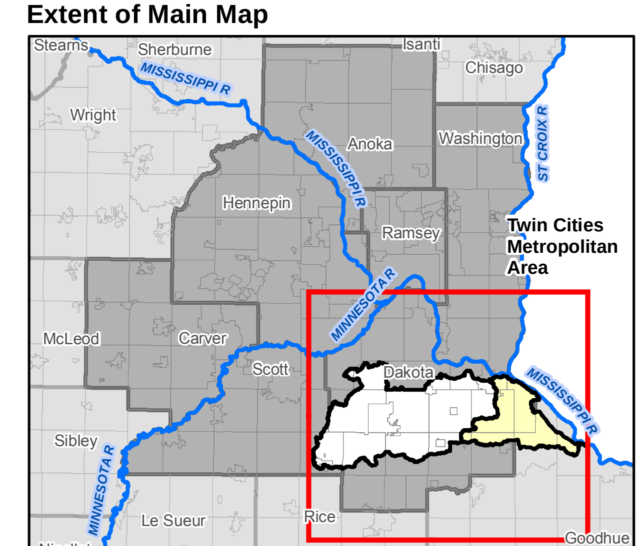
- Class A
- Class B
- Class C
- Class D
- Class Unknown

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 Vermillion River watershed contains 17 stream reaches that are included on the MPCA 2014 303d (Impaired Waters) list (Figure VR-4, Table VR-3). This includes six reaches of the Vermillion River, from the headwaters in New Market Township to the confluence with the Mississippi River, and 11 reaches of smaller tributary streams that feed the Vermillion River. Most of the Vermillion River watershed impairments are biological (Fecal Coliform, *E. coli*, and macroinvertebrate and fish bioassessements); the exceptions are mercury in fish tissue (all have approved plans), PCBs in fish tissue, and impairments for dissolved oxygen and temperature.

Table VR-3: Impaired Reaches in the Vermillion River Watershed as Identified on the MPCA 2014 Impaired Waters List

Reach Name	Reach Description	Reach ID	Affected Use(s)[1]	Approved Plan	Needs Plan[2,3]
Unnamed creek	Headwaters to Unnamed cr	07040001-546	AQR	---	*E.coli**
Unnamed creek	Headwaters to Unnamed cr	07040001-542	AQR	---	FC*
Unnamed creek	Unnamed cr to Unnamed cr	07040001-548	AQR	---	*E.col*i*
Unnamed creek	Unnamed cr to Vermillion R	07040001-527	AQR	---	FC*
Unnamed creek (Vermillion River Tributary)	Unnamed cr to Vermillion R	07040001-545	AQR, AQL	---	FC*, DO
Unnamed creek (Vermillion River Tributary)	Unnamed cr to T114 R20W S25, east line	07040001-668	AQR	---	FC*
Unnamed creek (Vermillion River Tributary)	Unnamed cr to T114 R19W S19, south line	07040001-670	AQR	---	*E.coli**
Unnamed creek (Vermillion River Tributary)	T114 R19W S30, north line to Unnamed cr	07040001-671	AQR	---	FC*
Vermillion River	T114 R18W S21, west line to Hastings Dam	07040001-692	AQR, AQL, AQC	FC, HgF	F-IBI
Vermillion River	Headwaters to T113 R20W S8, east line	07040001-516	AQR, AQC	HgF	*E.coli**
Vermillion River	T114 R19W S30, south line to S Br Vermillion R	07040001-507	AQR, AQL, AQC	FC, HgF	M-IBI, F-IBI
Vermillion River	Vermillion R/Vermillion Slough, Hastings Dam to Mississippi R	07040001-504	AQC, AQL	HgF, T	PCBF
Vermillion River	T113 R20W S9, west line to T114 R19W S31, north line	07040001-517	AQR, AQL, AQC	HgF	M-IBI, FC*, F-IBI, DO, T*
Vermillion River	S Br Vermillion R to T114 R18W S20, east line	07040001-691	AQC, AQC	HgF	---

Vermillion River, South Branch	Headwaters to T113 R19W S2, east line	07040001-706	AQR	---	FC*
Vermillion River, South Branch	T113 R19W S1, west line to T114 R18W S29, north line	07040001-707	AQR	---	FC*

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

[2] FC = Fecal Coliform; T = Turbidity; F-IBI = Fisheries Bioassessments; DO = Dissolved Oxygen; M-IBI = Aquatic Macroinvertebrates Bioassessments; PCBF = PCB in Fish Tissue

[3] * = Is addressed in the 2014 DRAFT Vermillion River Watershed TMDLs (MPCA *et al.*, 2014)

The Vermillion River watershed contains 5 lakes that are included on the MPCA 2014 303(d) list (Figure VR-4, Table VR-4). Most of the lakes have approved plans for their impairments. The remaining two lakes, Alimagnet and Unnamed, still need plans to address their nutrient impairments.

Table VR-4: Impaired Lakes in the Vermillion River Watershed as Identified on the MPCA 2014 Impaired Waters List

Lake Name	Lake ID	Affected Use(s)[1]	Approved Plan[2]	Needs Plan[2,3]
Alimagnet	19-0021-00	AQR	---	Nutrients*
Farquar	19-0023-00	AQR	Nutrients	---
Long	19-0022-00	AQR	Nutrients	---
Marion (East Bay)	19-0026-01	AQC	HgF	---
Marion (Middle Bay)	19-0026-02	AQC	HgF	---
Marion (West Bay)	19-0026-03	AQC	HgF	---
Unnamed	19-0349-00	AQR	---	Nutrients*

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

[2] HgF = Mercury in Fish Tissue;

[3] * = Is addressed in the 2014 DRAFT Vermillion River Watershed TMDLs (MPCA *et al.*, 2014)

The VRWJPO is currently working with the MPCA to develop the Vermillion River Watershed Restoration and Protection Strategy, or WRAPS. This process will allow the VRWJPO to create a plan to address the many impairments within the watershed. As a part of the process many reports have been produced such as, biological stressor identification (Wenck Associates, Inc. 2013), watershed monitoring and assessment (MPCA, 2014b), and TMDLs (MPCA *et al.*, 2014).

Hydrology

MCES has monitored flow of the Vermillion River at Hastings (VR 2.0) since 1995. Flow measurements were collected at 15-minute intervals and converted to daily averages. The hydrograph of the Vermillion River (Figure VR-5), 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, 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. Due to technical issues with the monitoring station, only grab samples have been collected since 2007.

The Vermillion River has both cool water reaches (headwaters to Empire) and warm water reaches (Empire to Hastings). The cool reaches have a groundwater source which helps to lower the water temperature and provide temperatures suitable for trout habitat. The warm reach flows are primarily derived from surface waters. Due to groundwater contributions, the Vermillion River maintains a baseflow and typically does not fully freeze during the winter months or run dry during prolonged periods with little precipitation.

The Vermillion River hydrograph is characteristic of a moderate prairie river system. Generally, the storm event daily average flows were less than 1,100 cubic feet per second (cfs); five spring rains or snowmelt-driven events exceeded this level in 1998, 2002, 2003, and 2012. Of those events, the highest recorded daily average flow in the Vermillion River - 2,035 cfs - occurred in 1998. The mean average daily flow is much lower - 139 cfs - which is higher than the median average daily flow of 99 cfs. This highlights the effect of larger events on the mean average daily flow value.

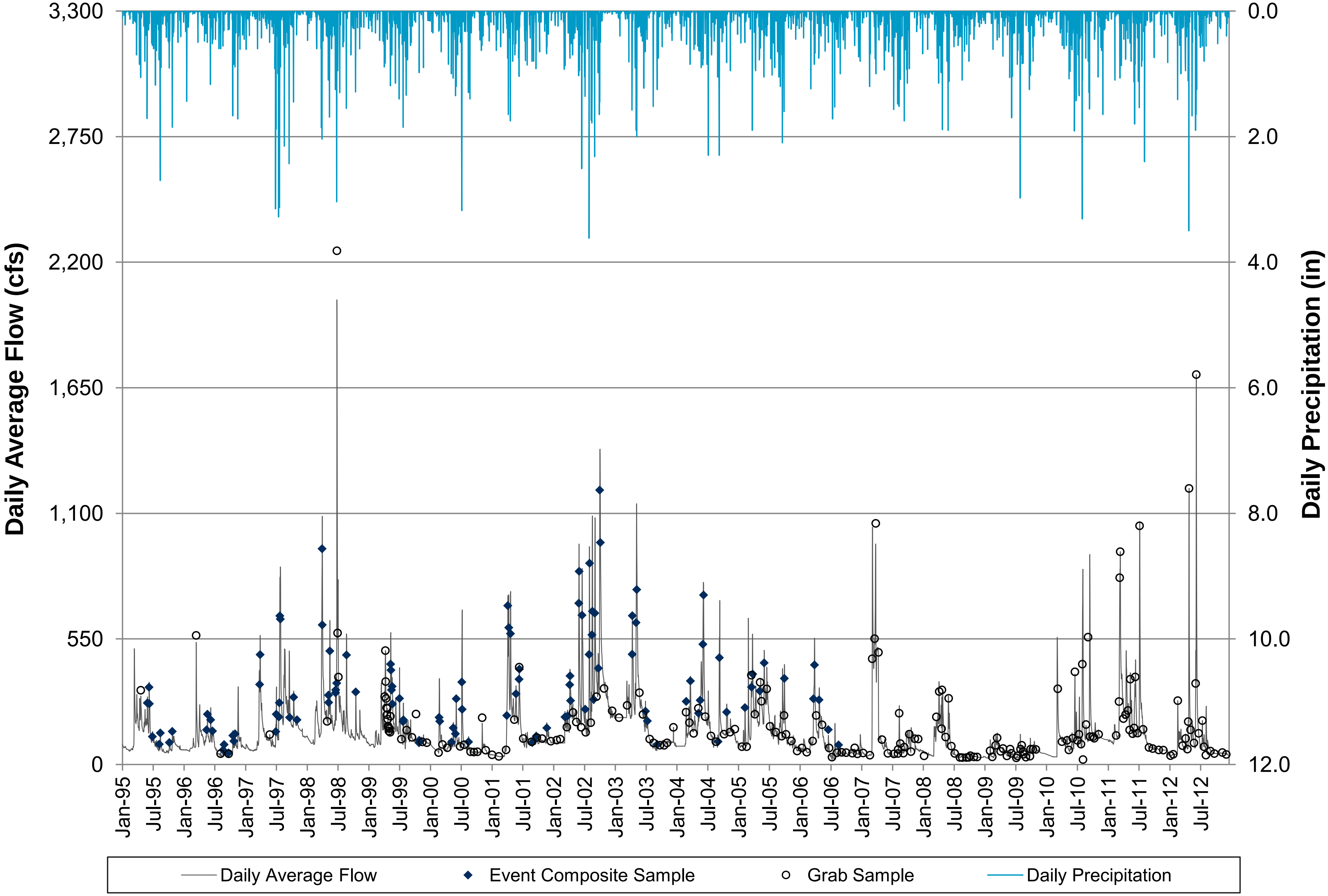
Analysis of the duration of daily average flows indicates the upper 10th percentile flows for period 1995-2012 ranged between approximately 267 to 2,035 cfs, while the lowest 10th percentile flows ranged from 21 to 43 cfs (See Figure VR-15 in the ***Flow and Load Duration Curves*** section of this report).

The variations in flow are partially driven by seasonal patterns in precipitation as well as by variation in frequency of intense storm events. However, nearly half of the precipitation most likely does not affect the stream as surface runoff. During the years 1995-2012, the median annual runoff ratio was 0.25, indicating 75% of the precipitation either infiltrated the soils, evaporated off of the surface, was evapotranspirated by vegetation, or was stored in watershed wetlands, lakes, and ponds.

As mentioned in the stream and watershed description, the primary Vermillion River soil type (Type B) facilitates moderately high infiltration which may extract much of the overland flow. Over time the infiltrated precipitation recharges the groundwater, which in turn feeds into the stream. This potential flow regime may account for the slight lag between the precipitation and rise in the flows and the nonlinear response between the magnitude of flows and the amount of precipitation (Figure VR-5).

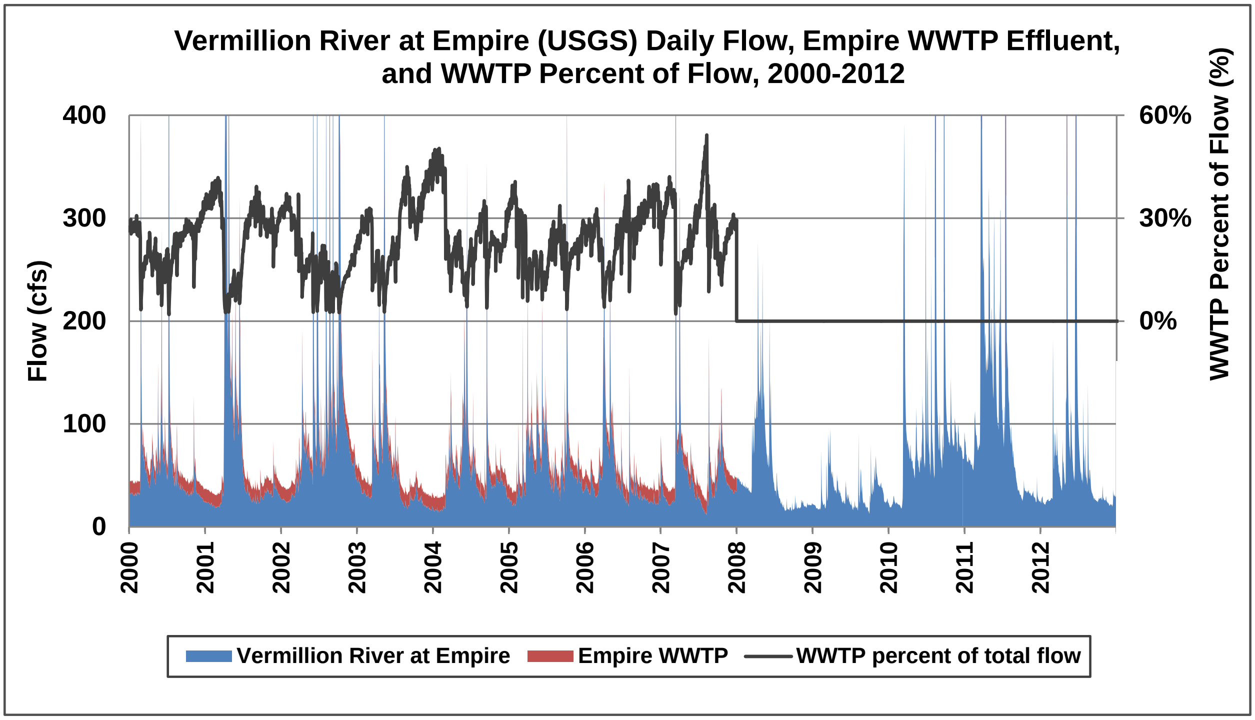
An additional complication in interpreting Vermillion River flow data is the influence of the effluent discharged from the Empire WWTP. The WWTP was commissioned in 1979 and discharged to the river until 2008, when the effluent was diverted to the Mississippi River. During periods of low flow, the effluent volume comprised a significant portion of the river flow, at times exceeding 50% (Figure VR-6).

Figure VR-5: Vermillion River Daily Average Flow, Sample Flow, and Precipitation, 1995-2012*



*Precipitation record was acquired from NWS COOP stations: 213567-Hastings Dam 2 and 217107-Rosemount Agr Exp Stn

Figure VR-6: Vermillion River at Empire Daily Flow, Empire WWTP Effluent Flow, and WWTP Percent of Flow, 2000-2012

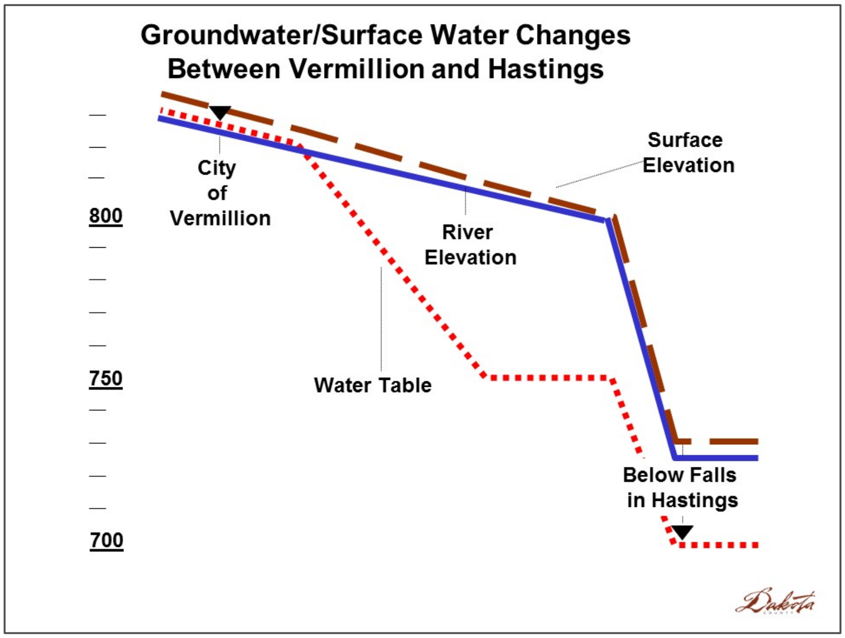


There have been many hydrologic studies of the Vermillion River since the 1970's, primarily focused on flood hazard planning within the watershed:

- 1974 – TR-20 Hydrologic Evaluation Study (USDA, 1974)
- 1989 – Eugene A. Hickock and Associates: Watershed Management Organization Study
- 1995 – Hydrology and Relation of Selected Water-Quality Constituents to Selected Physical Factors in Dakota County, Minnesota, 1990-1991 (Almendinger and Mitton, 1995)
- 1998 – HEC-1 Model Study (USACE, 1998)
- 2002 – Watershed Management Organization Volume Study (Montgomery-Watson-Harza, 2002)
- 2003 -- Hastings Area Nitrate Study Final Report. (Dakota County, 2003)
- 2009 – Vermillion River Hydrologic Study of Existing Conditions (Barr Engineering Company, 2009)

Past studies (Almendinger and Mitton, 1995; Dakota County, 2003) indicate that the complicated geology of the watershed drives both shallow groundwater discharge to the river, as well as flow from the river to surficial groundwater. A buried valley of an ancient precursor to the Mississippi River cuts across the Vermillion River from northeast to southwest upstream of the city of Hastings, near the city of Vermillion. The depth-to-bedrock in the buried valley (which is filled with later glacial outwash) is greater than 500 feet, in contrast to a depth of less than 50 feet outside of the buried valley. The buried valley provides a conduit for river water to flow downward to surficial aquifers. Dakota County's Hastings Area Nitrate Study (Dakota County, 2003) indicates that the quality of the Vermillion River in the vicinity of the buried valley may affect shallow individual household drinking water wells downstream near the city of Hastings (Figure VR-7). Conversely, the geology in the vicinity of the South Branch of the Vermillion River drives the discharge of both deep and shallow groundwater to the river (Almendinger and Mitton, 1995). Dakota County has found elevated nitrate levels in the South Branch, likely driven by both discharge of agricultural runoff and high nitrate groundwater to the river (T. Thiel, Dakota County, personal communication, 2015).

Figure VR-7: Groundwater and surface water elevations between the cities of Vermillion and Hastings (courtesy of Dakota County)



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 the Vermillion River watershed to groundwater withdrawals, MCES staff examined spatial datasets of vulnerable stream segments and basins created as part of the 2010 regional groundwater analysis. All of the groundwater-fed reaches and tributaries of the Vermillion River (generally, west of the township of Empire) were identified as potentially vulnerable. Additionally, all of the basins within the western portion of watershed were identified as vulnerable to groundwater withdrawals, including Rice Lake and Lake Marion, 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 the Vermillion River (1995-2012).

The purpose of this report is to assess and summarize data collected at stream outlet stations (in this case, WOMP station VR2.0, Vermillion River near Hastings). MCES also operates two stations, VR20.6 (near city of Farmington) and VR15.6 (near city of Empire), which bracket the Empire WWTP effluent discharge pipe, as part of its river monitoring program. Pollutant loads for those two stations are available, but will not be discussed in this report.

Figures VR-8 to VR-11 illustrate annual loads at the Vermillion River near Hastings (VR2.0) 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 Vermillion River loads and FWM concentrations with the other MCES-monitored metropolitan area tributaries.

The first charts in Figures VR-8 and VR-9 plot the annual flows from 1995-2012. The flow metrics indicate small year-to-year variations in annual flow rate, as expected from a groundwater fed stream. The highest average annual flow, and thus the highest volume of flow, occurred during 2002 (approximately 283 cfs average annual flow); the lowest average annual flow and lowest volume of flow occurred in 2009 (approximately 49.5 cfs average annual flow). The mean average annual flow was 139 cfs, which is close to the median average annual flow of 132 cfs, suggesting the annual flows were evenly distributed around the mean annual flow.

The annual mass loads for all of the parameters exhibit significant year-to-year variation, indicating the influence of precipitation and surficial flowpaths transporting pollutants within the watershed to the stream, as well as the influence of variable pollutant loads discharged by the Empire WWTP (VR-8). Both TP and TDP loads show a significant drop after 2006, which corresponds with the implementation of biological phosphorus (Bio-P) removal at the Empire WWTP – a process intended to reduce the amount of phosphorus in the effluent. Similarly, there appears to be a reduction in Cl loading after 2007, which corresponds with the 2008 diversion of the Empire WWTP effluent to the Mississippi River.

The annual FWM concentrations reinforce and emphasize the observations from the annual mass loads (Figure VR-9). The pollutant FWM concentrations fluctuate year-to-year, and were likely influenced by the frequency, magnitude, timing, and the routing of precipitation. The TP and TDP FWM concentrations exhibited a decrease after 2006, and chloride concentration decreased after 2007 (likely due to diversion of the Empire WWTP effluent from the Vermillion River to the Mississippi River). The NH_3 FWM concentrations showed two peaks - in 2003 and 2007 - corresponding with large snowmelt or spring rain events. It is widely accepted that soil microbes are highly active under insulating snows, accumulating large stores of NH_3 in the soils (Brooks et al., 2011). Snowmelt events produce a large volume of water that flows over the thawed soils, potentially transporting NH_3 into the stream.

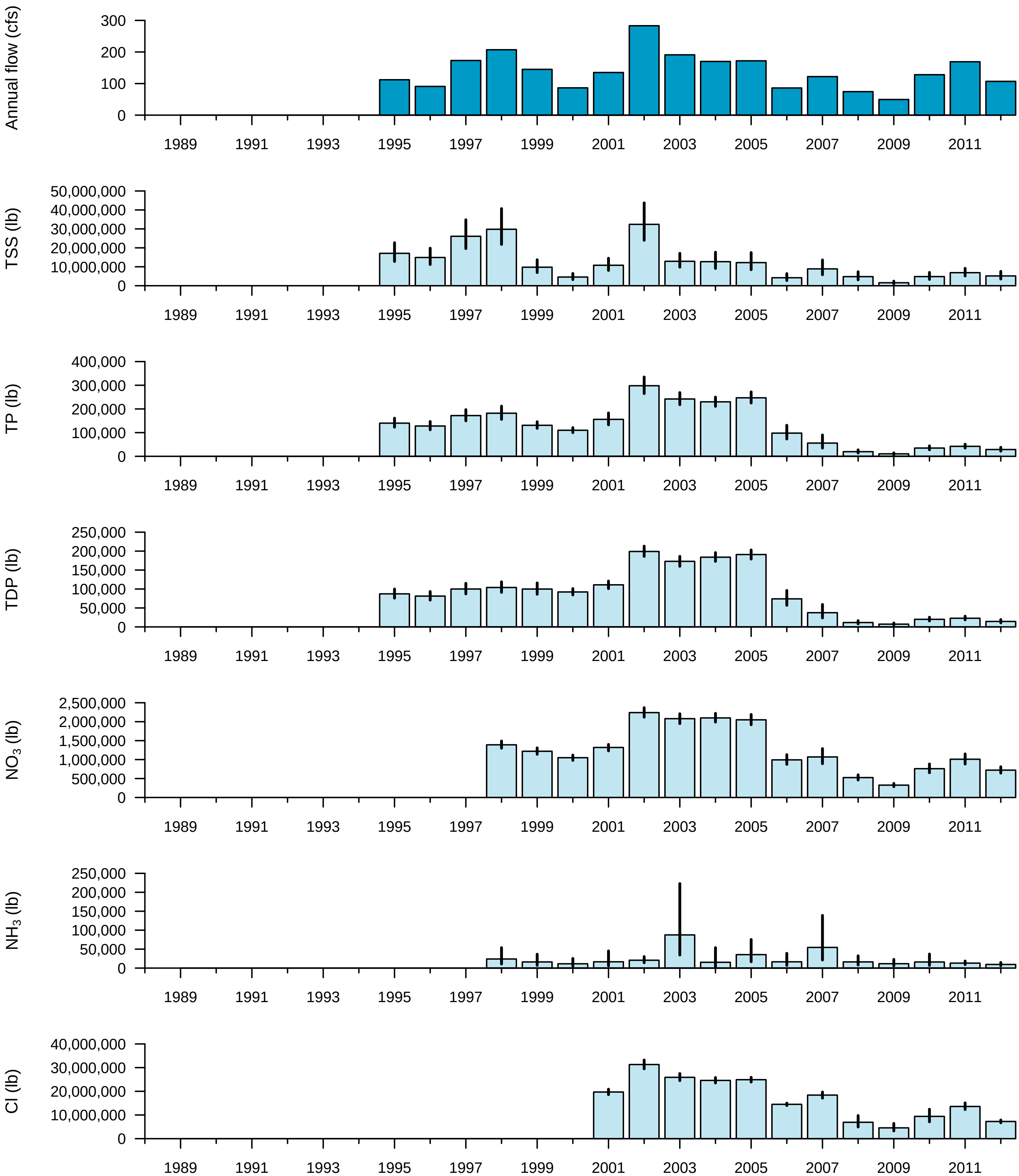
Figures VR-10 and VR-11 present the areal- and precipitation-weighted loads, respectively. These graphics are presented to assist local partners and watershed managers, and will not be discussed here.

The Flux32 loads and FWM concentrations were also compiled by month to allow analysis of time-based patterns in the loads in the Vermilion River (Figures VR-12 and VR-13). The results for each month were expressed in two ways: the monthly results for the most recent year of data (2012 for the Vermillion River) and the monthly average for 2003-2012 (with a bar indicating the maximum and minimum value for that month).

In general, the highest mass loads of all monitored pollutants in the Vermillion River occurred in March through June each year, likely due to effects of snow melt and spring rains. In 2012, the peak water volume and pollutant loads occurred in June.

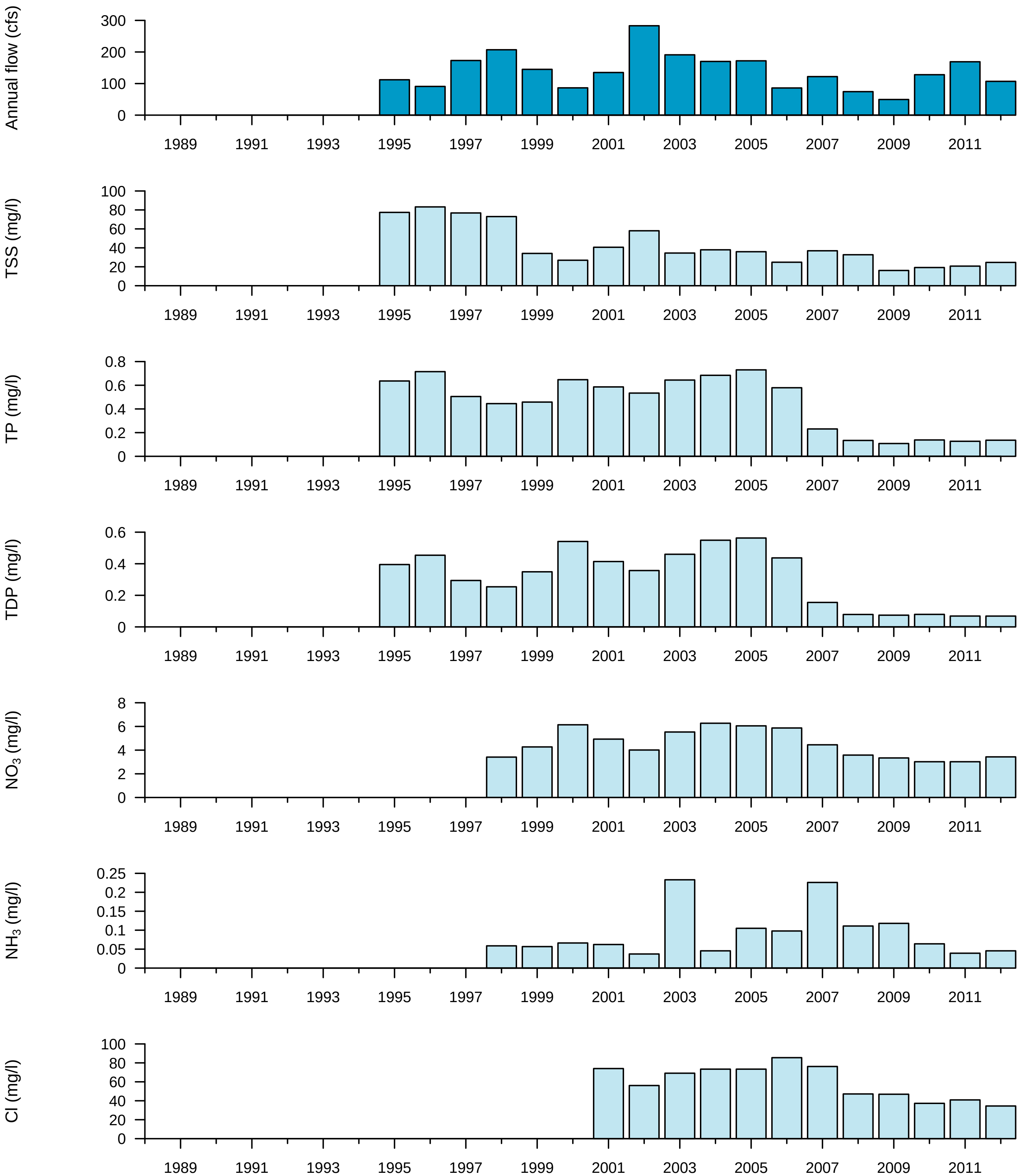
The TSS FWM concentrations show similar patterns as the loads, highlighting the relationship between higher flows and higher suspended sediments. The TP, TDP, and NO_3 FWM concentrations exhibited a very slight reduction during June through August, most likely attributable to biological uptake. The Cl FWM concentration was the highest during the late winter/early spring months, suggesting the influence of road salts.

Figure VR−8: Vermillion River*
Annual Mass Load



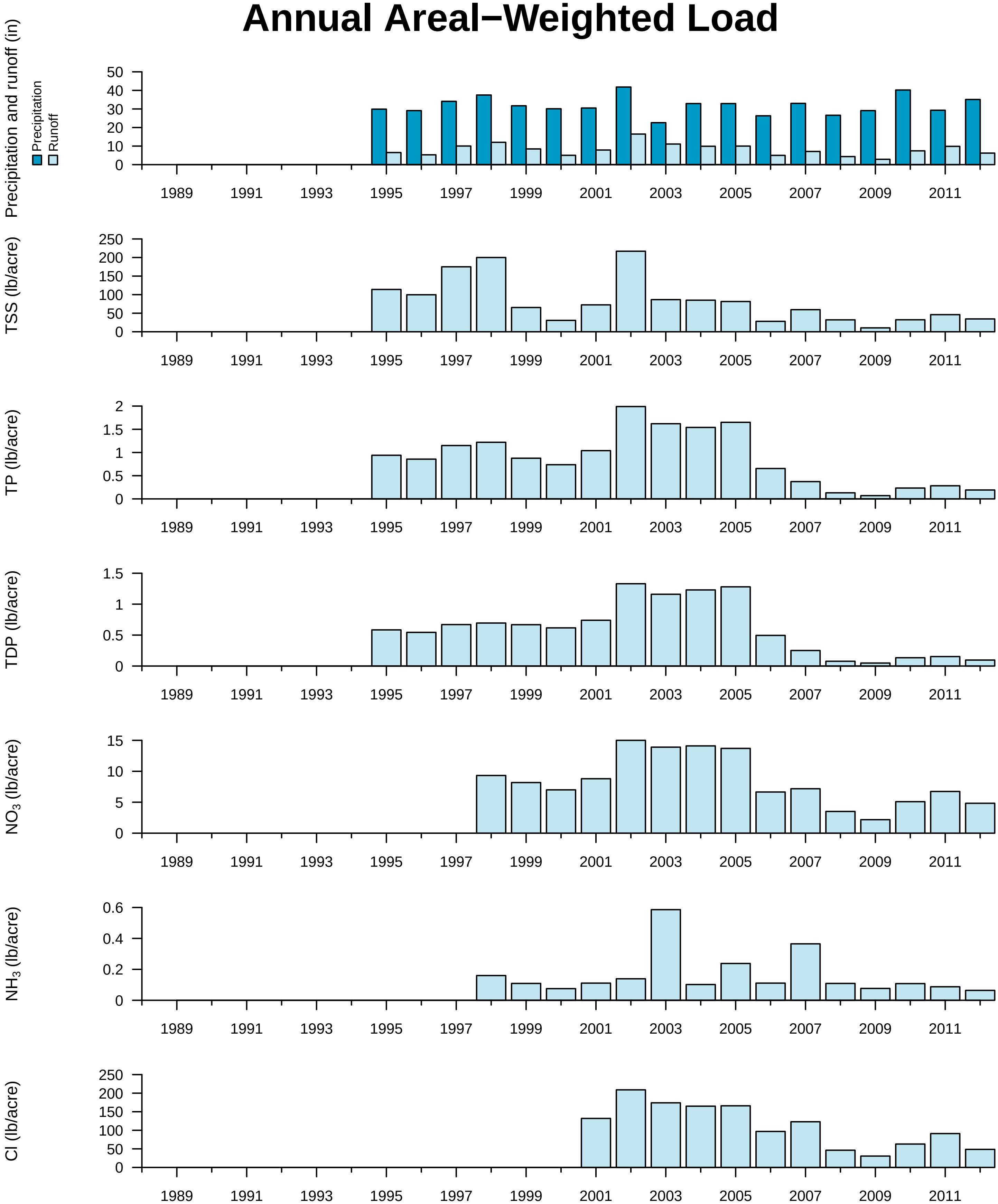
*TSS, TP, and TDP sampling began in 1995, NO3 and NH3 began in 1998, and Cl began in 2001.
Empire WWTP began diverting effluent from the Vermillion River to Mississippi River in January 2008.
Bars represent 95% confidence intervals as calculated in Flux32.

Figure VR−9: Vermillion River*
Annual Flow−Weighted Mean Concentration



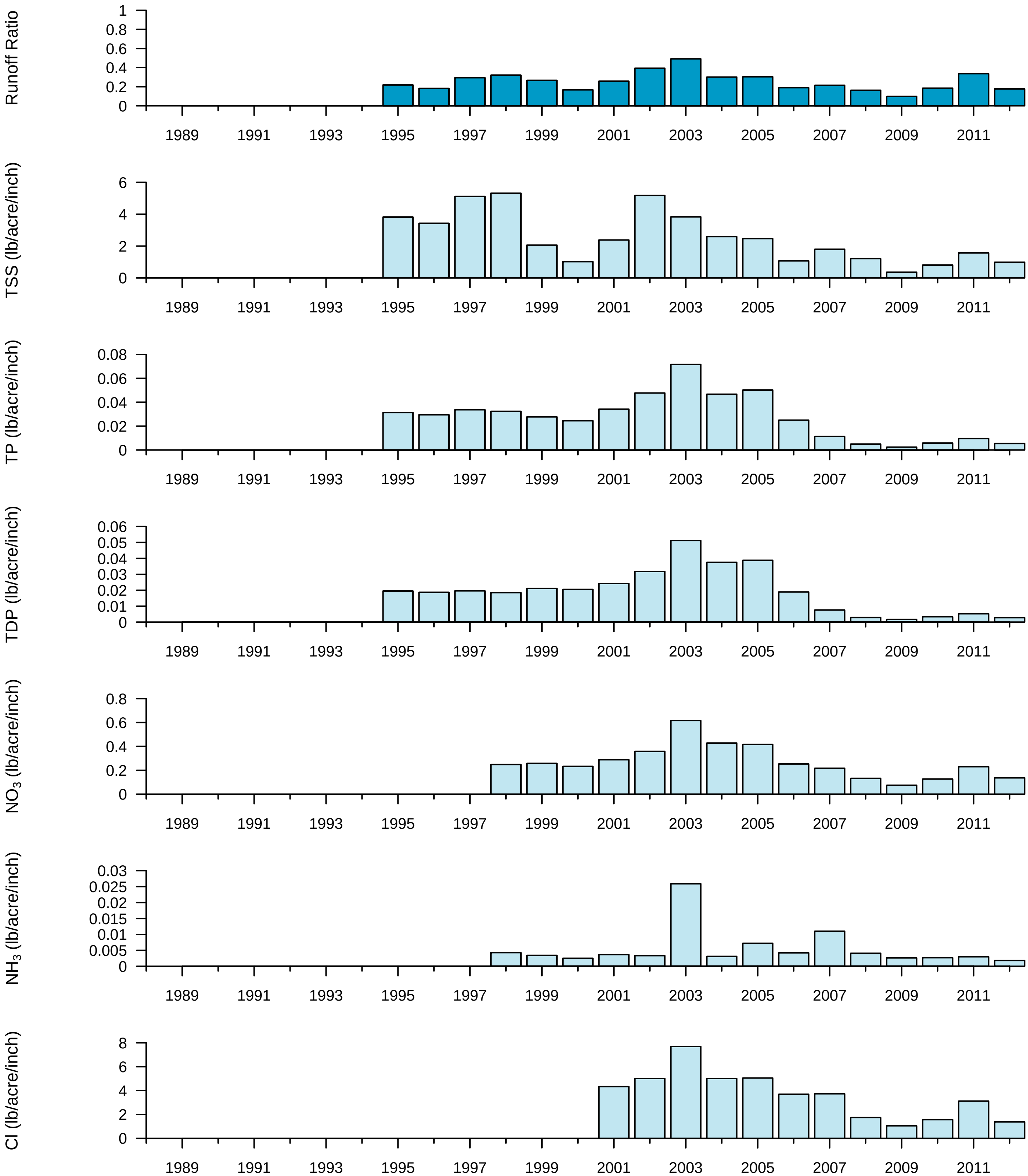
*TSS, TP, and TDP sampling began in 1995, NO3 and NH3 began in 1998, and Cl began in 2001.
Empire WWTP began diverting effluent from the Vermillion River to Mississippi River in January 2008.

Figure VR−10: Vermillion River*
Annual Areal−Weighted Load



*TSS, TP, and TDP sampling began in 1995, NO3 and NH3 began in 1998, and Cl began in 2001.
Empire WWTP began diverting effluent from the Vermillion River to Mississippi River in January 2008.

Figure VR−11: Vermillion River*
Annual Precipitation−Weighted Areal Load



*TSS, TP, and TDP sampling began in 1995, NO3 and NH3 began in 1998, and Cl began in 2001.
Empire WWTP began diverting effluent from the Vermillion River to Mississippi River in January 2008.

Figure VR−12: Vermillion River Mass Load by Month

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

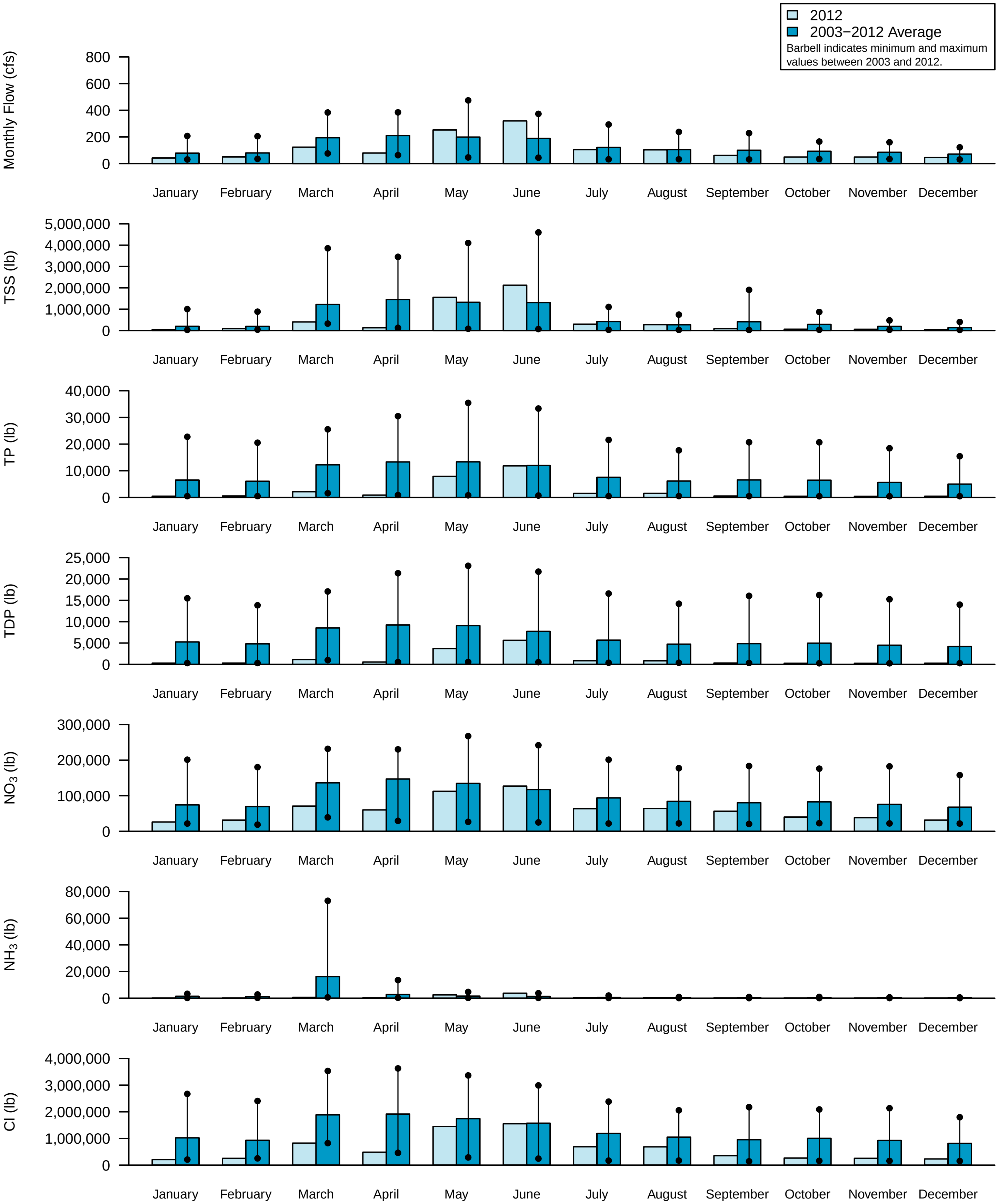
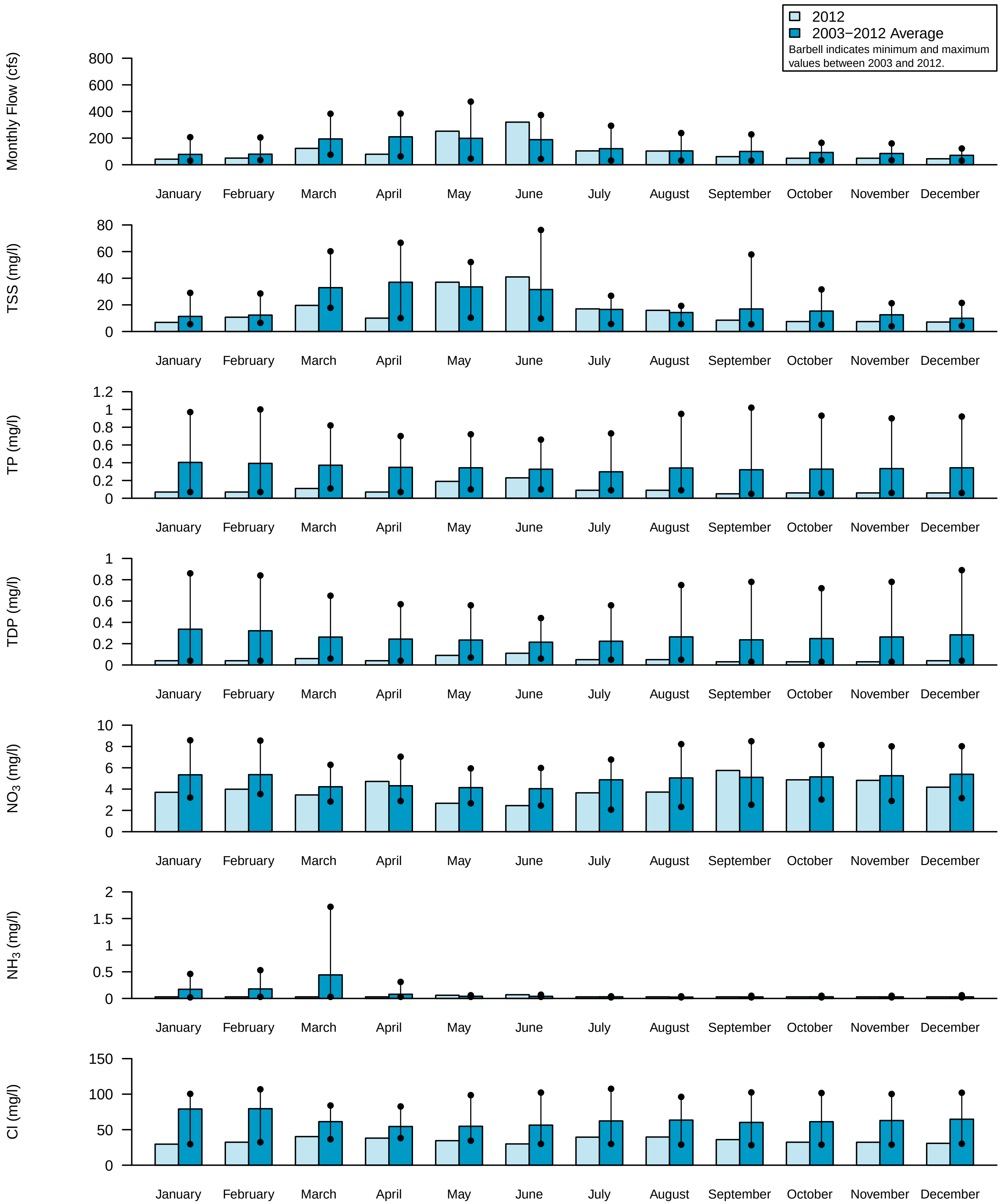


Figure VR−13: Vermillion River
Flow−Weighted Mean Concentation by Month

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



Dissolved Oxygen Assessment

Dissolved oxygen (DO) is the concentration of dissolved O_2 gas in the water. It is vital to aquatic organisms and mediates biochemical reactions. DO is influenced in part by water temperature, flow, nutrient levels, and the presence of aquatic plants and algae. In summer months (May – September), warmer water temperature decreases the physical capacity of water to hold DO. Photosynthesis, respiration and decomposition all increase during the summer and affect DO as well. Despite the complications of competing natural processes, DO measurements provide a quick assessment of water quality and ecosystem health.

The VRWJPO identified and studied stressors on aquatic organisms in the river as part of the WRAPS process. Low DO was highlighted as a localized threat to trout in the river, but not a sole driver of the biological impairments in the river (Wenck, 2013).

MCES continuously monitors DO in the Vermillion River downstream of the Empire WWTP at site VR 15.6, which was established to monitor the impacts of WWTP effluent on the Vermillion River. Even though MCES diverted the effluent to the Mississippi River in 2008, it continues to maintain the VR 15.6 continuous monitoring station and to measure water quality at the site year round. DO concentrations are collected every 15 minutes using an Insite Model 10 Optical Dissolved Oxygen Sensor, which is cleaned and calibrated twice weekly.

The Vermillion River DO data was examined from 2006 to 2012. This period of time does not constitute the entire period of record of continuous DO monitoring at the site. However, it does include two major changes in MCES wastewater treatment: phosphorous removal (Bio-P) was implemented in 2006 and the Empire WWTP effluent was diverted to the Mississippi River in 2008.

Daily Minimum DO

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

Actual daily minimum DO values were determined from the continuous monitoring record. Conformance to the water quality standard varies by season (Tables VR-5 and VR-6). Summer daily minimum DO was more likely to be below the standard, while winter daily minimum DO rarely was below with the standard.

In the assessed period, 20% of summer daily minimum values do not comply with the water quality standard (205 of 1002 assessed days). For most years after the effluent diversion, daily minimum DO standard compliance improved. 2010 is the exception: the number of days the daily minimum DO did not comply with the standard is similar to pre-diversion years. The most recent two years of record show improving compliance with the water quality standard.

Table VR-5: Vermillion River Summer Daily Minimum Dissolved Oxygen, 2006-2012

Year	Number of Days Assessed	Number of Days where Daily Minimum DO is less than 7 mg/L	% of Days where Daily Minimum DO is less than 7 mg/L
2006	132	44	33.3
2007	145	48	33.1
2008	151	8	5.3
2009	150	20	13.3
2010	144	41	28.5
2011	138	25	18.1
2012	142	19	13.4
Total	**1002**	**205**	**20.5**

In winter (October – April) colder water temperature increases the capacity of water to hold DO. Low DO is uncommon in flowing water in the winter. In the assessed period, less than one percent of winter daily minimum values did not comply with the water quality standard. After the effluent diversion, the daily minimum DO is at or above 7mg/L for all winter days assessed.

Table VR-6: Vermillion River Winter Minimum Dissolved Oxygen, 2006-2012

Year	Number of Days Assessed	Number of Days where Daily Minimum DO is less than 7 mg/L	% of Days where Daily Minimum DO is less than 7 mg/L
2006	152	7	4.6
2007	199	4	2.0
2008	176	0	0.0
2009	207	0	0.0
2010	180	0	0.0
2011	189	0	0.0
2012	191	0	0.0
Total	**1294**	**11**	**0.9**

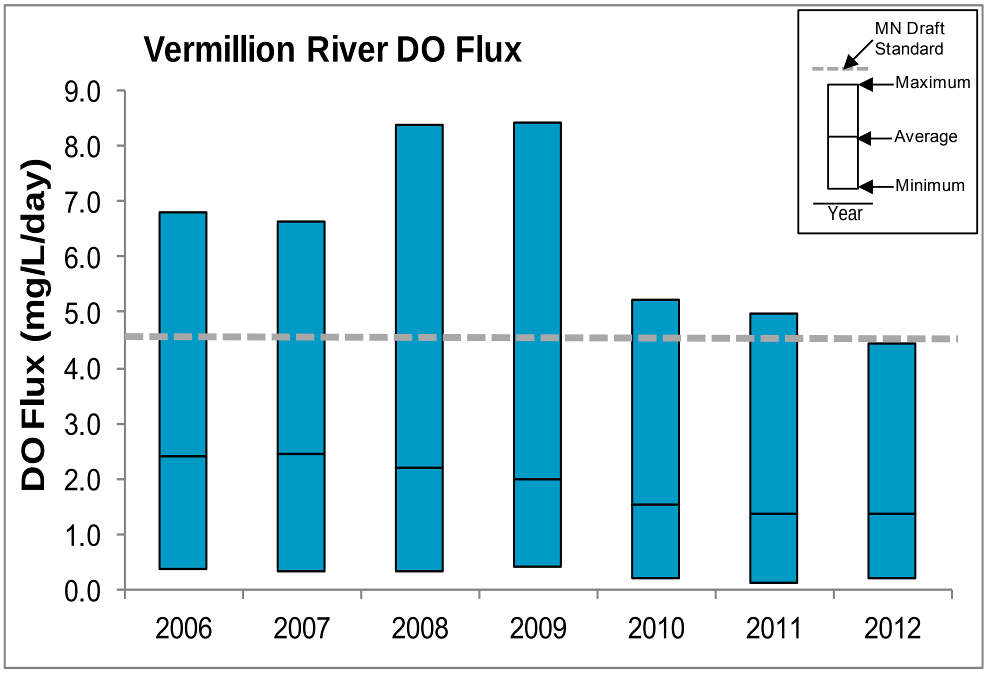
Daily DO Flux

Daily DO flux is the difference between the daily minimum and daily maximum DO. DO concentrations naturally exhibit a diel (24-hour) cycle. Photosynthesizing aquatic plants and algae increase DO concentrations during the day. At night, DO decreases when photosynthesis stops and respiration continues. A high daily DO flux value is a potential indicator of eutrophication.

The Vermilion River is in the MPCA's Southern Region of Minnesota for purposes of daily DO flux assessment, for which the MPCA set a draft standard of daily DO flux less than or equal to 4.5 mg/L (MPCA, 2013a). Actual daily minimum and maximum DO values were determined from the continuous monitoring record. The difference between the values is daily DO flux

(Figure VR-14). The minimum, average, and maximum daily DO flux values were calculated for each year. During the assessed period (2,154 days over seven years), the daily DO flux exceeded 4.5 mg/L 83 times, 3.9% of days. 75 exceedences occurred before effluent diversion is 2010. In 2012, all DO flux values were in compliance with the standard. The decrease in daily DO flux standard exceedences suggests the Vermillion River is not highly influenced by eutrophication.

Figure VR-14: Vermillion River at Empire (VR15.6) Daily Dissolved Oxygen Flux



Flow and Load Duration Curves

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

MCES developed flow and load duration curves for each stream location using recommendations of the U.S. Environmental Protection Agency (USEPA), including:

- Develop flow duration curves using average daily flow values for the entire period of record plotted against percent of time that flow is exceeded during the period of record.
- Divide the flow data into five zones: high flows (0-10% exceedance frequency); moist conditions (10-40%); mid-range flows (40-60%); dry conditions (60-90%); and low flows (90-100%). Midpoints of each zone represent the 5th, 25th, 50th, 75th, and 95th percentiles, respectively.
- Multiply concentration and flow for each sampling event for period of record, to result in approximate daily mass loads included on the curve as points.

- Multiply water quality standard concentration and monitored flow to form a line indicating allowable load. Sample load points falling below the line meet the standard; those falling above the line exceed the standard.

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

MCES selected four parameters to assess using load duration curves: TSS, TP, NO_3, and Cl. Each of the parameters was plotted using the Vermillion River stream monitoring station daily average flows and sample data, along with the most appropriate MPCA draft numerical standard as listed in Table VR-7. 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 response variables 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 1995-2012 flow duration curve and load duration curves for TSS, TP, NO_3, and Cl for the Vermillion River monitoring station (mile 2.0, below Highway 61 in Hastings) are shown in Figure VR-15. 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 10th percentile flows ranged between approximately 267 - 2,035 cfs, while the lowest 10th percentile flows ranged from 21 - 43 cfs). The steep curve in the High Flow category indicates that high flows last for short periods of time, usually attributed to rain-induced floods. The flat line in the Low Flow category indicates that the Vermillion River maintains baseflows throughout the year, which can be attributed to the groundwater contribution to stream flow.

The load duration curves provide insight into the influence of flow conditions on stream load compliance with state standards. At low flows, the Vermillion River loads were at or below the loads dictated by the draft standards for TSS, Cl, and the drinking water standard for NO_3. As the flows increased, the TSS daily loads exceeded the dark lines designating the standard. At all flows, TP samples exceeded the standard. Regardless of flow conditions, both NO_3 and Cl loads are consistently below the drinking water and Cl draft standards, respectively.

Table VR-7: Vermillion River 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)[3] of Monitoring Station	Chloride Draft Stnd[4] (mg/l)	TSS Draft Stnd[5] (mg/l)	TP Draft Criteria[6] (ug/l)	Nitrate DW Stnd[7] (mg/l)
Vermillion River below Hwy 61 at Hastings (VR2.0)	1B, 2A[2]	South	230	10	150	10

[1] Minn. Rules 7050.0470 and 7050.0430

[2] Trout stream identified in Minn. Rule 7050.0470

[3] MPCA, 2010.

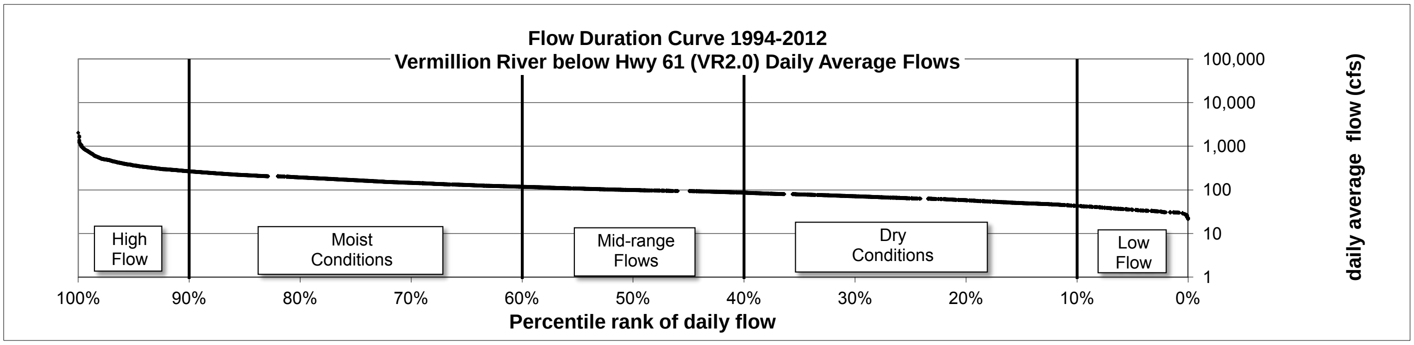
[4] Mark Tomasek, MPCA, personal communication, March 2013. MCES used 230 mg/l as the draft chloride standard pending results of EPA toxicity tests.

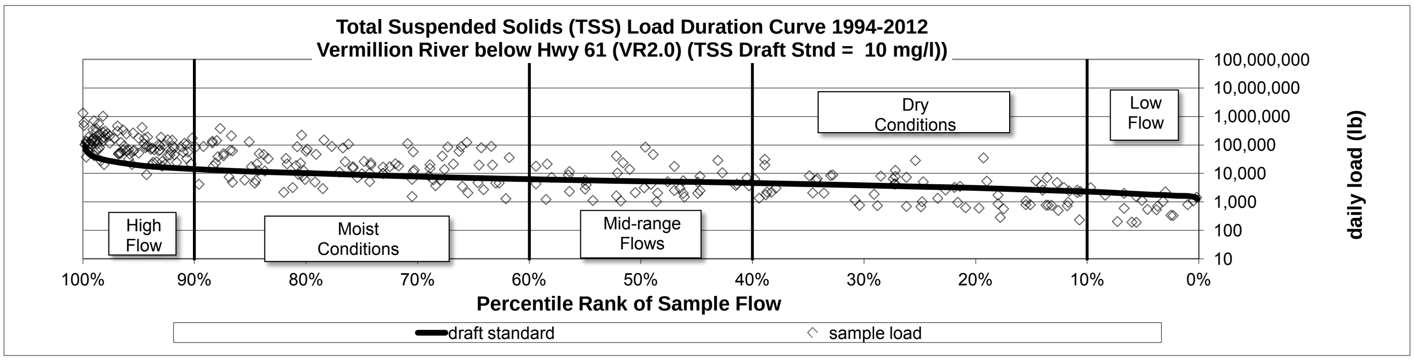
[5] MPCA, 2011a. Draft standard states TSS standard concentration for Class 2A and 2B water must not be exceeded more than 10% of the time over a multiyear data window, with an assessment period of April through September.

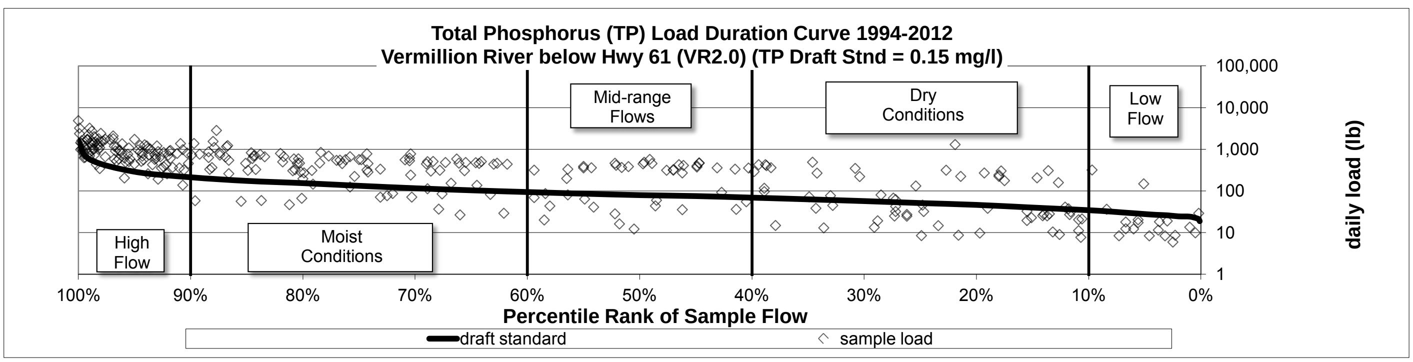
[6] MPCA, 2013a. To violate standard, concentration of causative variable (TP) must be exceeded, as well as one or more response variables: sestonic chlorophyll, BOD5, DO flux, and/or pH.

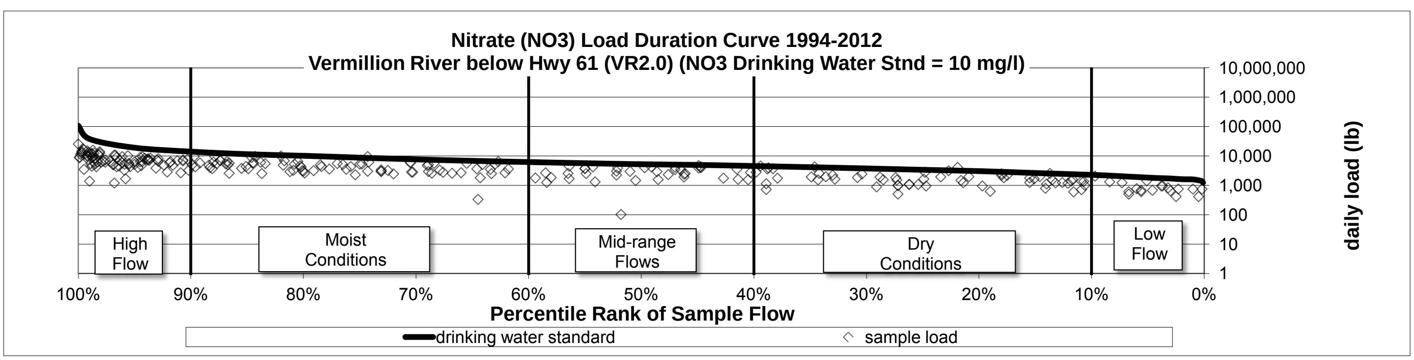
[7] MCES used the nitrate drinking water standard of 10 mg/l pending results of EPA toxicity tests and establishment of a draft nitrate standard for rivers and streams.

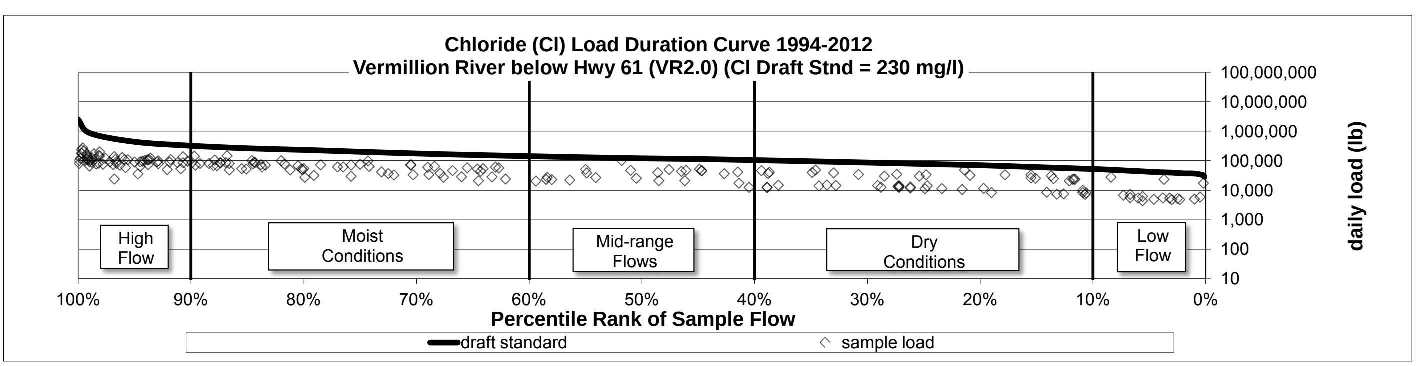
Figure VR-15: Vermillion River Flow and Load Duration Curves, 1994-2012











Aquatic Life Assessment Based on Macroinvertebrates

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

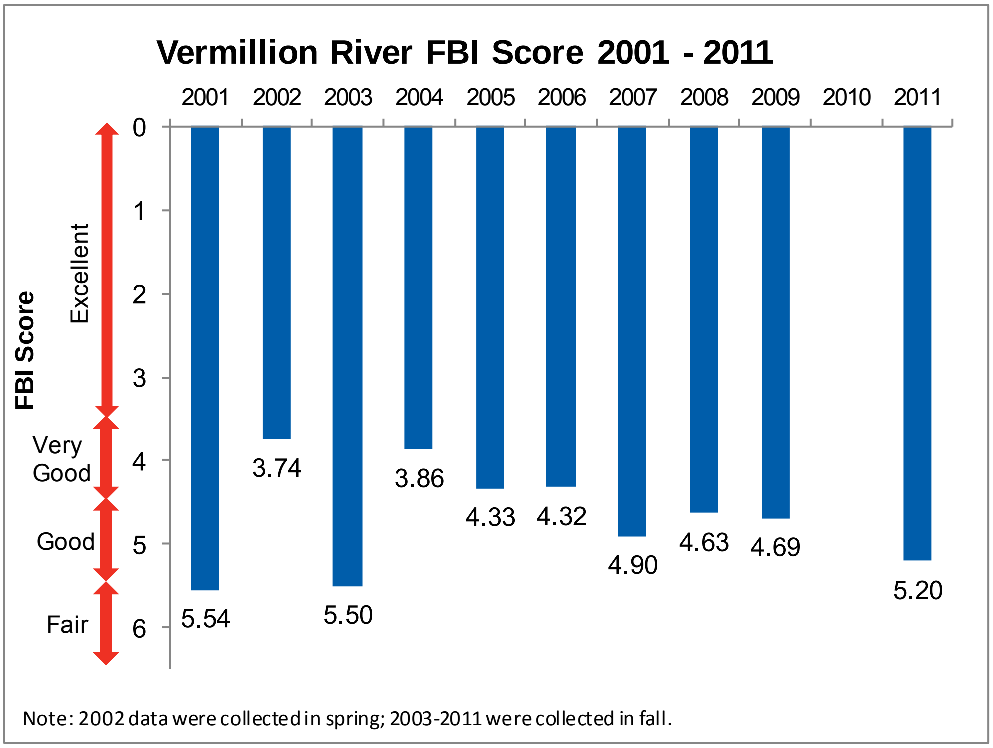
Each metric is independently important and clarifies one aspect of the ecosystem health: species richness, community diversity, water quality, and other factors. The results may have conflicting conclusions when comparing the single metric results. However, integrating the individual metrics into a multi-metric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

MCES has been sampling for macroinvertebrates in the Vermillion River near the Hastings monitoring station (VR2.0) since 2001. The 2002 macroinvertebrates were sampled in late spring; the remaining years (2001, 2003-2011) were collected in the fall (September or October). The entire dataset was analyzed with three metrics: Family Biotic Index (FBI), Percent Intolerant Taxa, and Percent POET Taxa. A subset of data, 2004-2009 and 2011, was analyzed using the multi-metric, Minnesota-specific, MPCA 2014 Macroinvertebrate Index of Biological Integrity (M-IBI).

Family Biotic Index (FBI)

FBI is a common water quality assessment. Each family is assigned a tolerance value that describes its ability to tolerate organic pollution. The values range from 0 – 10; zero is intolerant to pollution, 10 is quite tolerant of pollution. The tolerance values are used to calculate a weighted average tolerance value for the sample; allowing for comparisons from year to year. The Vermillion River FBI scores show very good water quality (2002, 2004 - 2006) to fair water quality (2001), indicating the presence of some organic pollution during most years (Figure VR-16).

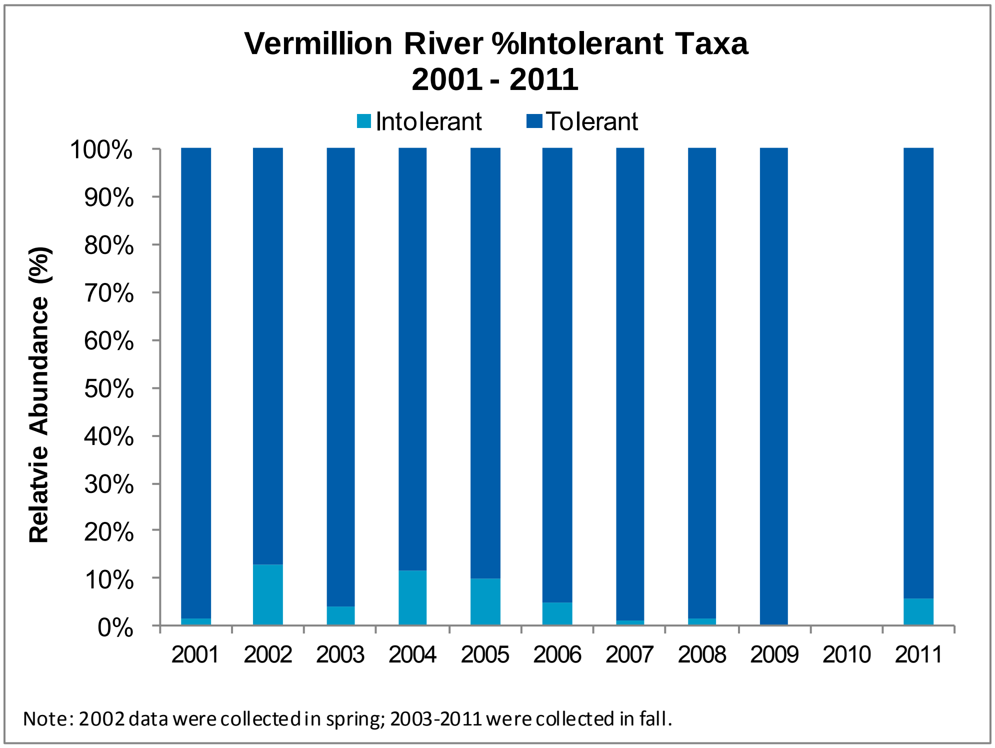
Figure VR-16: Vermillion River Annual Family Biotic Index (FBI) Scores, 2001-2011



Percent Intolerant Taxa

The Percent Intolerant Taxa is another assessment to evaluate the degree of pollution at the monitoring reach. This metric identifies the percent of taxa with a tolerance value of two or less (Figure VR-17). The presence of moderate numbers of intolerant taxa is an indicator of good aquatic health (Chirhart, 2003). The Vermillion River intolerant taxa were greater than 10% of the sample in 2002, 2004, and 2005. The highest percent intolerant taxa value, 13%, occurred in 2002. Intolerant taxa were present in all samples except 2009.

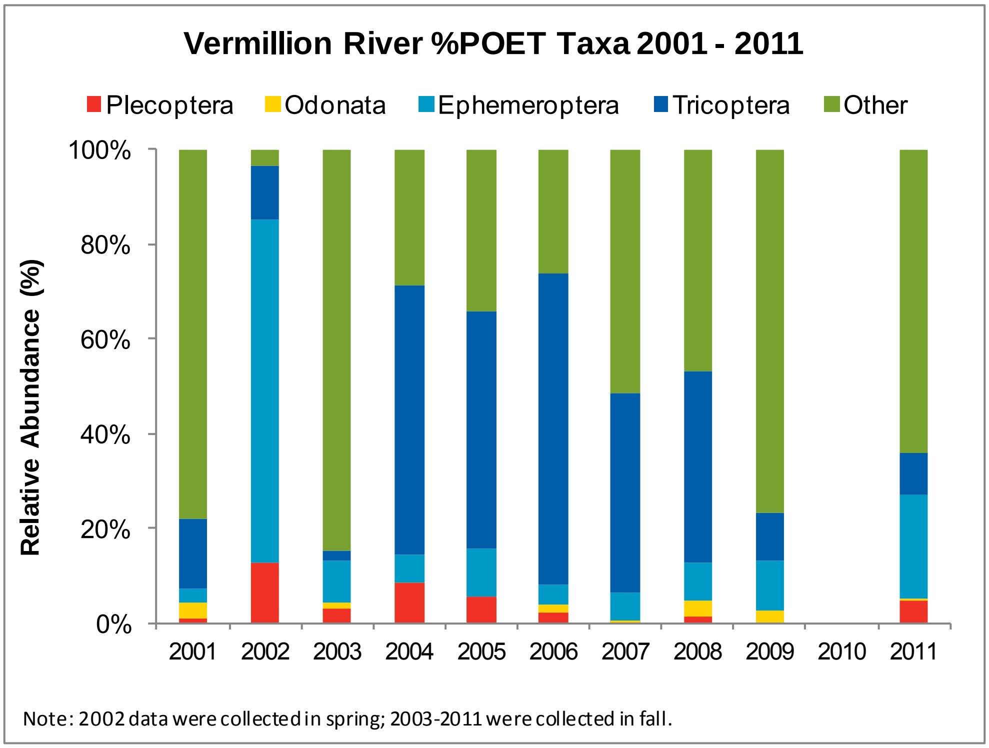
Figure VR-17: Vermillion River Percent Abundance of Pollution Intolerant Taxa, 2001-2011



Percent POET Taxa

The taxonomic richness metric, Percent POET Taxa (Figure VR-18), is the percent of individuals in the sample which belong to the orders **P**lecoptera (stoneflies), **O**donata (dragonflies and damselflies), **E**phemeroptera (mayflies), and **T**richoptera (caddisflies). Individuals in these orders vary in sensitivity to organic pollution and sedimentation. High percent POET taxa values indicate high community diversity due to good water quality. The percent POET taxa value was highest in 2002 at 97%, and lowest in 2003 at 15%.

Figure VR-18: Vermillion River Percent Abundance of POET Taxa, 2001-2011



Macroinvertebrate Index of Biotic Integrity (M-IBI)

The M-IBI score integrates community richness and composition, pollution tolerance, life histories, trophic interactions, and physical and other parameters that all are components of the biological integrity of the stream. These composite scores are usually shown in context with a threshold value and confidence levels to aid in the assessment of the water quality.

The MCES stream monitoring station falls within the warm water portion of the Vermillion River, and was analyzed using the MPCA thresholds for warm water macroinvertebrate communities.

All of the Vermillion River M-IBI scores were at or above the impairment threshold (Figure VR-19). Four scores, 2004, 2006, 2008, and 2009, were above the upper confidence level of impairment. This suggests the stream reach during those years was able to sustain the needs of aquatic life.

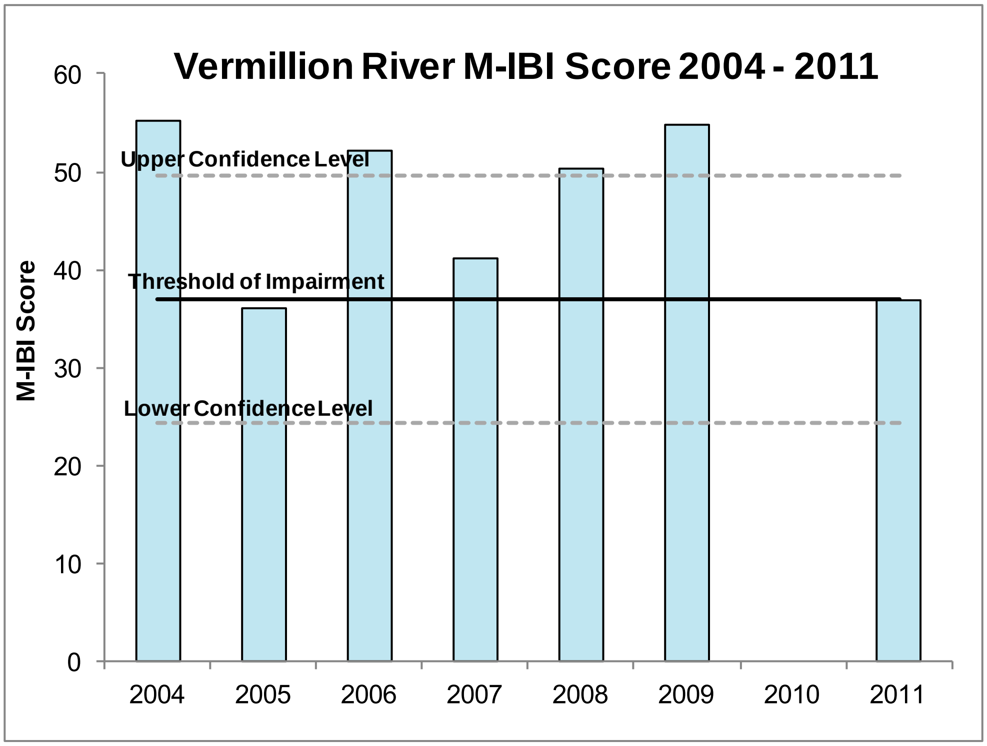
In 2005, 2007, and 2011, the M-IBI scores were between the threshold of impairment and the upper confidence level. When the scores fall between the confidence levels, it is difficult to confidently assess the water quality by biological assessment alone. It is necessary to incorporate other monitoring information, such as hydrology, water chemistry and land use change (MPCA, 2014c).

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

The 2007 - 2009 scores show an improving stream system that most likely could support the needs of aquatic life. There was an apparent disturbance in 2010-2011 that lowered the 2011 M-IBI score. Future M-IBI scores will show whether this was a singular disturbance or a decreasing trend.

The Vermillion River appears to be a healthy system that is able to provide for the needs of the aquatic community. MCES is planning additional future analysis to fully investigate our biological monitoring data.

Figure VR-19: Vermillion River Annual Macroinvertebrate Index of Biological Integrity (M-IBI) Scores, 2004-2011



Trend Analysis

Trend analysis was completed for the historical record of TP, NO_3, and TSS using the U.S. Geological Survey (USGS) program QWTREND (Vecchia, 2003). QWTREND removes the variability of annual flow and seasonality from the statistical analysis; 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 variations in flow rate; their results can be used to form general assumptions about changes in flows in the metropolitan area streams. Novotny and Stefan (2007) assessed flows from 36 USGS monitoring stations across Minnesota over a period of 10 to 90 years, finding that peak flow due to snowmelt was the only streamflow statistic that has not changed at a significant rate. Peak flows due to rainfall events in summer were found to be increasing, along with the number of days exhibiting higher flows.

Both summer and winter baseflow were found to be increasing, as well. Novotny and Stefan hypothesized that increases in annual precipitation, larger number of intense precipitation events, and more days with precipitation are driving the increased flows. Alterations in land use and land management have also likely contributed to increasing flow rates. For example, Schottler et.al. (2013) found that agricultural watersheds with large land use changes have exhibited increases in seasonal and annual water yields, with most of the increase in flow rate due to changes in artificial drainage and loss of natural storage. MCES staff plan to repeat the following trend analyses in five to 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 in the Vermillion River at VR 2.0 (Hastings; 1995-2012), VR 15.6 (Empire; 1976-2012), and VR 20.6 (Farmington; 1977-2012) stations for TSS, TP, and NO_3 using daily average flow, baseflow grab sample, and event composite sample data. MCES performed trends for all three stations to identify the influence of the Empire WWTP and its modifications during this period on the Vermillion River upstream and downstream from the WWTP. The results for VR 2.0 (Vermillion River at Hastings) were also summarized for 2008-2012 to allow equivalent comparison to the other streams assessed in this study. In addition, sufficient data exists to estimate trends for chlorophyll a concentration at VR 15.6 and VR 20.6. Chlorophyll a concentration is a response variable associated with the MPCA's TP standard; MCES staff evaluated this trend to assist the MPCA in evaluating the relationship between causative and response variables for the new TP standard.

While QWTREND allows identification of changes in pollutant concentration with time, it does not identify causation. WWTP process changes, like the implementation of Bio-P removal and the diversion of effluent discharge, should be evident in the concentration trends, but the effects of other more subtle changes within the watershed, such as land use change, implementation of multiple small BMPs within the watershed landscape, or changes in agricultural practices, will likely not be clearly evident.

Total Suspended Solids (TSS)

VR 20.6: Three trends were identified for TSS flow-adjusted concentrations in the Vermillion River upstream of the Empire WWTP during the assessment period 1977 - 2012 (Figure VR-20, top panel). The assessment was performed using QWTREND without the precedent five-year flow setting. The trends were statistically significant ($p=0.017$):

- Trend 1: 1977 - 1988, TSS flow-adjusted concentration decreased from 7.1 mg/l to 5.2 mg/l (-27%) at a rate of -0.16 mg/l/yr.
- Trend 2: 1989 to 1999, TSS flow-adjusted concentration increased from 5.2 mg/l to 6.7 mg/l (28%) at a rate of 0.14 mg/l/yr.
- Trend 3: 2000 to 2012, TSS flow-adjusted concentration decreased from 6.7 mg/l to 6.3 mg/l (-6%) at a rate of -0.03 mg/l/yr.

VR 15.6: Three trends were identified for TSS flow-adjusted concentrations in the Vermillion River downstream of the Empire WWTP during the assessment period 1976 - 2012 (Figure VR-21, top panel). The assessment was performed using QWTREND without precedent five-year flow setting. The trends were statistically significant ($p=1.15 \times 10^{-6}$):

- Trend 1: 1976 to 1990, TSS flow-adjusted concentration decreased from 19 mg/l to 6.3 mg/l (-67%) at a rate of -0.85 mg/l/yr.

- Trend 2: 1991 to 2002, TSS flow-adjusted concentration increased from 6.3 mg/l to 8.8 mg/l (39%) at a rate of 0.21 mg/l/yr.

- Trend 3: 2003 to 2012, TSS flow-adjusted concentration decreased from 8.8 mg/l to 6.8 mg/l (-22%) at a rate of -0.19 mg/l/yr.

VR 2.0: One trend was identified for TSS concentrations in the Vermillion River near Hastings, MN during the assessment period 1995 - 2012 (Figure VR-22, top panel). The assessment was performed using QWTREND without precedent five-year flow setting. The trends were statistically significant ($p=2.0x10^{-6}$):

- Trend 1: 1995 to 2012, TSS flow-adjusted concentration decreased from 20.8 mg/l to 7.2 mg/l (-65%) at a rate of -0.75 mg/l/yr.

The five-year trend in TSS flow-adjusted concentration in the Vermillion River at VR2.0 (Vermillion River near Hastings) for period 2008 - 2012 was calculated to compare with other MCES-monitored streams, shown in the report section ***Comparison with Other Metro Area Streams***. TSS concentration decreased 8.8 mg/l to 7.2 mg/l (-19%), at a rate of -0.33 mg/l/yr, indicating an improvement in TSS water quality during that time.

Total Phosphorus

VR 20.6: Three trends were identified for TP flow-adjusted concentrations in the Vermillion River upstream of the Empire WWTP during the assessment period 1979 - 2012 (Figure VR-20, middle panel). The assessment was performed using QWTREND without the precedent five-year flow setting. The trends were statistically significant ($p=9.1x10^{-9}$):

- Trend 1: 1979 to 1994, TP flow-adjusted concentration decreased from 0.10 mg/l to 0.05 mg/l (-51%) at a rate of -0.003 mg/l/yr.

- Trend 2: 1995 to 1998, TP flow-adjusted concentration increased from 0.05 mg/l to 0.06 mg/l (31%) at a rate of 0.004 mg/l/yr.

- Trend 3: 1999 to 2012, TP flow-adjusted concentration decreased from 0.06 mg/l to 0.05 mg/l (-24%) at a rate of -0.001 mg/l/yr.

VR 15.6: Four trends were identified for TP flow-adjusted concentrations in the Vermillion River downstream of the Empire WWTP during the assessment period 1979 - 2012 (Figure VR-21, middle panel). The assessment was performed using QWTREND without the precedent five-year flow setting. The trends were statistically significant ($p=4.0x10^{-5}$):

- Trend 1: 1979 to 2005, TP flow-adjusted concentration increased from 0.49 mg/l to 0.66 mg/l (36%) at a rate of 0.007 mg/l/yr.

- Trend 2: 2006 to 2006, TP flow-adjusted concentration sharply decreased from 0.66 mg/l to 0.13 mg/l (-80%) at a rate of -0.53 mg/l/yr.

- Trend 3: 2007 to 2008, TP flow-adjusted concentration decreased from 0.13 mg/l to 0.05 mg/l (-61%) at a rate of -0.040 mg/l/yr.

- Trend 4: 2009 to 2012, TP flow-adjusted concentration increased from 0.05 mg/l to 0.16 mg/l (216%) at a rate of 0.027 mg/l/yr.

VR 2.0: Four trends were identified for TP flow-adjusted concentrations in the Vermillion River at Hastings during the assessment period 1995 - 2012 (Figure VR-22, middle panel). The assessment was performed using QWTREND without precedent five-year flow setting. The trends were statistically significant ($p=3.5x10^{-6}$):

- Trend 1: 1995 to 2005, TP flow-adjusted concentration increased from 0.56 mg/l to 1.00 mg/l (76%) at a rate of 0.39mg/l/yr.

- Trend 2: 2006 to 2006, TP flow-adjusted concentration sharply decreased from 1.00 mg/l to 0.11 mg/l (-89%) at a rate of -0.89 mg/l/yr.

- Trend 3: 2007 to 2008, TP flow-adjusted concentration decreased from 0.11 mg/l to 0.08 mg/l (-28%) at a rate of -0.015 mg/l/yr.

- Trend 4: 2009 to 2012, TP flow-adjusted concentration decreased from 0.08 mg/l to 0.04 mg/l (-45%) at a rate of -0.009 mg/l/yr.

The five-year trend in TP flow-adjusted concentration at VR 2.0 (Vermillion River at Hastings) (2008 - 2012) was calculated to compare with other MCES-monitored streams, shown in the report section ***Comparison with Other Metro Area Streams***. TSS concentration decreased 0.09mg/l to 0.04 mg/l (-53%), at a rate of -0.0096 mg/l/yr.

Chlorophyll-a

VR 20.6: Three trends were identified for chlorophyll-*a* flow-adjusted concentrations in the Vermillion River upstream of the Empire WWTP during the assessment period 1979 - 2012 (Figure VR-20, third lowest panel). The assessment was performed using QWTREND without the precedent five-year flow setting. The trends were found to be statistically significant ($p=2.8x10^{-9}$):

- Trend 1: 1979 to 1995, chl-*a* flow-adjusted concentration decreased from 4.8 µg/l to 4.6 µg/l (-6%) at a rate of -0.016 µg/l/yr.

- Trend 2: 1996 to 2005, chl-*a* flow-adjusted concentration increased from 4.7 µg/l to 8.5 µg/l (86%) at a rate of 0.39 µg/l/yr.

- Trend 3: 2006 to 2012, chl-*a* flow-adjusted concentration decreased from 8.5 µg/l to 4.8 µg/l (-44%) at a rate of -0.53 µg/l/yr.

VR 15.6: Three trends were identified for chlorophyll-*a* flow-adjusted concentrations in the Vermillion River downstream of the Empire WWTP during the assessment period 1979 - 2012 (Figure VR-21, third lowest panel). The assessment was performed using QWTREND without the precedent five-year flow setting. The trends were found to be statistically significant ($p=2.5x10^{-9}$):

- Trend 1: 1979 to 1995, chl-*a* flow-adjusted concentration decreased from 4.8 µg/l to 4.7 µg/l (-2%) at a rate of -0.0071 µg/l/yr.
- Trend 2: 1996 to 2004, chl-*a* flow-adjusted concentration increased from 4.7 µg/l to 9.5 µg/l (102%) at a rate of 0.54 µg/l/yr.
- Trend 3: 2005 to 2012, chl-*a* flow-adjusted concentration decreased from 9.5 µg/l to 5.4 µg/l (-43%) at a rate of -0.52 µg/l/yr.

VR 2.0: No trend calculated due to insufficient chlorophyll a data.

Nitrate

VR 20.6: Three trends were identified for NO_3 flow-adjusted concentrations in the Vermillion River upstream of the Empire WWTP during the assessment period 1979 - 2012 (Figure VR-20, lowest panel). The assessment was performed using QWTREND without the precedent five-year flow setting. The trends were statistically significant ($p=6.0 \times 10^{-6}$):

- Trend 1: 1979 to 1991, NO_3 flow-adjusted concentration increased from 1.6 mg/l to 2.0 mg/l (33%) at a rate of 0.040 mg/l/yr.
- Trend 2: 1992 to 1996, NO_3 flow-adjusted concentration decreased from 2.0 mg/l to 1.6 mg/l (-25%) at a rate of -0.10 mg/l/yr.
- Trend 3: 1997 to 2012, NO_3 flow-adjusted concentration increased from 1.6 mg/l to 1.9 mg/l (21%) at a rate of 0.021 mg/l/yr.

VR 15.6: No trends were identified for NO_3 flow-adjusted concentrations in the Vermillion River downstream of the Empire WWTP during the assessment period 1976 - 2012 (Figure VR-21, lowest panel). The assessment was performed using QWTREND without precedent five-year flow setting. The trends were not statistically significant ($p=0.36$) and thus are not reported. MCES staff tried multiple approaches to estimate a statistically-significant trend, with no results, likely due to large variations in Empire WWTP effluent NO_3 concentrations during the 1980s-1990s, which resulted in highly variable concentrations in the river during that time. Examination of the concentration data (Figure VR-26 in ***Trends Discussion***) indicates that the Empire effluent diversion likely caused an abrupt decrease in Vermillion River NO_3 concentration in 2008.

VR 2.0: Two trends were identified for NO_3 flow-adjusted concentrations in the Vermillion River near Hastings, MN during the assessment period 1998 - 2012 (Figure VR-22, lowest panel). The assessment was performed using QWTREND without precedent five-year flow setting. The trends were statistically significant ($p=2.5 \times 10^{-14}$):

- Trend 1: 1998 to 2000, NO_3 flow-adjusted concentration increased from 3.6 mg/l to 6.7 mg/l (89%) at a rate of 1.1 mg/l/yr.
- Trend 2: 2001 to 2012, NO_3 flow-adjusted concentration decreased from 6.7 mg/l to 3.4 mg/l (-49%) at a rate of -0.28 mg/l/yr.

The five-year trend in NO_3 flow-adjusted concentration in the Vermillion River near Hastings (VR 2.0) (2008 - 2012) was calculated to compare with other MCES-monitored streams, shown in the report section ***Comparison with Other Metro Area Streams***. NO_3 flow-adjusted concentration decreased from 4.4 mg/l to 3.4 mg/l (-49%), at a rate of -0.19 mg/l/yr.

Figure VR−20: Vermillion River 20.6 Trends for TSS, TP, Chl-*a* and NO_3

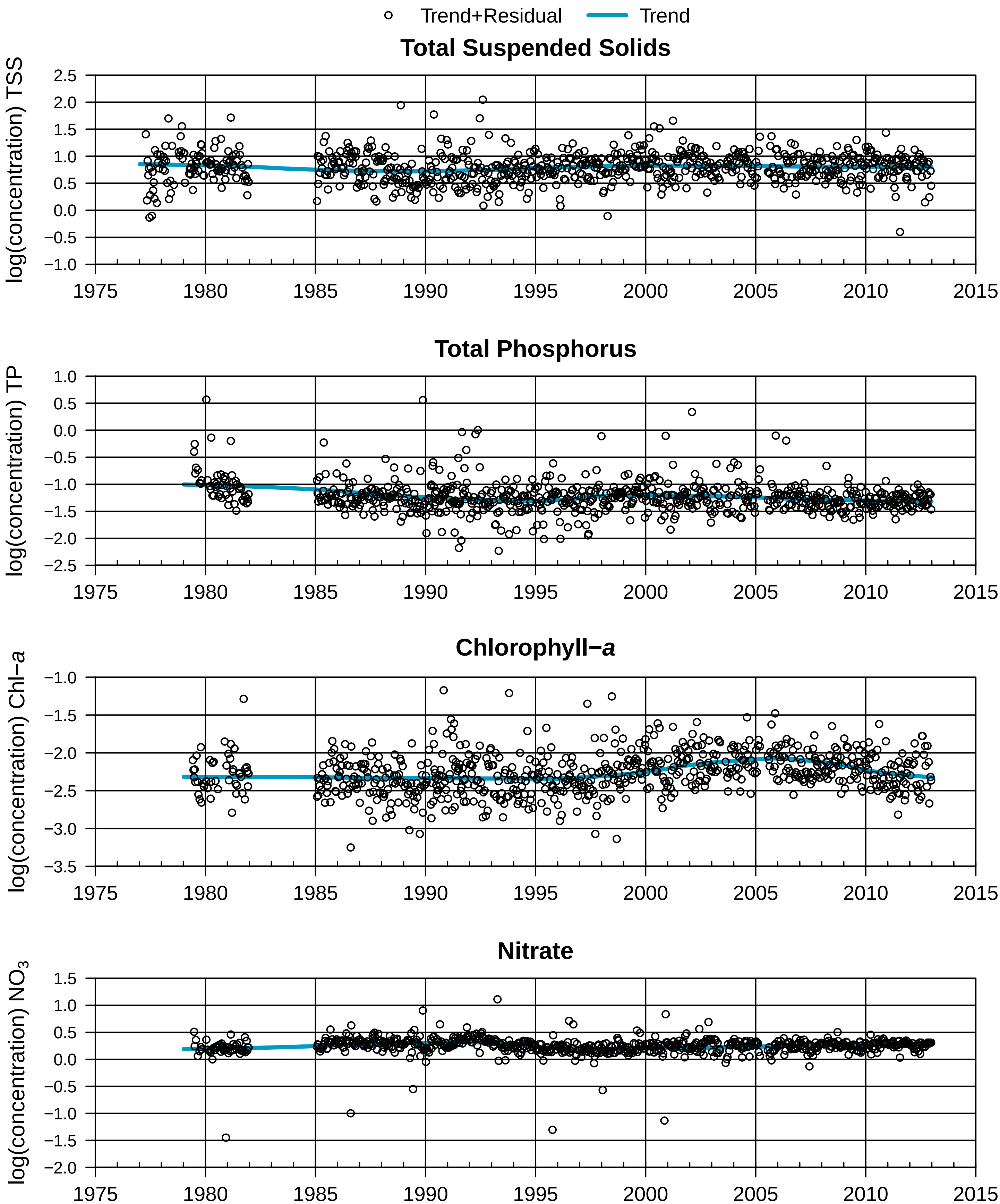


Figure VR−21: Vermillion River 15.6 Trends for TSS, TP, Chl-*a* and NO_3

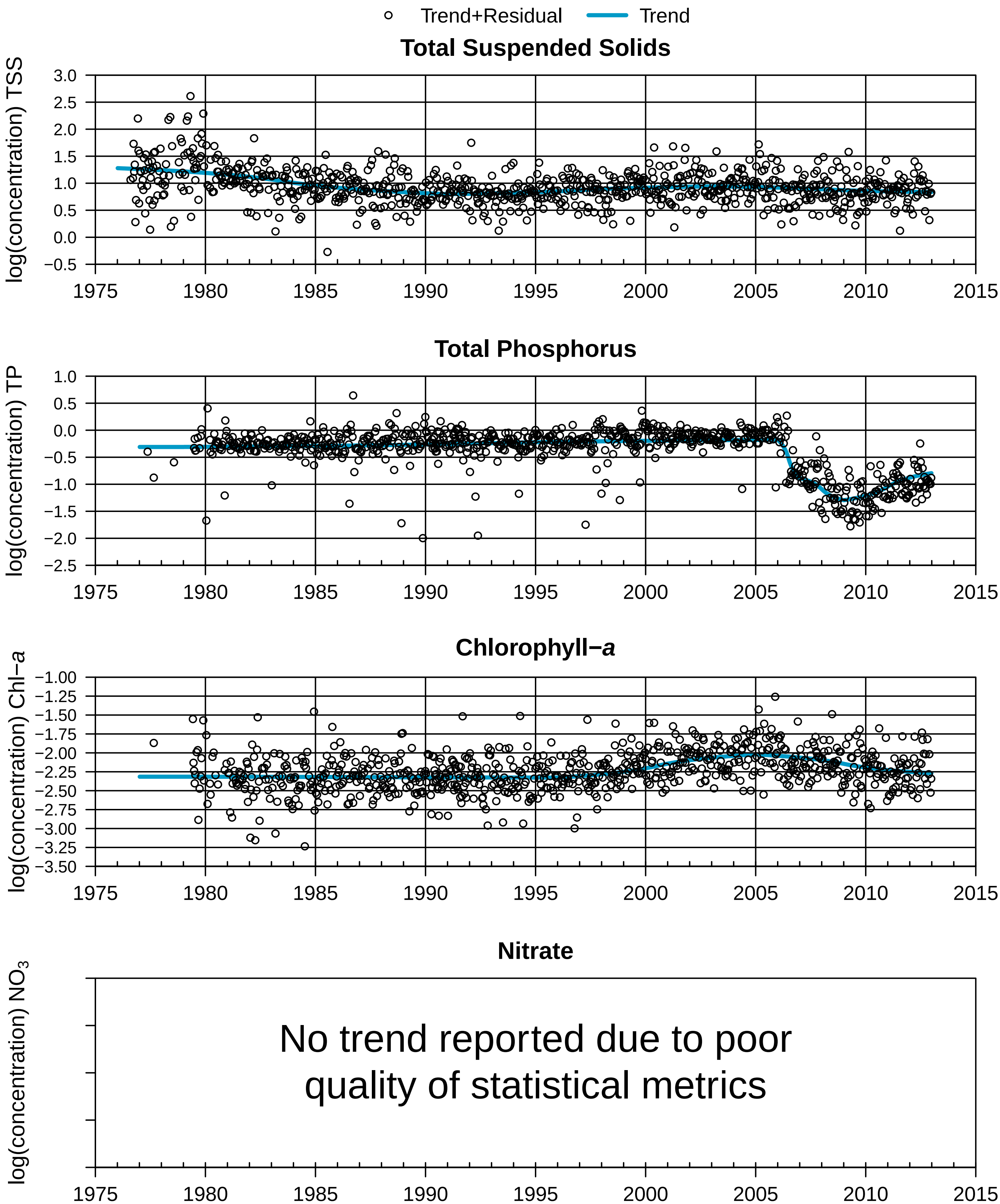
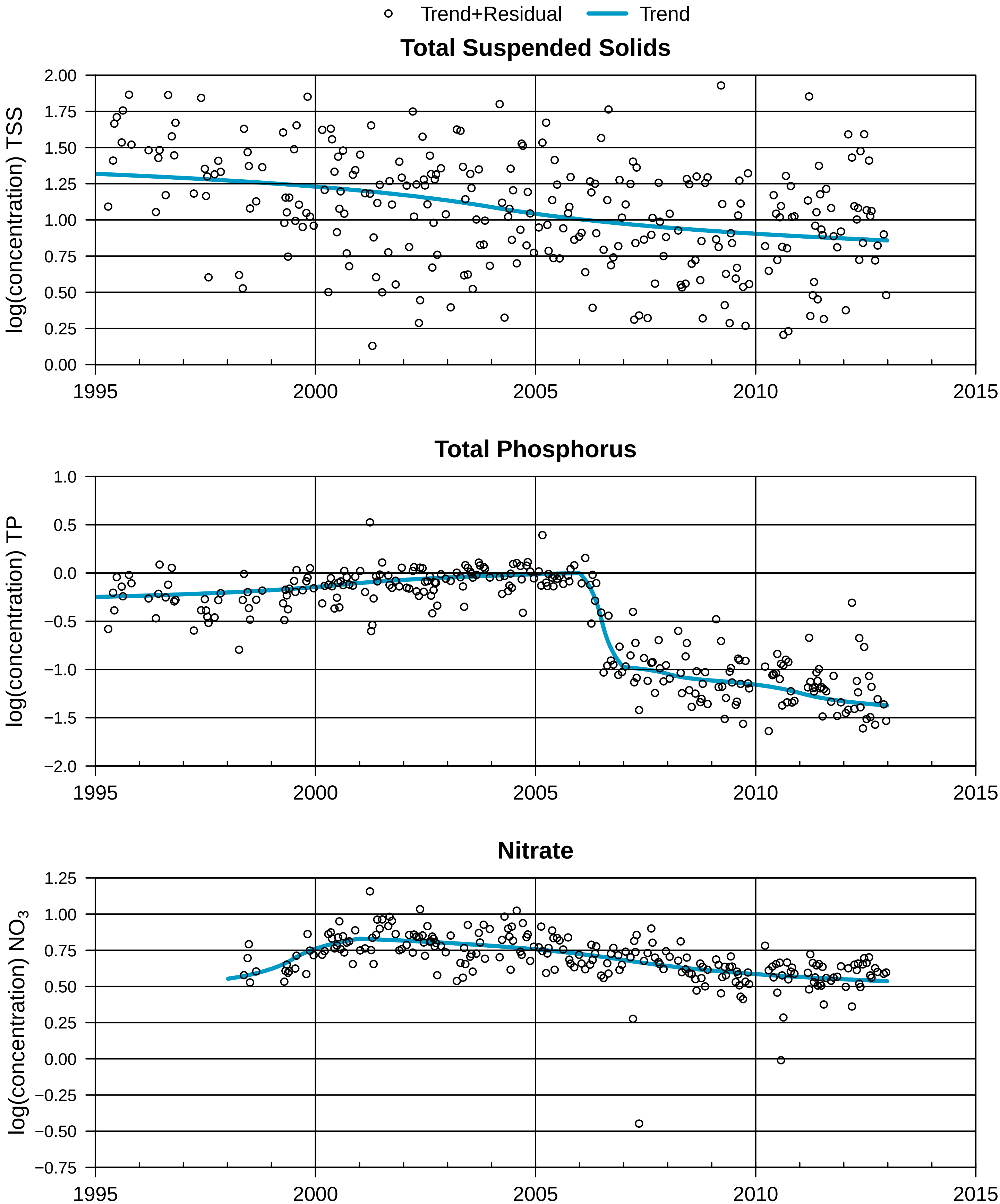


Figure VR−22: Vermillion River 2.0 Trends for TSS, TP and NO_3



Trends Discussion

While MCES staff have assessed monitoring data and trend analysis statistics, more work is needed to assign causative actions to the trend analysis results. TSS and TP chemistry, delivery, transport and remediation are complicated, although fairly well-understood. Identifying contributing events, implementation practices, and other causative actions is expected to be somewhat straightforward for these two parameters. A simple example of potential causation for TP trends is displayed in a series of graphs, illustrating the estimated TP trends [VR20.6, Vermillion River at Farmington (upstream of the Empire WWTP); VR15.6, Vermillion River at Empire (downstream of the Empire WWTP); and VR2.0, Vermillion at Hastings], potential impacts of increasing population and associated increasing WWTP discharge of TP to the Vermillion River (Figures VR-23 to VR-25).

Figure VR-23: Populations in Cities of Farmington, Apple Valley, and Lakeville, 1970-2012

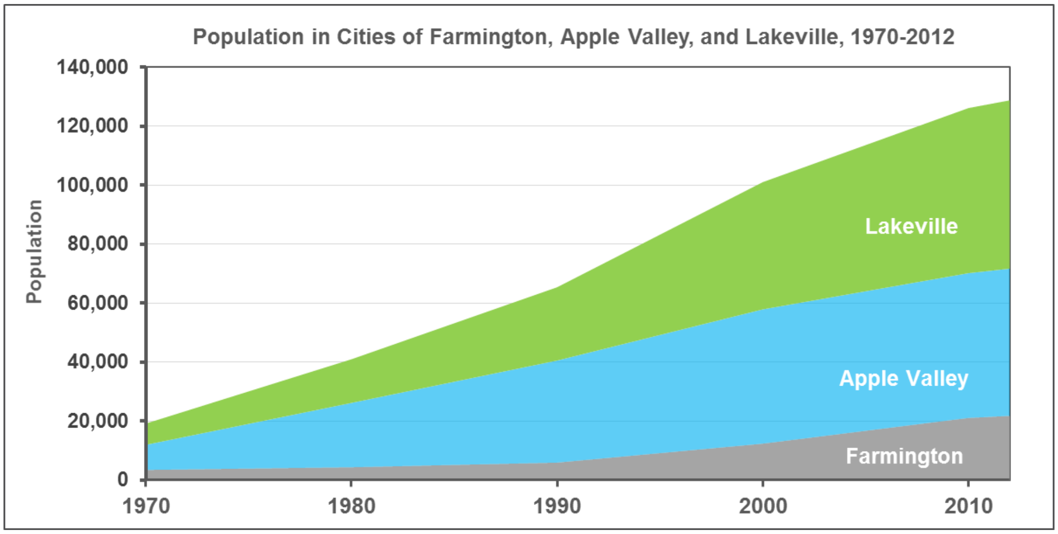
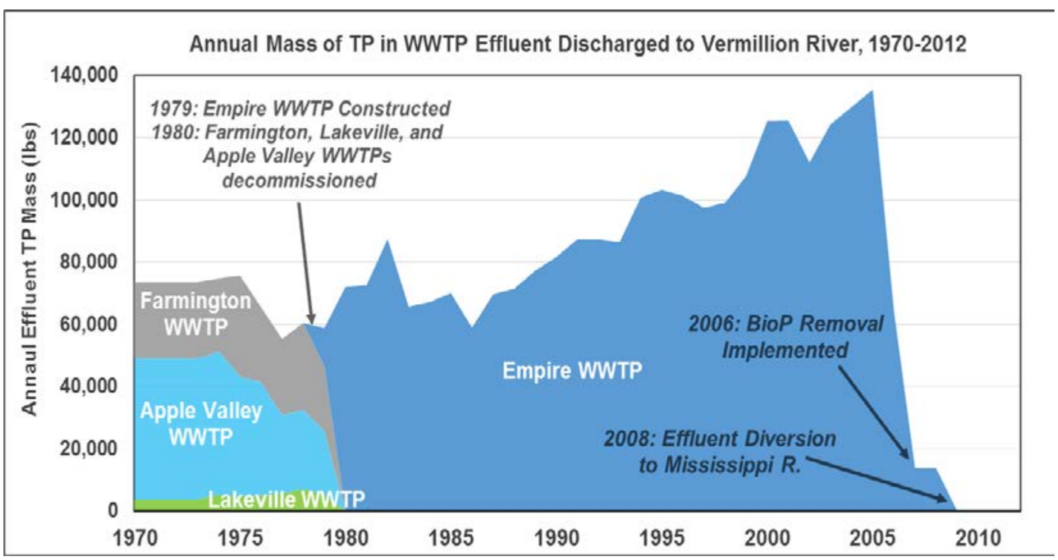


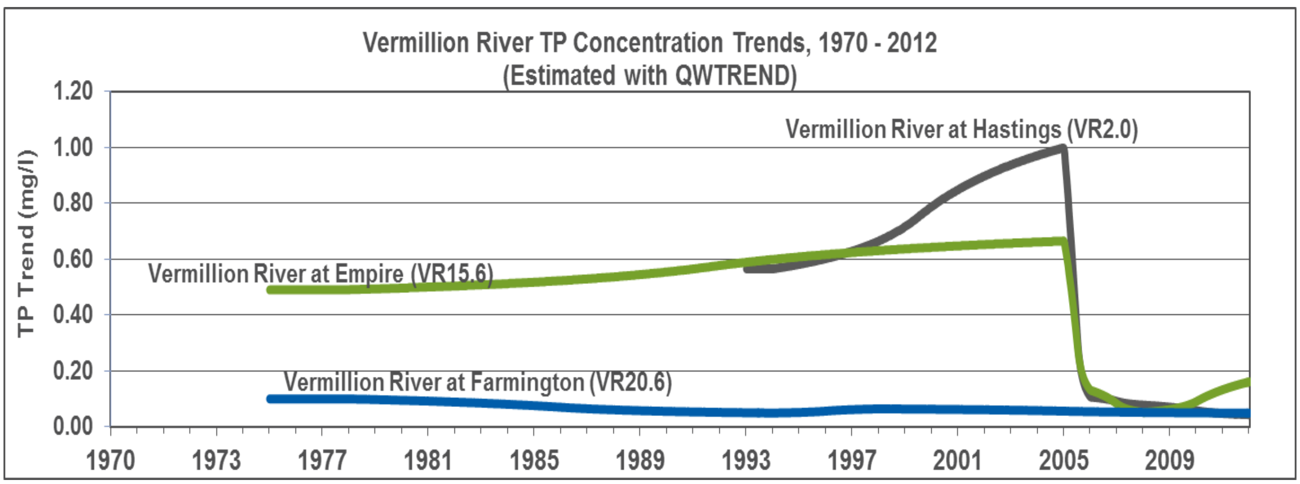
Figure VR-24: Annual Mass of TP in WWTP Effluent Discharged to Vermillion River: 1970-2012



Several observations can be made from the trend lines in Figure VR-25:

- The TP trend at Farmington (VR20.6), located above the Empire WWTP effluent outfall, shows a gradual decline in TP concentration over time, despite increasing population within cities discharging stormwater to the river. This may indicate effectiveness of stormwater practices installed during construction, changes in landowner behavior due to environmental education programs, installation of stream restoration projects, and other unidentified improvement projects.
- The TP trend at Empire (VR15.6) appears to reflect increasing volumes of WWTP effluent discharge related to increasing watershed population. The trend line also reflects the drastic decrease in effluent TP concentration in 2006 due to implementation of biological phosphorus removal at the Empire WWTP, and complete removal of effluent discharge during the 2008 diversion to the Mississippi River. The increase in river TP concentration post-diversion may be caused by release of TP from enriched river sediments or pore-waters to order to reach equilibrium of concentration.
- The TP trend at Hastings (VR2.0) closely follows the trend at Empire, indicating concentration increase prior to Empire WWTP biological phosphorus implementation and diversion. The elevated concentration estimated at Hastings (in comparison to that at Empire) may be caused by the discharge from the South Branch tributary or stormwater discharge from the developed area upstream of Hastings.

Figure VR-25: Vermillion River TP Concentrations at Farmington, Empire, and Hastings, 1970-2012



NO_3 chemistry and transport dynamics within the natural environmental are significantly more complicated. The NO_3 trends for most of 21 streams assessed in the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams* showed periods of both rising and falling flow-adjusted concentrations. NO_3 concentrations may be affected by periods of saturated and unsaturated soil conditions related to precipitation patterns, by agricultural crop rotations, by changing levels of fertilizer applications, or other unidentified causative variables, rather than true long-term improvement in concentrations based on intentional implementation of best management practices. The NO_3 dynamics in the Vermillion River likely have been historically driven by saturated soil conditions, variability in WWTP effluent concentrations, and discharge to the river of high nitrate shallow groundwater from agricultural areas. The NO_3 trend for the Vermillion River at Farmington (VR20.6; upstream of Empire WWTP) is similar to that seen in other metropolitan-area streams: alternating periods of increasing and decreasing concentration, which may be driven by long-term precipitation cycles causing periods of saturated and unsaturated soils conditions. Saturated soils conditions may lead to soil anoxia and denitrification, thus decreasing NO_3 concentrations. MCES made numerous attempts to estimate a statistically valid trend for the Vermillion River at Empire (VR15.6, downstream of Empire WWTP effluent outfall), but none of the estimates met the statistical quality parameters set by MCES (p-value and AIC). Examination of river and WWTP effluent NO_3 concentrations over time revealed that the effluent NO_3 has been highly variable, even on a daily basis, which has resulted in variable concentrations in the river unrelated to flow conditions. MCES WWTP staff (G. Sprouse; C. Johnson; pers. comm., 2015) report the following have likely influenced the variability in effluent NO_3 over time:

- NO_3 in the effluent is likely directly related to the ammonia (NH_3) and total Kjeldahl nitrogen (TKN) in the influent sewage. The Empire WWTP has historically had a number of industrial contributors that, when discharging, produce sewage with a higher-than-domestic-sewage TKN concentration. For example, Kemps (a producer of dairy products, located in Farmington) reported in November 2011 strength of total discharge of 6,333 mg/l CBOD5 (5-day Carbonaceous Biochemical Oxygen Demand), 570 mg/l TSS, 119 mg/l TKN, and 132 mg/l TP.
- The decrease in effluent NO_3 concentration in 2005-2006 is likely due to the implementation of biological phosphorus reduction (Bio-P) at the Empire WWTP. The implementation changed the WWTP process to include anoxic tanks [with the specific goal of providing denitrification of RAS (Return Activated Sludge) to protect the Bio-P process] and aerobic tanks (which would also denitrify any NO_3 that is delivered to the tanks).
- Before the WWTP expansion in 2007, the return/recycle flows within the WWTP flowed directly to the headworks and were not metered or equalized. The return flow would have included stormwater runoff from the biosolids storage areas during precipitation events, as well as belt press pressate, resulting in variable TKN concentration sewage delivered to the WWTP process tanks, resulting in variable NO_3 in the WWTP effluent.
- The effluent diversion completed in 2008 resulted in removal of the WWTP NO_3 contribution, which ranged from a maximum of 870,000 lb/yr (2004) to a minimum of 420,000 lb/yr (2006) for period 1997-2007.

MCES staff were able to estimate a NO_3 trend for the Vermillion River at Hastings (VR2.0), which indicates the flow-adjusted NO_3 concentration during 1998-2012 (the period of record for that station) peaked in 2001 and gradually decreased during 2001-2012.

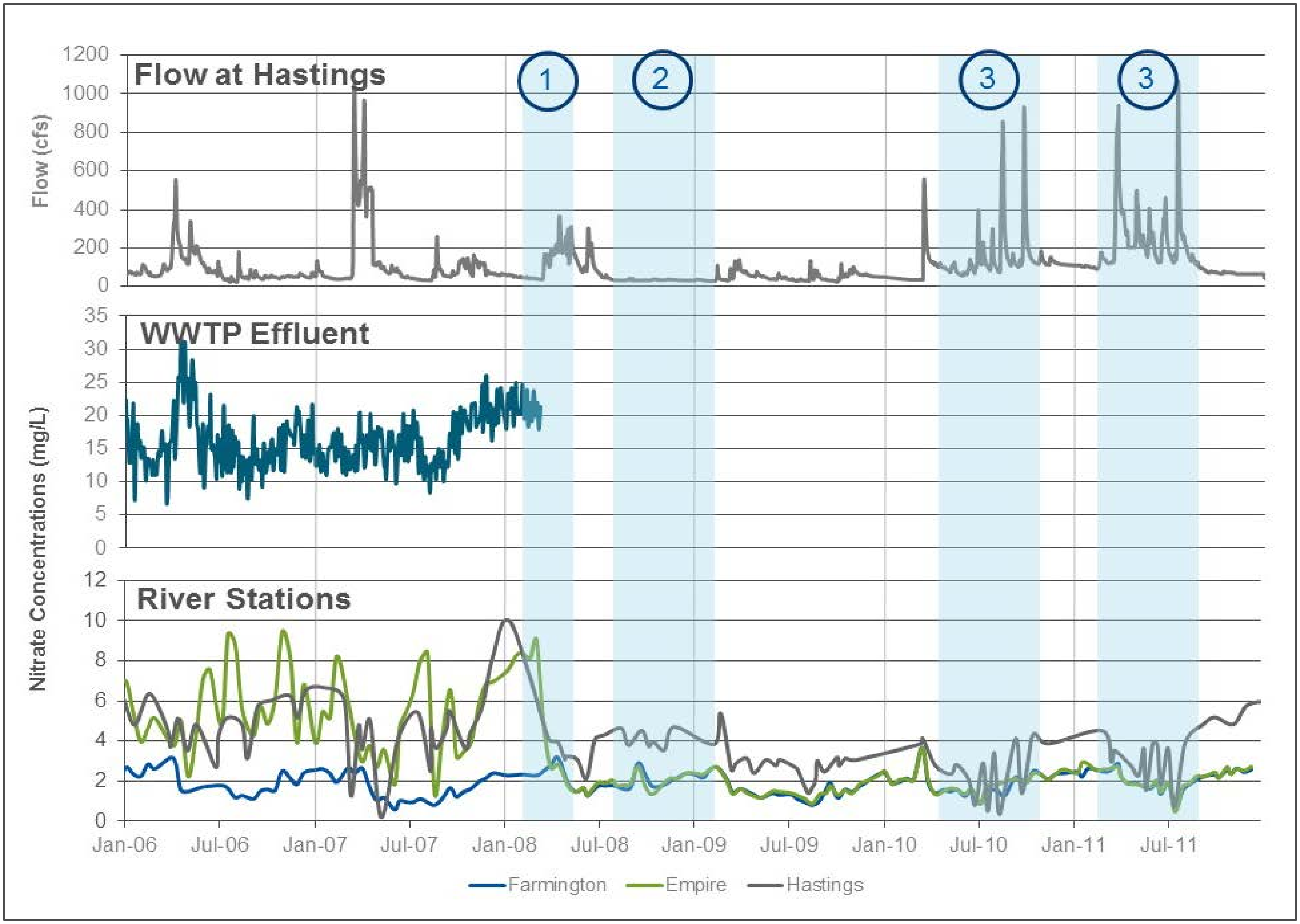
VRWJPO staff investigated baseflow NO_3 concentrations in the South Branch tributary concurrently to the MCES NO_3 trend analysis. The VRWJPO's initial results indicate baseflow NO_3 concentrations are gradually increasing in the South Branch, likely reflecting increasing agricultural activities in that subwatershed. Figure VR-26, which shows Vermillion River flow at

Hastings, daily NO_3 concentration in the Empire WWTP effluent, and sample NO_3 concentrations in the Vermillion River at Farmington, Empire, and Hastings during 2006-2012, illustrates the complicated NO_3 dynamics in the river. Examination of the graphics indicates that:

- WWTP effluent concentration has been highly variable, ranging from 6.7 mg/l (3/21/2006) to 31.5 mg/l (4/18/2006), with a median value of 15.7 mg/l, during 2006-2008 (when effluent diversion was completed).
- The NO_3 concentration at Farmington (VR20.6), upstream of the effluent outfall, varies slightly, centered on approximately 2 mg/l.
- The NO_3 concentration at Empire (VR15.6), immediately downstream of the effluent outfall, appears to vary in relation to the effluent concentration and ranged from approximately 1.5 mg/l to 9.5 mg/l during period 2006-2008.
- The NO_3 concentration at Hastings (VR2.0), appears to also vary relative to effluent concentration.
- The highlighted area #1 on Figure VR-26 indicates the timing of the effluent diversion. Post-diversion, the NO_3 concentrations at Farmington and Empire are identical.
- The highlighted area #2 on Figure VR-26 indicates the NO_3 concentration at Hastings under baseflow conditions. The concentrations at Farmington (VR20.6) and Empire (15.6) remain low, while the concentration at Hastings is elevated. The VRWJPO hypothesizes that the concentration increase is due to high NO_3 baseflow entering from the South Branch, which enters the river downstream of the Empire monitoring station, approximately at mile 11.
- The highlighted areas #3 on Figure VR-26 indicate that during stormflow conditions, the NO_3 concentrations at Hastings are diluted; the concentrations are elevated again once baseflow conditions return.
- NO_3 concentration in the Vermillion River upstream of Hastings is of great interest to the VRWJPO due to potential contamination of shallow drinking water wells in Hastings. As the Vermillion River flows over the buried bedrock valley near the city of Vermillion, river potentially enters the shallow aquifer, and may influence shallow well quality.

MCES staff will repeat the trend analysis in 5- 10 years, and will continue to collaborate with the VRWJPO to investigate the NO_3, TSS, and TP dynamics in the Vermillion River.

Figure VR-26: Nitrate Concentrations in Empire WWTP Effluent and the Vermillion River at Hastings (VR2.0), Empire (VR15.6), and Farmington (VR20.6) and Flow in the Vermillion River at Hastings: 2006-2012



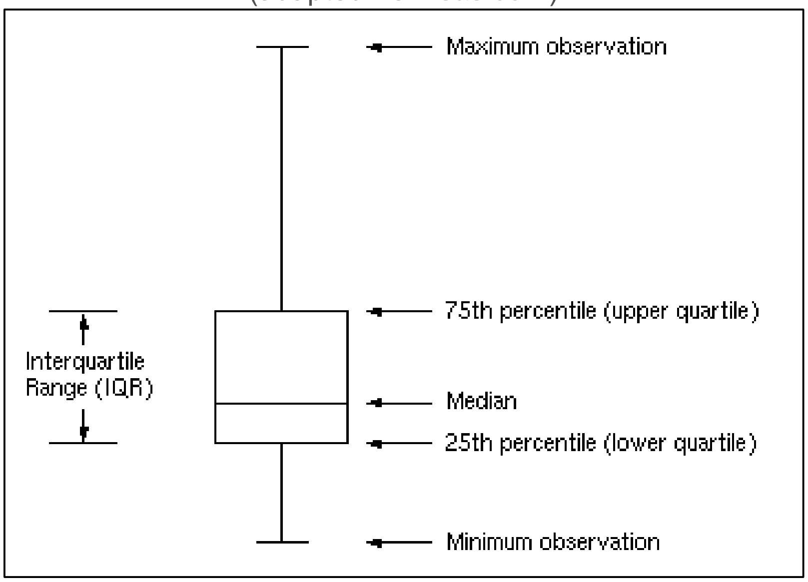
Comparison with Other Metro Area streams

Chemistry

Box-and-whisker plots are used to summarize the comparison of the historical flow, TSS, TP, NO_3, and Cl data for the Vermillion River with those of the other metropolitan area streams monitored by MCES and with the major receiving water (in this case the Mississippi River). The comparisons are shown in Figure VR-28 to Figure VR-31.

Figure VR-27 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 extent of the whiskers designate the maximum and minimum values.

Figure VR-27: General Schematic of a Box-and-Whisker Plot
(adapted from *sas.com*)



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

Total Suspended Solids. The median annual FWM concentration for TSS in the Vermillion River is the lowest of the Mississippi River tributaries below the Minnesota River confluence (Figure VR-28; Table VR-8). The FWM concentration in the Vermillion River is also lower than that in the Mississippi River (as measured at St. Paul, Minnesota, 29 mg/l vs. 55 mg/l, respectively), indicating that the Vermillion River is serving to dilute the TSS concentration in the Mississippi. It is apparent that the Vermillion River has significantly lower FWM TSS concentrations and annual yields (expressed in lb/acre) than the other agricultural tributaries entering the Mississippi or Minnesota Rivers monitored by MCES.

Median annual runoff ratio for the Vermillion River is similar to the other metropolitan area streams, with the exception of Eagle, Valley, and Browns Creek. These streams are groundwater-fed, like the Vermillion River, but clearly they have a larger contribution of groundwater in their total flows. The larger groundwater fraction increases the runoff ratios for these watersheds.

*Total Phosphorus***.** Unlike TSS, the FWM TP concentration in the Vermillion River is higher than the Mississippi River and thus served to increase the TP concentration in the river (Figure VR-29; Table VR-8). The Vermillion River has the lowest FWM TP concentration in comparison to the other Mississippi River tributaries below the Minnesota River confluence, and the lowest of the large, agricultural watersheds (for example, Crow River, Cannon River, Sand Creek). The Vermillion River annual yield interquartile range is the largest of any stream in the metropolitan area, but this demonstrates the influence of changes of WWTP operations on TP concentrations within this watershed.

Nitrate. The Vermillion River median annual FWM NO_3 concentration of 4.02 mg/l is lower than the drinking water standard (Table VR-7). However, when compared to the other Mississippi River tributaries below the Minnesota River confluence, this concentration is more similar to other agricultural watersheds (for example, the Cannon River) than the urban watersheds (Fish and Battle Creeks) The concentration of NO_3 in the Vermillion is greater than that in the Mississippi River, and thus serves as a source of NO_3 to the river (Figure VA-30; Table VR-8). The median annual yield of the Vermillion River is the comparable to other large, agricultural watersheds, including the Crow River, the Cannon River, and Bevens Creek.

Chloride. The Cl annual median FWM concentration is higher than the Cannon River, but less than Battle and Fish Creek (Figure VR-31; Table VR-8). This is notable, as the Vermillion River is a mix of both urban and agricultural land uses, which results in this mid-level of Cl load. The Vermillion River median Cl FWM concentration is higher than the Mississippi River and is considered a source of Cl contamination. Diversion of the Empire WWTP effluent to the Mississippi River likely caused a decrease in Cl concentration in the river after 2008.

Macroinvertebrates

The historic biomonitoring data, summarized as M-IBI scores, are also shown as box-and-whisker plots (Figure VR-32). The streams were organized by type, which is consistent with the MPCA impairment thresholds.

The M-IBI scores for the Vermillion River at Hastings (VR2.0) were above the MPCA impairment threshold for warm water streams, which suggests that the stream habitat and water quality were typically able to sustain the needs of aquatic life. Note that the Vermillion River at Hastings is classified as a warm water reach, in contrast with the cold water reaches upstream near Empire. The Vermillion River M-IBI scores were atypical in comparison with other warm water streams in the metropolitan area, which appear to have more stressed macroinvertebrate communities than those in the Vermillion River and those in the metropolitan area cold water streams, like Eagle and Valley Creeks.

Figure VR−28: Total Suspended Solids for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

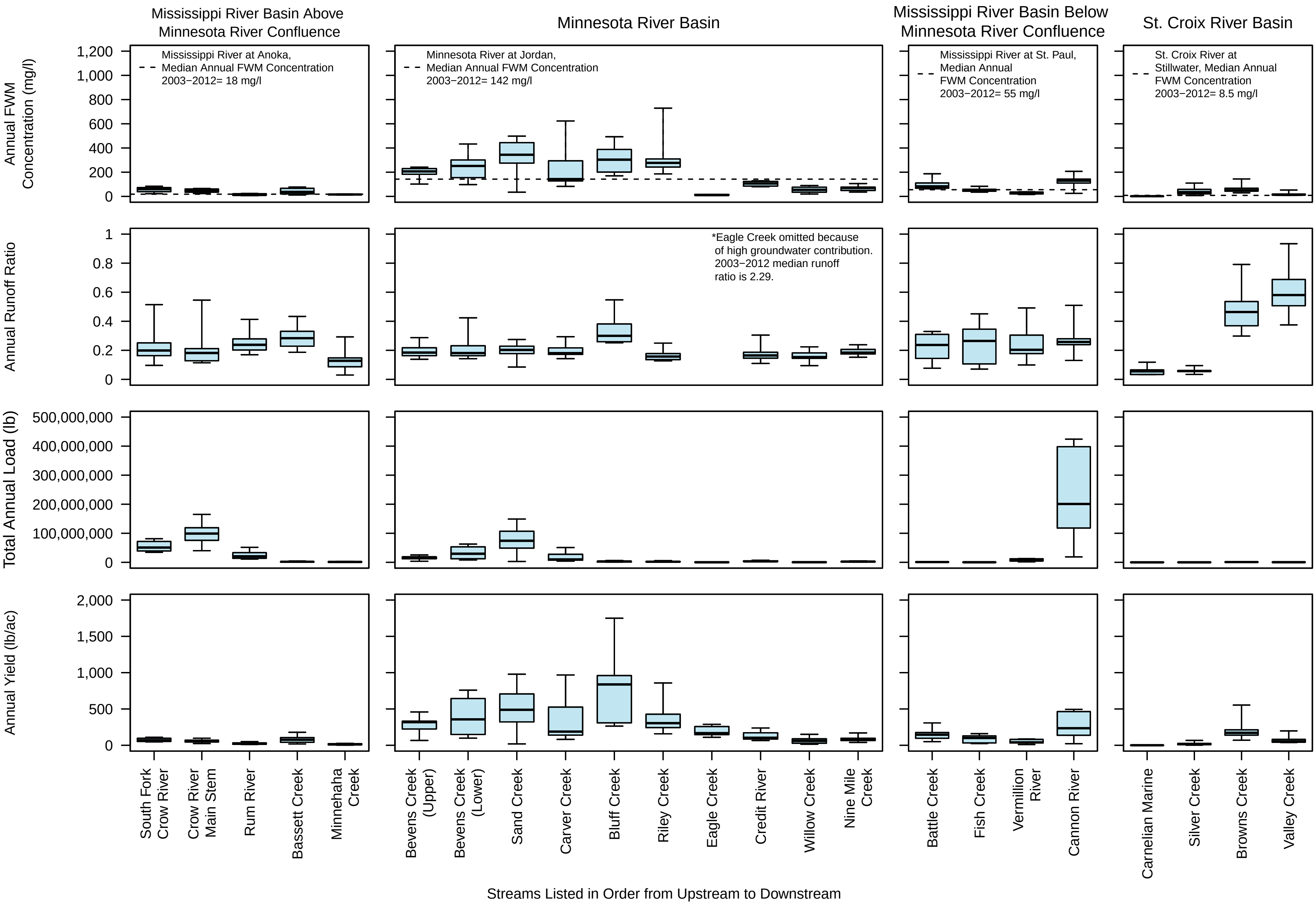


Figure VR−29: Total Phosphorus for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

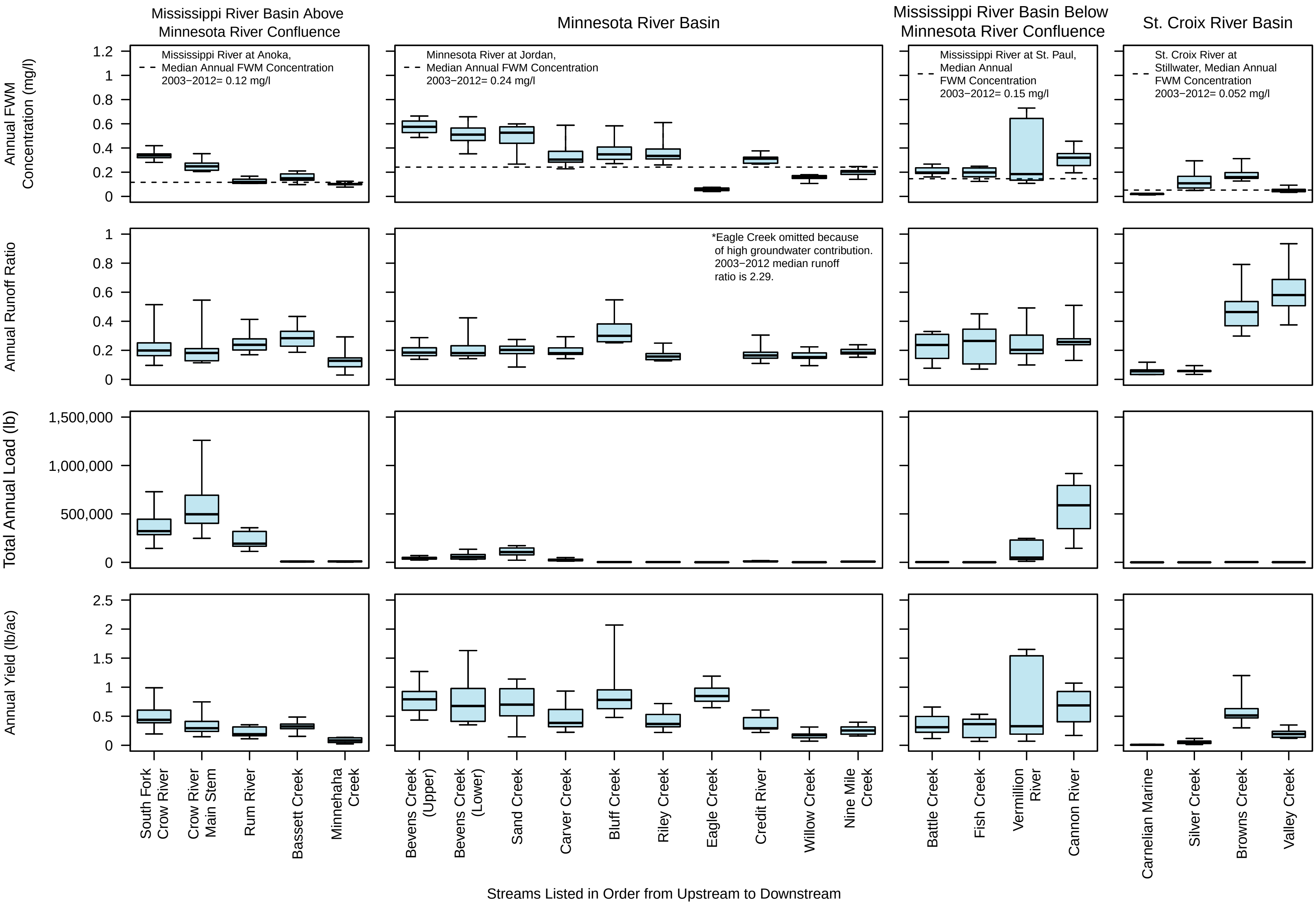


Figure VR−30: Nitrate for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

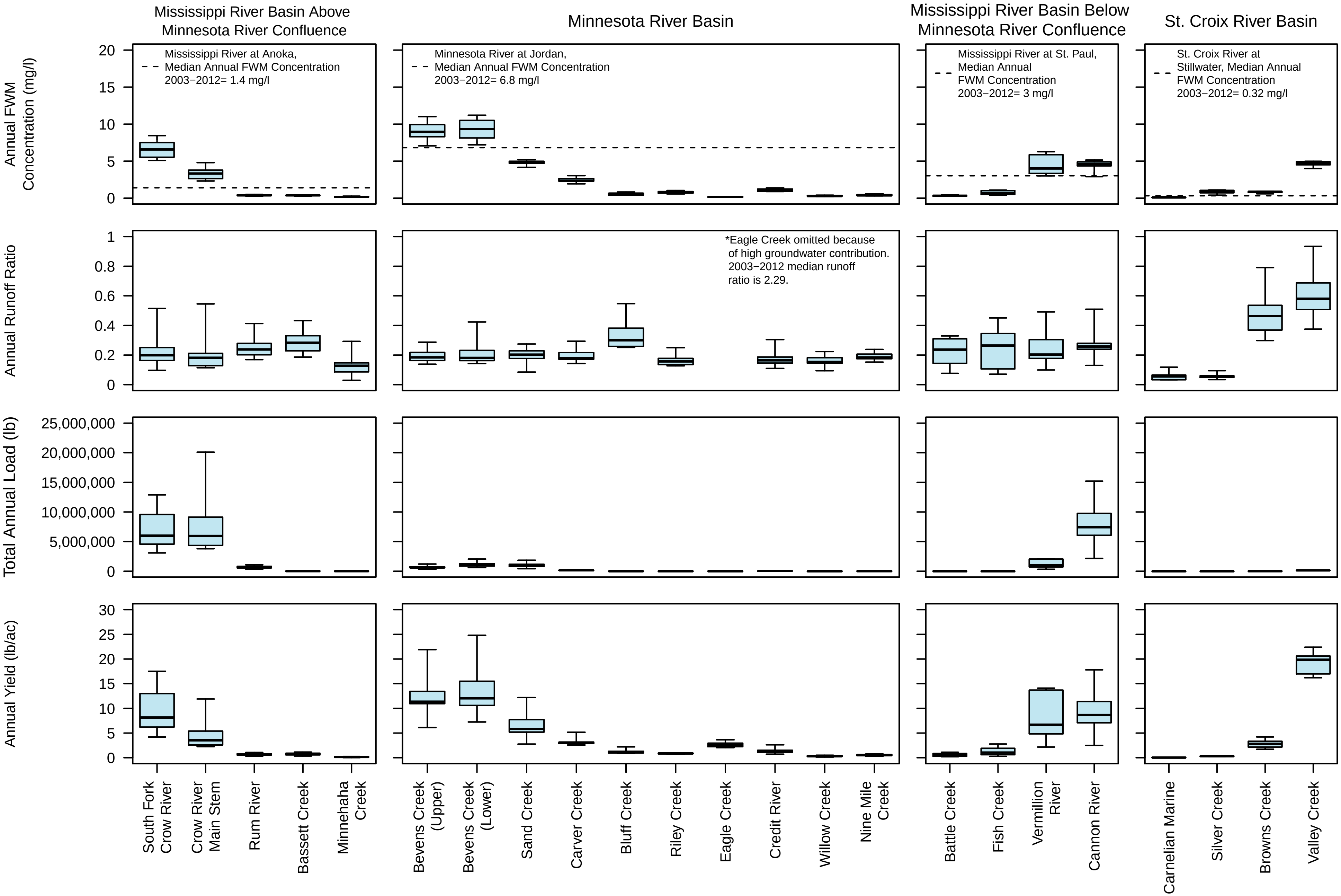


Figure VR−31: Chloride for MCES−Monitored Streams, 2003−2012

Organized by Major River Basin

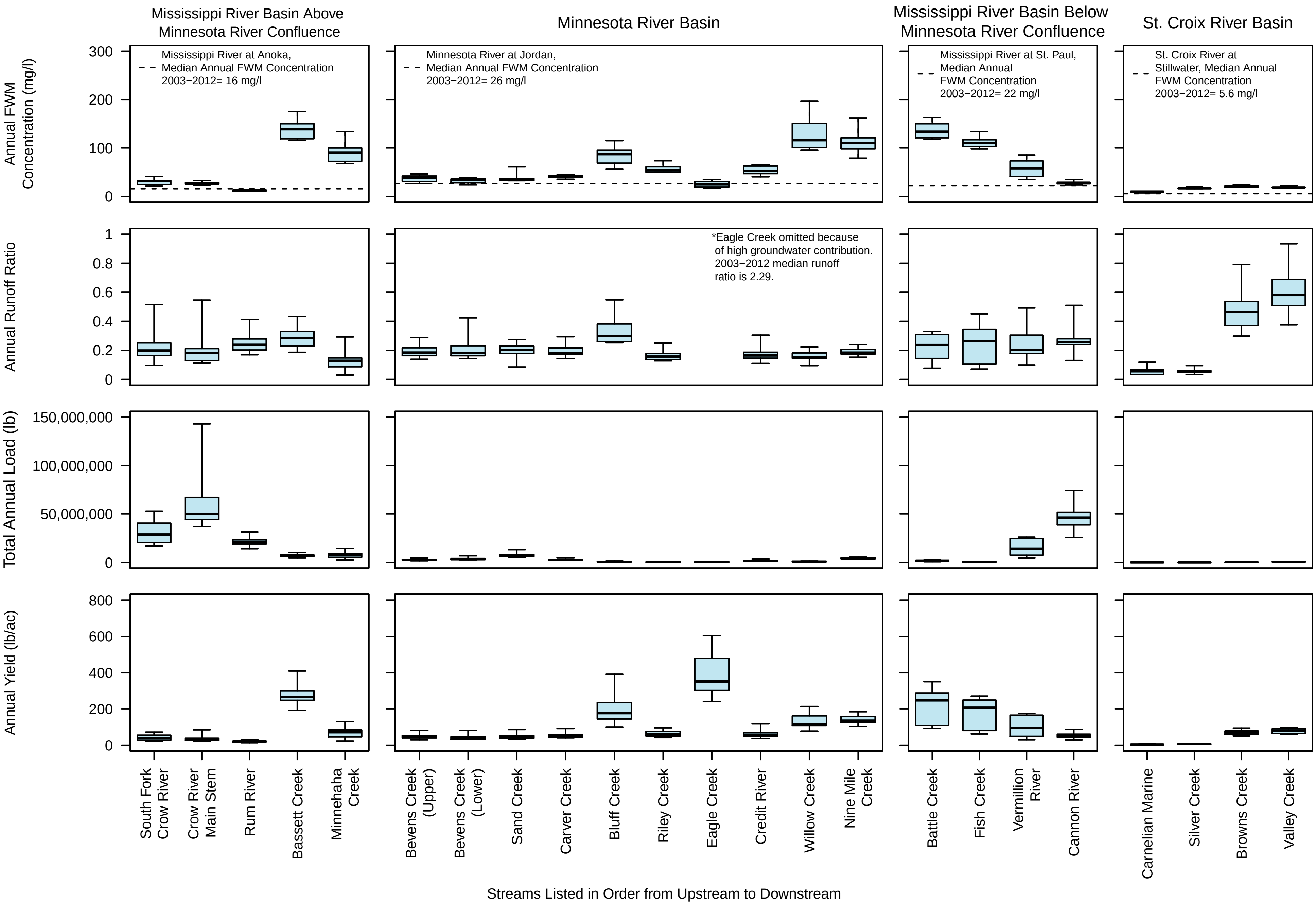


Table VR-8: Annual Median Concentrations, Loads, and Yields for MCES-Monitored Streams, 2003-2012

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

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

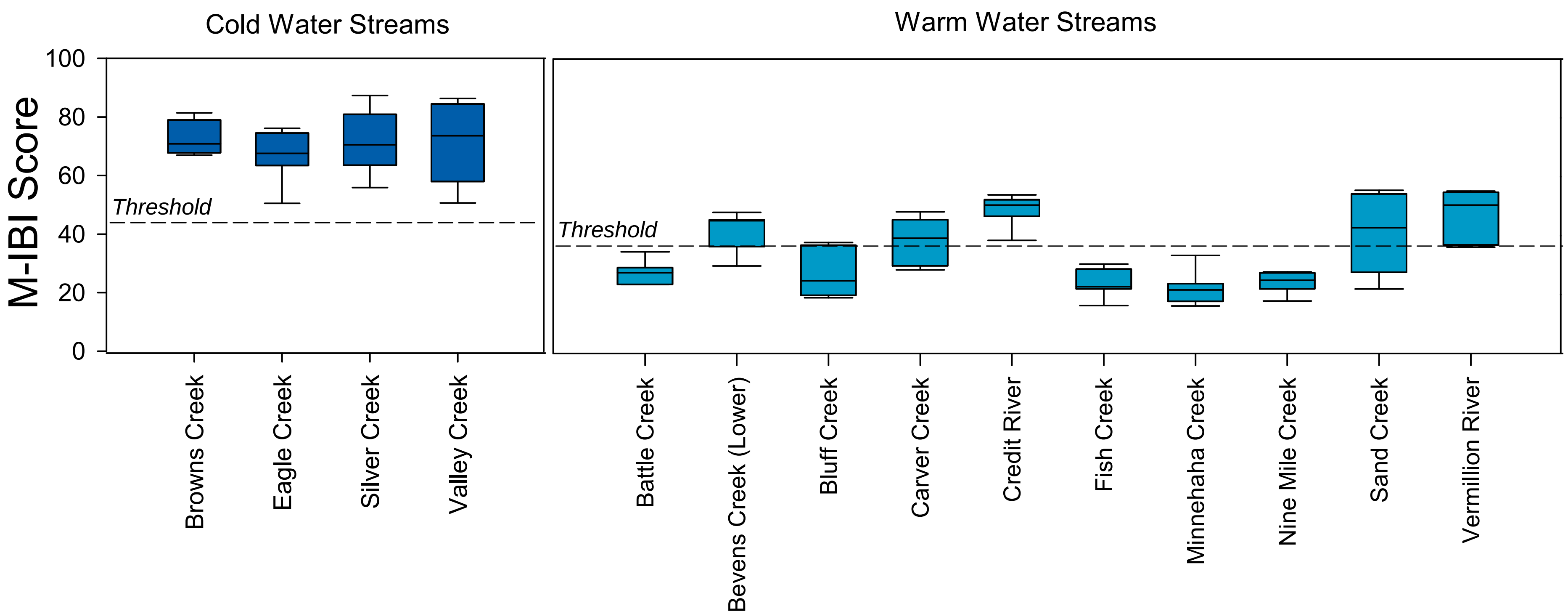
[2] FWM conc = annual flow-weighted mean concentration estimated using Flux32 (Walker, 1999).

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

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

Figure VR-32: M-IBI Results for MCES-Monitored Streams, 2004-2011

Organized by Stream Type



Higher M-IBI scores are indicative of a better water quality.
Each stream type has system-specific impairment thresholds set by the MPCA (2014b).
If a portion of the box plot is below the threshold, the stream may not have supported the needs of aquatic life during the study period.

Metropolitan Area Trend Analysis

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

Estimated trends in flow-adjusted concentrations of TSS, TP, and NO_3 in MCES-monitored streams are presented below in two ways. First, results are tabulated with directional arrows indicate improving (blue upward arrow) and declining (red downward arrow) water quality, paired with percent change in concentration estimated for 2008-2012 (Figure VA-33). 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 VA-34).

In general, of the 20 monitoring stations assessed, most exhibited improving water quality (and thus decreasing 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 Vermillion River is one of 11 streams to have decreasing TSS, TP, and NO_3 concentrations since 2008, suggesting an improvement in water quality and indicating that the efforts of the VRWJPO, MnDNR, MCES, private landowners, and others have been effective in improving the water quality in this watershed.

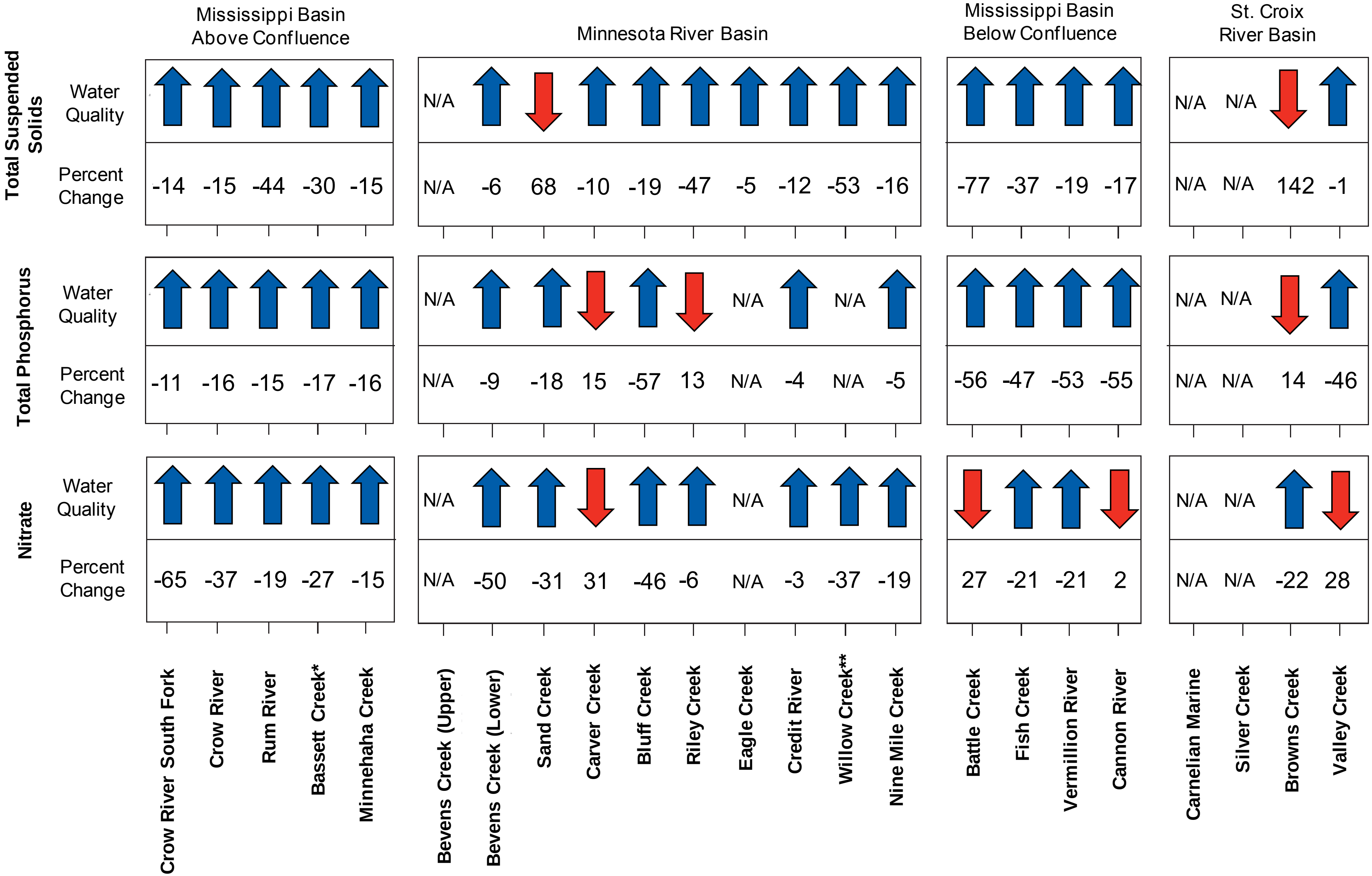
While MCES staff have assessed monitoring data and trend analysis statistics, more work is needed to assign causative actions to the trend analysis results. TSS and TP chemistry, delivery, transport and remediation are complicated, although fairly well-understood. Identifying contributing events, implementation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

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

MCES staff will repeat the trend analysis in 5 -10 years, and in the meantime will continue to investigate the $NO_{3,}$ TSS, and TP dynamics in streams entering the metropolitan area with local partners and state agency staff.

Figure VR-33: 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)



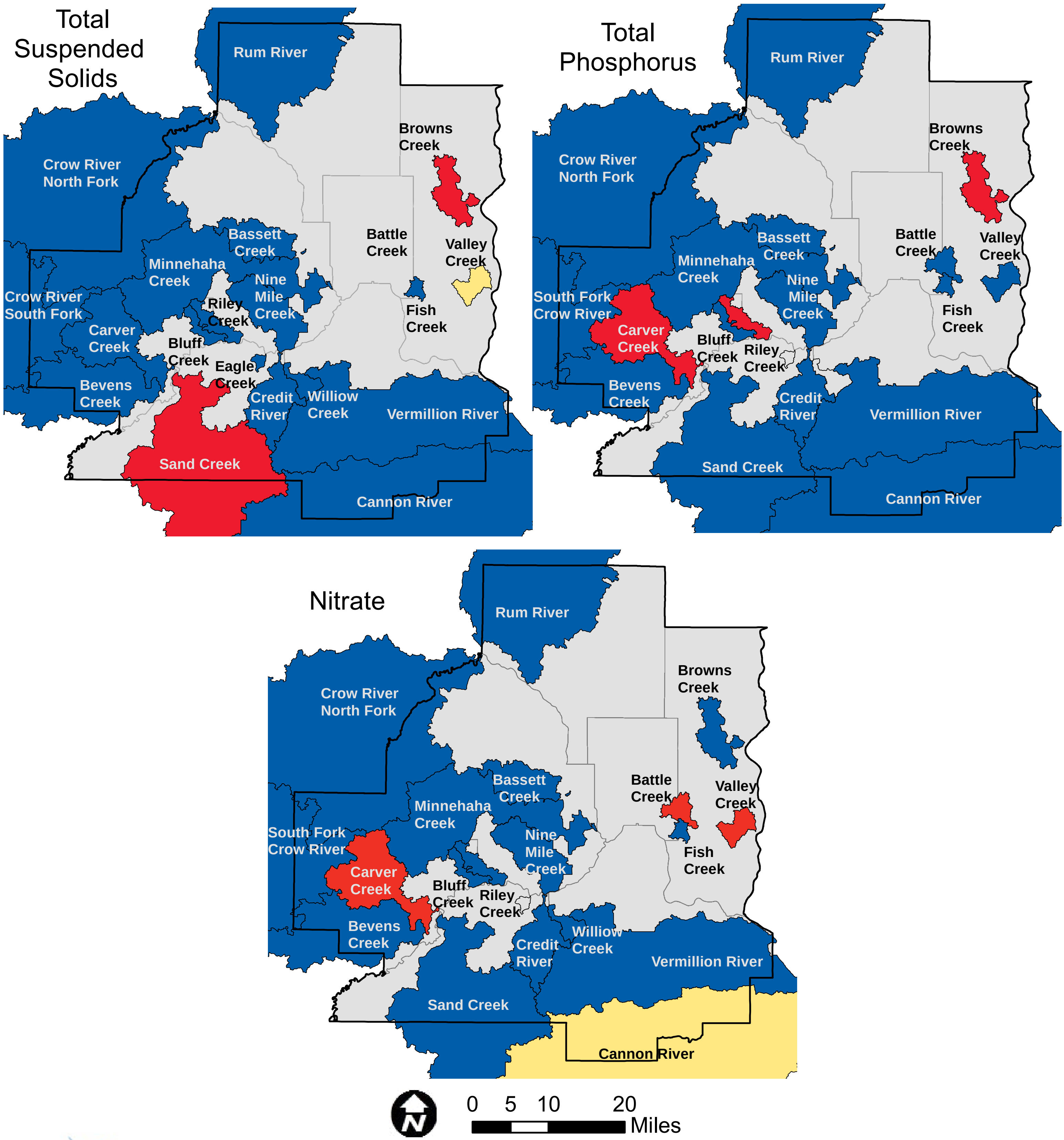
Blue arrows indicate improved water quality; Red arrows indicate declining water quality.

"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 VR-34: Regional Maps of Estimated Trends in Flow-Adjusted Stream Concentrations of TSS, TP, and NO3, 2008-2012

(As estimated by QWTrend)



Less than -3% Change (Indicates Increasing Water Quality)

-3% to 3% Change

Greater than 3% Change (Indicates Decreasing Water Quality)

METROPOLITAN COUNCIL

Conclusions

The Vermillion River is located in the southeast metropolitan area and is a tributary to the Mississippi River. It drains approximately 312 square miles of agricultural areas, forest, wetlands, grasses, and urban areas (cities of Elko New Market, Apple Valley, Lakeville, Farmington, and Hastings) through portions of Scott, Dakota, and Goodhue counties.

The watershed is approximately 50% agricultural and 25% urban. The watershed soils, primarily type B, provide good drainage. The watershed geology is complicated by multiple past glaciations. Past studies indicate that the complicated geology of the watershed drives both shallow groundwater discharge to the river, as well as flow from the river to surficial groundwater. A buried valley of an ancient precursor to the Mississippi River cuts across the Vermillion River from northeast to southwest upstream of the city of Hastings, near the city of Vermillion. The depth-to-bedrock in the buried valley (which is filled with later glacial outwash) is greater than 500 feet, in contrast to a depth of less than 50 feet outside of the buried valley. The buried valley provides a conduit for river water to flow downward to surficial aquifers. Thus, the water quality in the Vermillion River may affect shallow drinking water wells near Hastings.

Several reaches of the upper Vermillion River are classified as cold water fisheries and are MnDNR designated trout streams. A number of reaches are listed as impaired on the MPCA 303(d) list, caused by multiple stressors such as temperature, bacteria, dissolved oxygen concentration, and mercury.

MCES operates three monitoring stations on the Vermillion River. VR2.0 (the Vermillion River near Hastings), is operated as part of the Watershed Outlet Monitoring Program (WOMP). VR20.6 (Vermillion River near Farmington) and VR15.6 (Vermillion River near Empire) historically were operated as part of the river monitoring program, to assess water quality upstream and downstream of the Empire WWTP effluent outfall. Since the diversion of the Empire effluent from the Vermillion River to the Mississippi River in 2008, the stations serve to assess continued changes in water quality post-diversion.

Hydrology in the Vermillion River is affected by multiple factors. Lake outlet discharge, particularly of Lake Marion, provides some flow to the river, thus periodic changes in lake level may affect baseflow. Prior to diversion in 2008, the Empire WWTP effluent at times provided significant portions of flow to the river, particularly during low flow conditions. The river reaches upstream of the buried bedrock valley receive shallow groundwater discharge, providing another source of constant baseflow. In particular, the VRWJPO has found that the South Branch, which enters the Vermillion River at approximately mile 11 downstream of the Empire WWTP effluent outfall, is influenced by shallow groundwater discharge from a highly agricultural area. The Vermilion River flow responds quickly to precipitation events, indicating the potential effect of surface runoff from urban areas. The river likely loses some flow as it crosses the buried bedrock valley near the city of Vermillion, upstream of Hastings.

Water quality in the Vermillion River is likely affected by multiple factors: agricultural activity, WWTP effluent discharge, urbanization, alteration of riparian area vegetation, and others. TSS concentration and annual loads in the Vermillion River are lower than other tributaries entering the Mississippi River in the lower part of the metropolitan area (eg.,Battle Creek, Fish Creek, and the Cannon River). Annual FWM TSS concentration is lower than the Mississippi River, indicating Vermillion River discharge is not degrading the river in terms of TSS.

TP concentration and load in the Vermillion River have been historically influenced by the discharge of effluent from the Empire WWTP. In 2006, implementation of biological phosphorus (Bio-P) reduction at the WWTP caused a sharp decrease in effluent TP concentration; and in 2008, diversion of the Empire WWTP effluent to the Mississippi River removed the effluent TP load from the river altogether. Historically, the TP concentration and areal yield in the Vermillion River has exceeded that of most of the tributaries monitored by MCES, even those in the heavily-agricultural Minnesota River basin; the TP concentration has also exceeded that in the Mississippi River. Diversion of the Empire WWTP effluent has resulted in significantly lower TP concentrations in the Vermillion River; future analysis of monitoring data will likely indicate that the Vermillion River TP concentration and load is similar to those of other Mississippi River tributaries and lower than the Minnesota River tributaries.

NO_3 concentration and load dynamics in the Vermillion River have historically been complicated by discharge of high NO_3 concentration effluent from the Empire WWTP and discharge of high NO_3 concentration shallow groundwater from agricultural areas, for example in the South Branch subwatershed. The NO_3 concentration in the Vermillion River is higher than in most other Mississippi River tributaries monitored by MCES, with the exception of the highly agricultural Crow and Cannon River systems, and the areal yield is high as well. Recent monitoring data indicates the Empire effluent diversion in 2008 has resulted in lower NO_3 concentrations in the Vermillion River. A secondary effect of the effluent diversion is that other NO_3 sources to the Vermillion River have become evident in monitoring data. For example, the VRWJPO has monitored NO_3 concentration in the South Branch during baseflow conditions, with results indicating that those concentrations are increasing. Examination of NO_3 concentration at VR2.0 (Hastings) for the same time period indicates high concentrations during baseflow, likely originating from the South Branch. This dynamic was “washed-out” by high concentration effluent discharge until the diversion in 2008. Data collected after the effluent diversion clearly shows an increase in NO_3 concentration downstream of VR15.6 during baseflow conditions.

Recommendations

This section presents recommendations for monitoring and assessment of the Vermillion River, as well as recommendations for partnerships to implement stream improvements. MCES recognizes that cities, counties, and local water management organizations, like the VRWJPO, are ideally suited to target and implement volume reduction, pollutant removal, and stream restoration projects within the watershed. It is beyond the scope of this document to suggest locations for implementation projects. Instead, MCES encourages the local water management organization to use the results of this report to leverage funding and partnerships to target, prioritize, and implement improvement projects. MCES will repeat its analysis of water quality trends in 5 -10 years, to assess potential changes in water quality.

The following recommendations have been drafted from the results of this report and are intended to assist MCES and its partners in directing future assessment work:

- MCES should work with our partners, particularly the VRWJPO, to identify all water quality and flow monitoring occurring on the Vermillion River, to avoid duplication of efforts.

- MCES and partners (especially MnDNR, the counties, and VRWJPO) should create a timeline of past projects and management activities that may have improved or altered stream flow and/or water quality. This information would allow more accurate assessment and interpretation of MCES trend analyses when they are repeated in 5 -10 years.

- MCES and the VRWJPO should continue to collaborate on investigating the complicated dynamics in the Vermillion River. Suggestions for future study include:
    i. Changes to the Vermillion River occurring after the Empire WWTP effluent diversion. Parameters of particular interest are flow, nutrient concentrations, chloride concentration, pollutant loads, in-stream temperature dynamics, dissolved oxygen, and macroinvertebrates.
    ii. Nitrate dynamics in the Vermillion River and the South Branch tributary and the potential effect on Hastings drinking water wells.

- Starting in 2015, Dakota County will conduct fish surveys on the Vermillion River, taking over those duties from the MnDNR. One long-term fish survey location is on the MCES Empire WWTP property. It is recommended that MCES continue to allow fish survey access to the Vermillion River on the Empire WWTP property.

- MCES staff should participate in future assessments and plan preparations for the Vermillion River watershed led by the MPCA.

- Local surface water management plans should acknowledge the heightened potential for surface waters to be impacted by groundwater changes in this area.

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