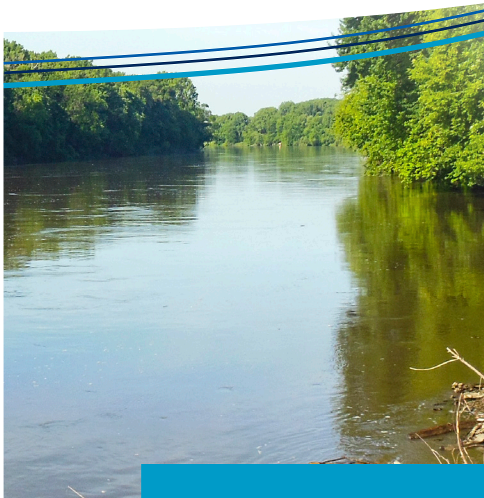
REGIONAL ASSESSMENT OF RIVER WATER QUALITY IN THE TWIN CITIES METROPOLITAN AREA 1976-2015

Minnesota, Mississippi, St. Croix Rivers



SUMMARY REPORT

July 2018

The Twin Cities metropolitan area is a region of 3,000 square miles encompassing seven counties and 181 communities. The area developed around its three major rivers – the Mississippi, Minnesota, and St. Croix – which have shaped the identity of the region and contribute immeasurably to the quality of life of its three million residents.

The Regional Assessment of River Water Quality in the Twin Cities Metropolitan Area is a major study conducted by the Metropolitan Council that examines the water quality of these rivers over a 40-year period. Based on river data collected between 1976 and 2015, the study is one of the most extensive of its kind carried out in the metropolitan area. The results provide a base of technical information that can support sound decisions about water resources in the area – decisions by the Council, state agencies, watershed districts, conservation districts, county and city governments, and property owners. The data used in this study can be downloaded from the Council's website at https://eims.metc.state.mn.us/.

METROPOLITAN COUNCIL

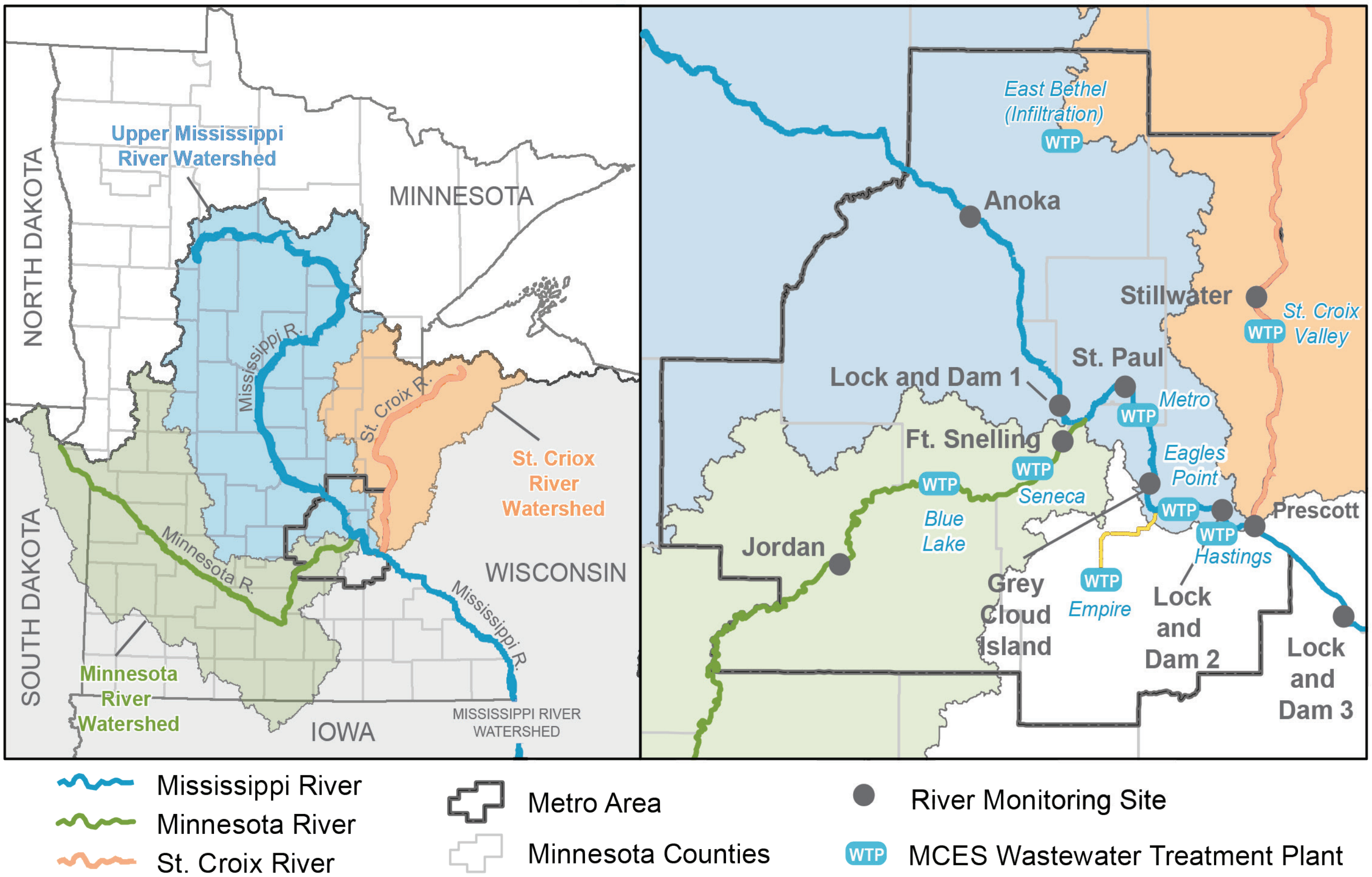
Role of the Metropolitan Council and its Environmental Services Division

This study supports the regional polices established in the Council's Thrive MSP 2040 and Water Resources Policy Plan to collaborate with partners to promote the long-term sustainability and health of the region's water resources, including surface water, wastewater, and water supply. The Metropolitan Council is committed to the conscientious stewardship of the region's water resources and works with its partners to maintain and improve the health and function of these resources.

This commitment and these efforts are carried forward by the Council's Environmental Services division (MCES) in two areas of responsibility. First, MCES operates eight wastewater treatment plants (WWTPs) that serve more than 100 communities and 2.6 million residents in the metro area, achieving near-perfect compliance with federal and state discharge standards. Progressively more effective wastewater treatment facilities, implementation of urban and agricultural best management practices (BMPs), and separation of storm and wastewater sewers have contributed to significant improvements in regional river water quality.

Another MCES responsibility is to strengthen understanding of the impacts of its operations and other factors on water quality in the region. MCES programs monitor and assess the quality of regional surface waters, including a river monitoring program that covers more than 150 miles of the Mississippi, Minnesota, and St. Croix rivers in the seven-county metro area.

Figure 1: Major Rivers, Watersheds, MCES WWTPs, and Monitoring Sites in the Metro Area



Focus of the Study

This study examined recent river water quality conditions and long-term water quality trends for select water quality indicators, or parameters, at 10 MCES river monitoring sites across three major regional rivers. The study:

- Documents recent water quality conditions (2006-2015) and spatial changes along these rivers
- Analyzes long-term water quality trends (1976-2015)
- Discusses the factors contributing to water quality changes
- Identifies current water quality issues and needs for improvement
- Makes general recommendations for future water quality monitoring, data assessment, and management actions that can improve and protect regional river water quality

Study Area

The study area encompasses the three major rivers and their watersheds in the metro area (Figure 1). The Mississippi River, after flowing from its headwaters at Lake Itasca in northern Minnesota, enters the metro area to the northwest. From there, it travels about 72 miles before exiting the metro area to the southeast. The Minnesota River, a tributary of the Mississippi, enters the metro area to the southwest. From there, it flows approximately 66 miles before entering the Mississippi River near historic Fort Snelling. The St. Croix River, also a Mississippi tributary, reaches the metro area from the northeast and forms the area's eastern border with Wisconsin. The river drains into the Mississippi near Prescott, Wisconsin.

Before the Mississippi, Minnesota, and St. Croix rivers enter the metro area, their water quality is significantly influenced by land cover and land use in the upstream watersheds (Figure 1). Across the state, land cover transitions from agriculture in the southwest to forest and wetland in the northeast (Figure 2).

The Upper Mississippi River watershed has a relatively balanced mix of agricultural and natural areas. Most of the Minnesota River watershed is agriculture, whereas the St. Croix River watershed consists mostly of natural areas, such as forest and wetlands. (Homer et al., 2011; UMN,

2016. *Full citations are available in the main report*.). In turn, the metro area impacts the water quality of the rivers as they move through the region.

Pollutants that impact water quality enter rivers from both point and nonpoint sources. Point sources are identifiable, discrete locations, such as pipe outfalls, whereas nonpoint sources are diffuse, often coming from a wide area when precipitation and runoff occur. The water quality of each river can be affected by point and nonpoint sources in their watersheds.

Within the metro area, common point sources of pollution include WWTPs, feedlots, and municipal stormwater. The primary nonpoint sources of pollution include river tributaries, direct runoff into rivers from adjacent land uses, and atmospheric deposition.

Current Designated Impairments of Regional Rivers

As a result of both point and nonpoint sources of pollution, portions of the three metro area rivers are currently listed by the Minnesota Pollution Control Agency (MPCA) as impaired waters. The designations (Figure 3) mean that water quality standards are not met for dissolved oxygen, fecal coliform bacteria, eutrophication/nutrients, or total suspended solids/turbidity (MPCA, 2016a).

Additional water quality impairments in the regional rivers include those for mercury, polychlorinated biphenyls (PCBs), and perfluorooctanesulfonic acid (PFOS) in water and/or fish tissue.

Nonetheless, significant efforts have greatly improved river water quality for certain pollutants over time. These efforts include improvements in water-related infrastructure; a wide range of regional, state, and federal regulations; and local pollution control efforts. For example:

- MCES WWTPs have been upgraded to reduce pollutant concentrations in their discharges and treat larger volumes of water as the metro area population grows.
- The infrastructure of the sewer systems leading to MCES WWTPs has also been upgraded as needed, including separation of combined sewers to eliminate overflows of raw sewage into the Mississippi River.
- Regulations at the regional, state, and federal levels have resulted in greater pollution control efforts. These regulations address such issues as restricting the use of phosphorus fertilizers on lawns, requiring industrial facilities to pretreat their wastewater before releasing it to WWTPs, and setting water quality standards in response to the 1972 Clean Water Act.
- Local organizations such as watershed management organizations, watershed districts, soil and water conservation districts, cities, townships, universities, and private development communities are implementing a wide variety of water resources projects, with a cumulative benefit for regional rivers.

Figure 2: Land Cover of Mississippi, Minnesota, and Minnesota Watersheds

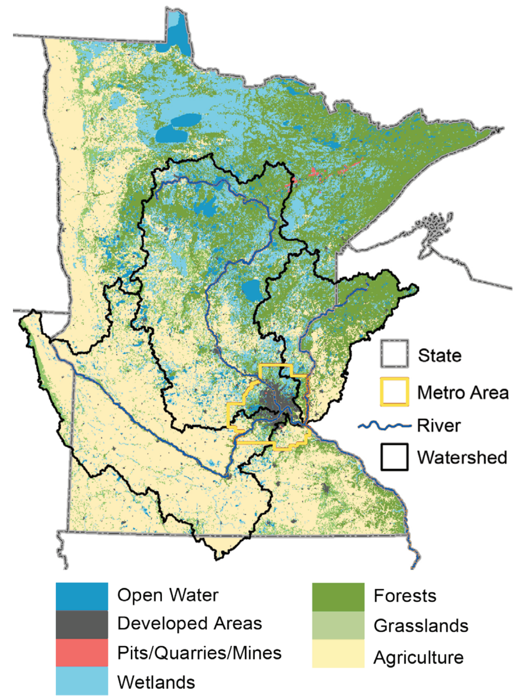
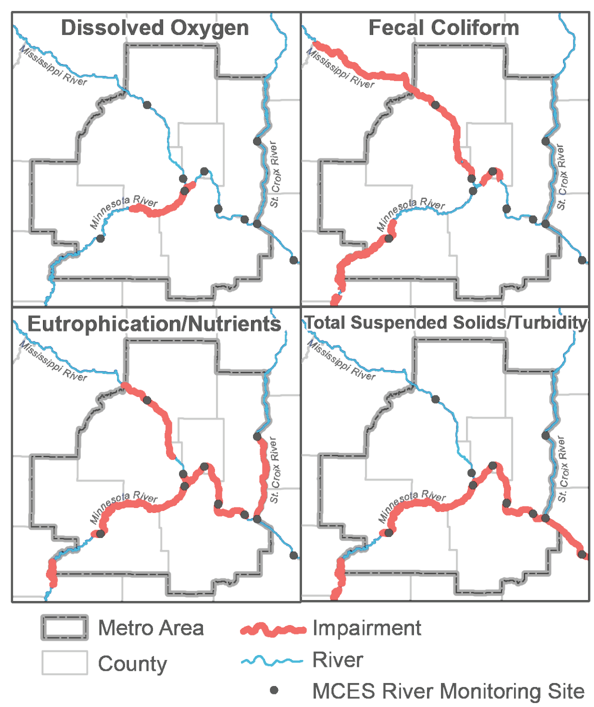


Figure 3: Water Quality Impairments in Regional Rivers



Study Methods

Water Quality Monitoring Sites

During the 1976-2015 period, water samples were drawn from six monitoring sites on the Mississippi River, two on the Minnesota River, and two on the St. Croix River (Figure 1). The location of these sites made it possible to assess the water quality of all three rivers as they entered and left the metro area, as well as evaluate water quality changes that occur as the rivers pass through the region.

Water Quality Parameters and Data Analysis

The study collected and analyzed data on 15 parameters:

- River flow
- Dissolved oxygen (DO)
- 5-day biochemical oxygen demand (BOD_5)
- Water temperature
- pH
- Conductivity
- Total suspended solids (TSS)
- Total phosphorus (TP)
- Corrected chlorophyll-*a* (Chl-*a*)
- Total nitrogen (TN)
- Nitrate-nitrogen (NO_3)
- Ammonia-nitrogen (NH_3)
- Fecal coliform bacteria (FC)
- *Escherichia coli* bacteria (*E. coli*)
- Chloride (Cl)

To characterize recent water quality (2006-2015), 10-year median concentrations were calculated and plotted for each parameter at each monitoring site.

To summarize water quality patterns (1976-2015), annual and monthly median concentrations were calculated and plotted for each parameter at each monitoring site. Plotting these measured concentrations over time can provide a general indication about the overall water quality conditions of the rivers.

Nine of the 15 parameters underwent statistical analysis to determine long-term water quality trends during the 1976-2015 period. Selection of these parameters reflects general water quality concerns, as well as limitations of the statistical analysis to evaluate trends:

- BOD_5
- TSS
- TP
- Chl-*a*
- TN
- NO_3
- NH_3
- FC
- Cl

The trend analysis was conducted using QWTREND, a statistical model developed by the USGS (Vecchia, 2005) to analyze non-monotonic water quality trends based on flow-adjusted concentrations. The flow-adjusted trends illustrate the nature of long-term changes in water quality, including the influences of pollutant sources, pollution control efforts, and other factors affecting water quality over time.

The study used river flows as measured by the U.S. Geological Survey and the U.S. Army Corps of Engineers at relevant river sites from 1971 to 2015.

Select Findings

Six of the 15 water quality parameters are indicators of primary concern: flow, TSS, TP, NO_3, FC, and Cl. Detailed information about all 15 parameters can be found in the main report.

Flow

Flow has a considerable influence on the water quality of a river. High flows often reflect substantial delivery of pollutants from the watershed, while low flows can increase the concentration of pollutants from point sources, with less water available for dilution. The amount and timing of precipitation in a watershed are the main factors affecting flow in streams and rivers (USGS, 2016a).

Figure 4 shows the median flows measured from 2006 to 2015 at river monitoring sites in the metro area. The Mississippi River had the highest 10-year median flow as it entered the metro area. The median flow of the St. Croix River was slightly higher than that of the Minnesota River. The incoming waters of the Mississippi, Minnesota, and St. Croix rivers accounted for 46%, 25%, and 29%, respectively, of their total median flow within the metro area. Flow increased in all three rivers as they moved through the region, reflecting contributions from tributaries and point sources. As expected, notable increases in Mississippi River flow occurred downstream of its confluence with the Minnesota and St. Croix rivers.

Flow contributions from MCES WWTPs were minimal in typical conditions. During the 2006-2015 period, the median Metro WWTP flow was 3% of the Mississippi River median flow, while the Blue Lake and Seneca WWTPs were 2% of the Minnesota River flow. During low river flows, WWTPs contribute a larger proportion of the river flow, whereas during high-river flow conditions, their relative contributions are reduced.

The study did not evaluate long-term flow trends, but other studies have shown that flows in the Mississippi, Minnesota, and St. Croix rivers have been increasing (MPCA, 2017b;USGS, 2004). Typically, climate change, urbanization, and agricultural practices are the factors identified as the cause of increasing river flows.

Total Suspended Solids (TSS)

TSS are organic and inorganic particles suspended in water, including sediment, algae, plant material, and other fine organic matter (MPCA, 2011; USEPA, 2012f). Excessively high TSS concentrations can cause detrimental effects on river ecosystems by limiting light available for plant growth, affecting the health of organisms, and degrading aquatic habitat. Moreover, TSS can transport other pollutants like phosphorus and trace metals.

Recent Conditions. Recent 10-year median TSS concentrations (Figure 5) show that concentrations in the Minnesota River (35-48 mg/L) were higher than the concentrations in the Mississippi River (9-25 mg/L) and the St. Croix River (2-6 mg/L). High TSS concentrations in the Minnesota River are primarily associated with eroding fields, ravines, gullies, and streambanks in the watershed (MPCA, 2009c).

TSS concentrations in the metro Mississippi River were influenced by the Minnesota and St. Croix rivers. A notable increase in the Mississippi River TSS

Figure 4: Median River Flows (cfs), 2006-2015

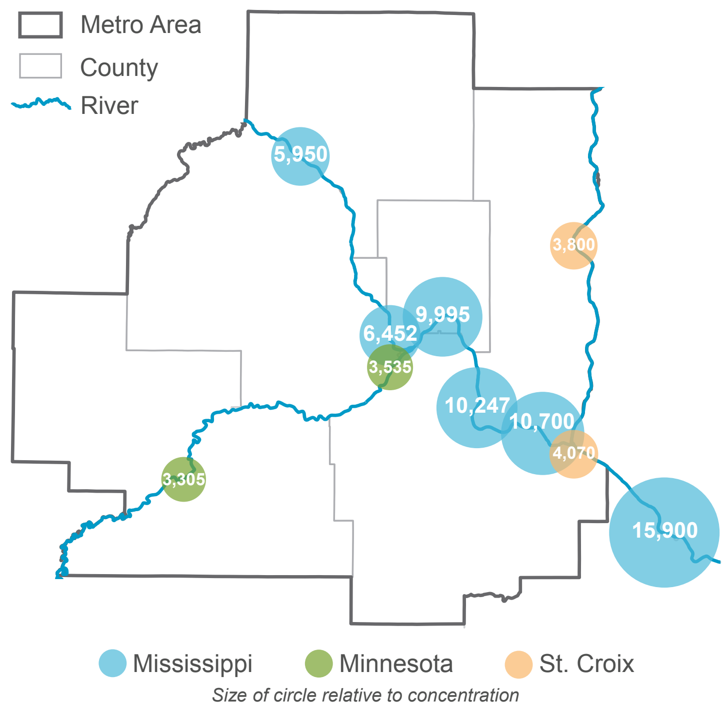
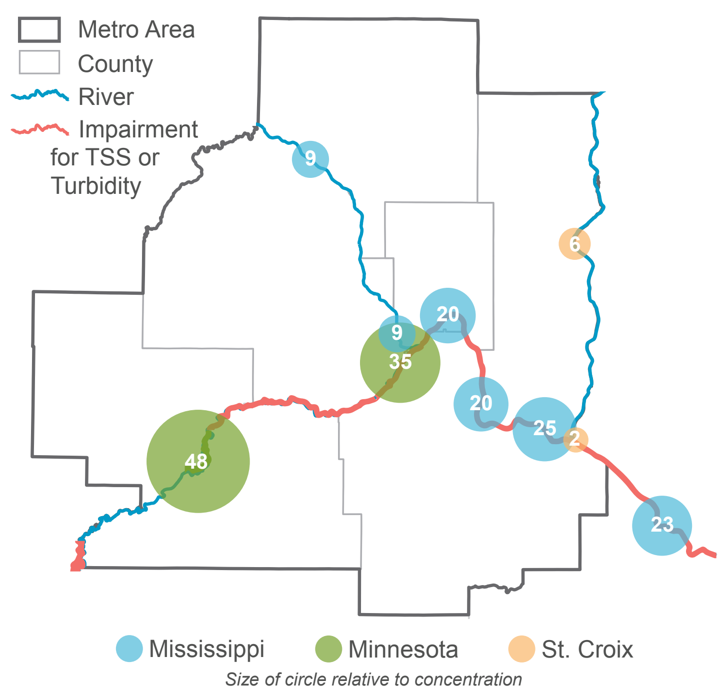


Figure 5: Median River TSS Concentrations (mg/L), 2006-2015



concentration occurred downstream from the Minnesota River confluence, while a slight decrease occurred downstream from the St. Croix River confluence.

The high TSS concentrations in the Minnesota River are partially responsible for the water quality impairment that extends from Jordan to upper Lake Pepin. In both the metro Minnesota and St. Croix rivers, TSS concentrations decreased as the rivers moved through the metro area, partially due to the influence of a deeper river channel in the lower Minnesota River and Lake St. Croix in the lower St. Croix River. MCES WWTPs did not appear to influence the median TSS concentrations in metro area rivers. Ten-year median TSS concentrations in major WWTP discharges ranged from 2-3 mg/L, with these discharges contributing only 1-3% of the median Mississippi and Minnesota River flows.

40-Year Trends. QWTREND analysis of long-term water quality trends shows that flow-adjusted TSS concentrations have significantly decreased across all three rivers during the last 40 years (Figure 6), indicating an improvement in water quality. Reductions in TSS concentrations ranged from 34-74% in the Mississippi River, 37-51% in the Minnesota River, and 48-75% in the St. Croix River.

Differences in reduction rates along these rivers are likely due in part to the separation of combined sewer overflows and TSS-related projects in tributary watersheds intended to meet the Total Maximum Daily Loads established by the Minnesota Pollution Control Agency. Improved treatment at MCES WWTPs in the metro area has also resulted in long-term decreasing TSS trends across regional rivers. For example, mean annual TSS concentrations in the Metro WWTP discharge to the Mississippi River have been reduced from 128 mg/L to 3 mg/L (98%) since implementation of secondary wastewater treatment technology in 1966 and advanced secondary treatment technology in 1984. Similar wastewater treatment technology has been implemented at the other MCES WWTPs discharging to metro area rivers.

Total Phosphorus (TP)

TP is a nutrient existing naturally in rivers and is important for river health. However, excess TP can be harmful, leading to severe algae growth and low oxygen concentrations that can cause uninhabitable conditions for most aquatic life, poor drinking water quality, unpleasant environments for recreation, and potential health impacts for people and pets (MPCA, 2004b).

Figure 6: Flow-Adjusted TSS Trends, 1976-2015

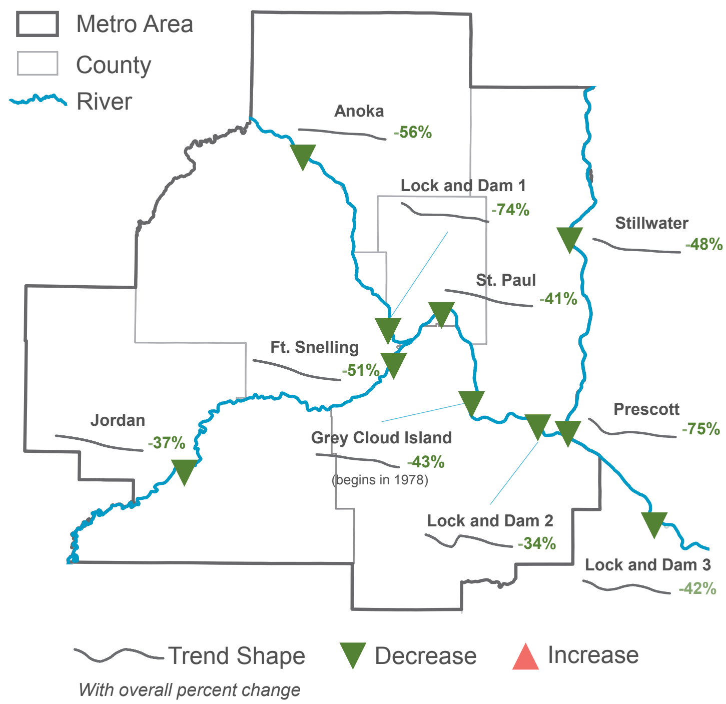
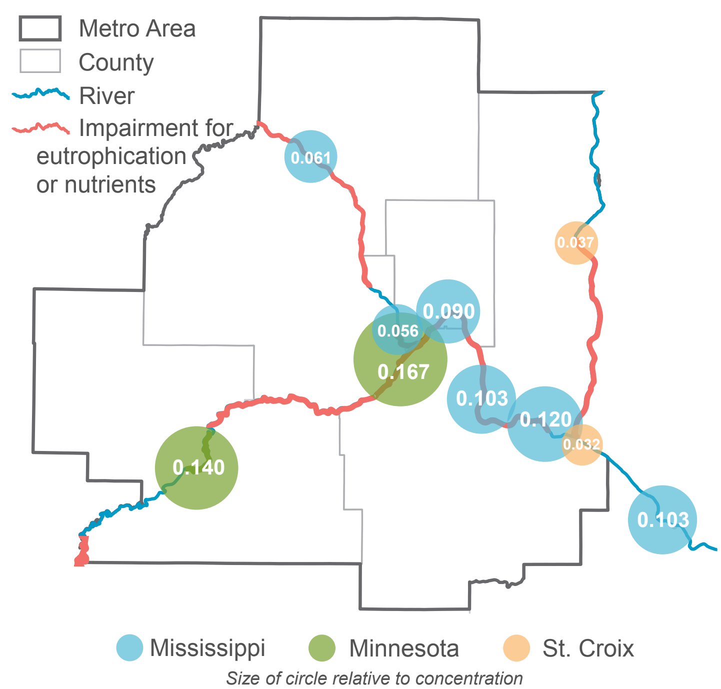


Figure 7: Median River TP Concentrations (mg/L), 2006-2015



Recent Conditions. Recent 10-year median TP concentrations (Figure 7) show that concentrations were highest in the Minnesota River (0.140-0.167 mg/L), intermediate in the Mississippi River (0.056-0.120 mg/L), and lowest in the St. Croix River (0.032-0.037 mg/L).

TP concentrations in the metro Mississippi River were influenced by the Minnesota and St. Croix rivers. A notable increase in the Mississippi River TP concentration occurred downstream from the Minnesota River confluence, while a slight decrease occurred downstream from the St. Croix River confluence. Higher TP concentrations in the Mississippi River at Grey Cloud Island and Lock and Dam 2, and in the Minnesota River at Fort Snelling likely reflect phosphorus contributions from MCES WWTPs.

The TP concentration increased in the Minnesota River and decreased slightly in the St. Croix River as these rivers passed through the metro area. Changes in TP concentrations along regional rivers reflect contributions from tributaries, point sources (such as WWTPs) and settling of TSS-associated phosphorus due to the presence of lock and dams and Lake St. Croix, where the river flow slows.

40-Year Trends. QWTREND analysis of long-term water quality trends shows that flow-adjusted TP concentrations have significantly decreased across all three rivers during the last 40 years, indicating an improvement in water quality (Figure 8).

Reductions in TP concentrations ranged from 36-59% in the Mississippi River, 44-51% in the Minnesota River, and 26-32% in the St. Croix River.

While decreases in TP concentrations varied from site to site along the Mississippi River, steeper declines occurred in the Minnesota and St. Croix rivers at the downstream sites.

Decreasing TP concentrations in the three major metro area rivers likely reflect multiple efforts to reduce phosphorus inputs to Minnesota's surface waters. These efforts include upstream watershed improvements in agricultural and urban storm water management practices, adoption of phosphorus-related regulations (bans on phosphorus in laundry detergent, automatic dishwasher detergent, and lawn fertilizer), and implementation of phosphorus removal technology at MCES WWTPs.

The investments in phosphorus removal at MCES WWTPs have resulted in a combined 88% reduction in TP loads discharged from MCES WWTPs to the three major metro area rivers since 2000 (Figure 9).

Figure 8: Flow-Adjusted TP Trends, 1976–2015

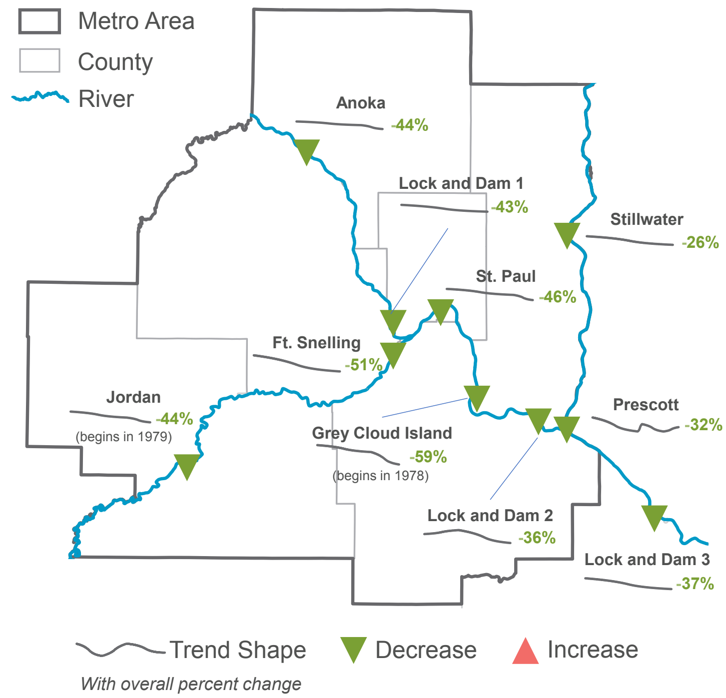
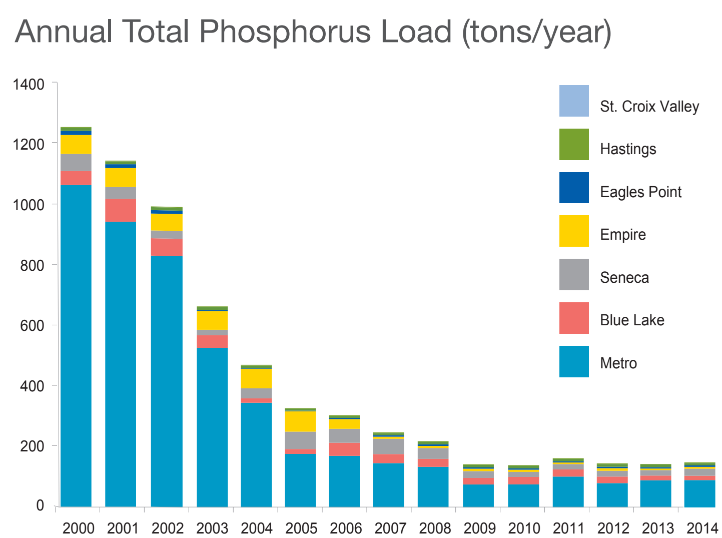


Figure 9: Annual TP Loads from MCES WWTPs, 2000-2014



Nitrate-Nitrogen (NO_3)

NO_3 is a form of nitrogen that exists naturally in rivers and is an important nutrient for plant growth. NO_3 concentrations are generally low in natural environments, but human activities can elevate concentrations beyond natural levels, causing problems for human health and aquatic life, and contributing to downstream eutrophication problems.

Recent Conditions. Recent 10-year median NO_3 concentrations (Figure 10) show that concentrations were highest in the Minnesota River (2.94-3.02 mg/L), intermediate in the Mississippi River (0.66-2.02 mg/L), and lowest in the St. Croix River (0.24-0.58 mg/L). Statewide, croplands are the most common source of nitrogen reaching surface waters (MPCA, 2013). So, with agriculture being the predominant land cover in the Minnesota River Basin, it follows that the Minnesota River would have higher NO_3 concentrations than the Mississippi and St. Croix rivers, which have a lower percentage of agricultural land cover in their contributing watersheds.

NO_3 concentrations in the metro Mississippi River were influenced by the Minnesota and St. Croix rivers. A notable increase in the Mississippi River NO_3 concentration occurred downstream from the Minnesota River confluence, while a slight decrease occurred downstream from the St. Croix River confluence. NO_3 concentrations in both the Minnesota and St. Croix rivers increased slightly as the rivers moved through the metro area.

MCES WWTPs are point-source contributors of NO_3 to metro area rivers. Recent 10-year median NO_3 concentrations in major WWTP discharges ranged from 14.6-17.5 mg/L, with these discharges contributing 1-3% of the median Mississippi and Minnesota River flows. Increases in NO_3 concentrations in the Mississippi River at Grey Cloud Island and Lock and Dam 2 and in the Minnesota River at Fort Snelling likely reflect NO_3 contributions from MCES WWTPs.

40-Year Trends. QWTREND analysis of long-term water quality trends (Figure 11) shows that, with the exception of the Minnesota River at Jordan, NO_3 concentrations have significantly increased across all three rivers during the last 40 years, indicating declining water quality. Increases in NO_3 concentrations ranged from 181-302% in the Mississippi River, with the greatest increase occurring at Grey Cloud Island, downstream from the Metro WWTP. Although a partial decreasing

Figure 10: Median River NO_3 Concentrations (mg/L), 2006-2015

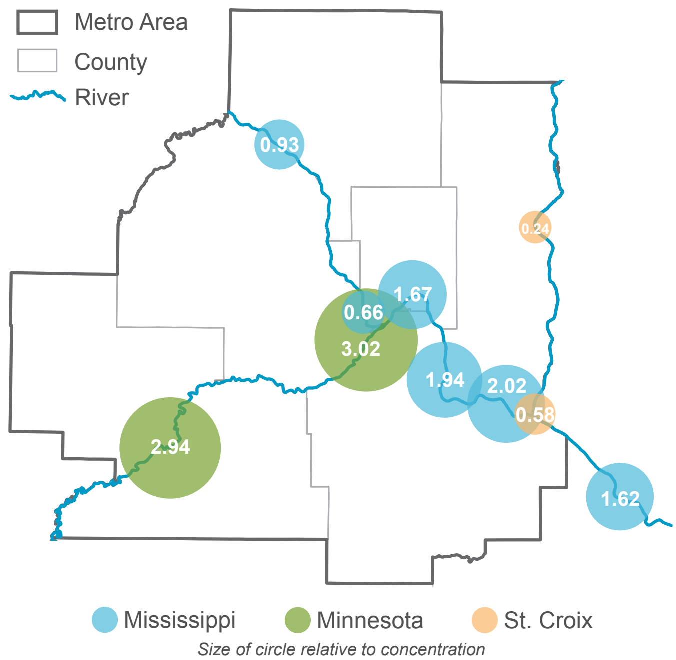
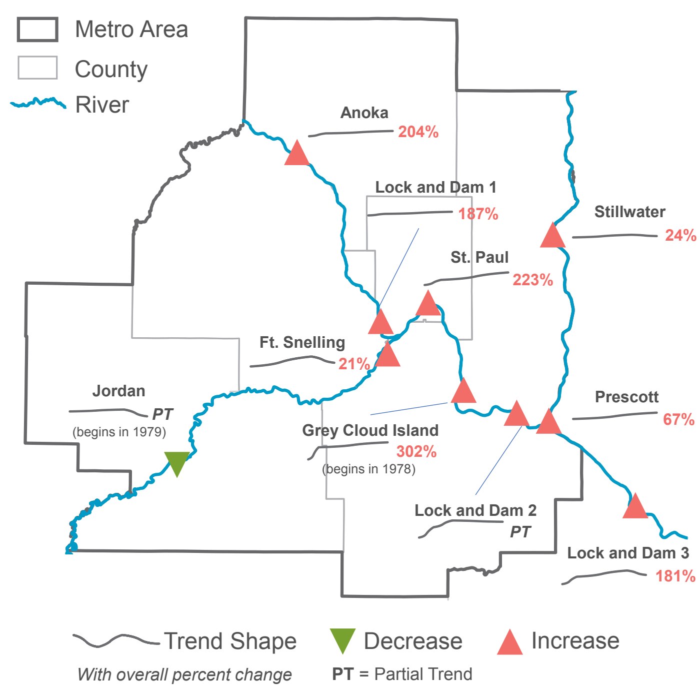


Figure 11: Flow-Adjusted NO_3 Trends, 1976-2015



NO_3 trend (PT) was evident in the Minnesota River at Jordan, a 21% increase occurred at Fort Snelling. Increases in NO_3 concentrations ranged from 24-67% in the St. Croix River.

Sources of NO_3 contributing to increasing concentrations in regional rivers during the past 40 years include cropland tile drainage, groundwater, atmospheric deposition, point sources, forests, agricultural runoff, and septic systems (MPCA, 2013).

At major MCES WWTPs, the advanced secondary treatment process implemented in 1984 significantly reduced harmful NH_3 concentrations discharged to the regional rivers. However, the process resulted in a large increase in discharged NO_3 concentrations, which partially contributed to the increasing trends noted in the Mississippi River at Grey Cloud Island and in the Minnesota River at Fort Snelling.

Fecal Coliform Bacteria (FC)

FC are mostly harmless bacteria that typically originate from human, pet, livestock, and wildlife waste. Their presence is usually an indication of fecal contamination in water (MPCA, 2008a). Fecal contamination can also introduce harmful pathogens into the water, which can cause illness to anyone exposed to them.

Recent Conditions. As the rivers enter the metro area, recent 10-year median FC concentrations (Figure 12) were highest in the Mississippi River (34 organisms/100 mL), intermediate in the Minnesota River (20 organisms/100 mL), and lowest in the St. Croix River (10 organisms/100 mL).

FC concentrations increased in the Mississippi and Minnesota rivers as they moved though the metro area. The highest FC concentrations were evident near the central urban areas of Minneapolis and Saint Paul, and downstream from the Metro WWTP (for example, 54 organisms/100 mL in the Minnesota River at Fort Snelling and 62 organisms/100 mL in the Mississippi River near Grey Cloud Island).

Urban areas can be a significant source of bacteria, and pets, wildlife, and humans tend to be the main contributors, often via stormwater and wastewater. At Grey Cloud Island in the Mississippi River and Fort Snelling in the Minnesota River, the two sites closest to the discharge of MCES's largest WWTPs, the median FC concentrations are higher compared to other sites in the metro area. The WWTPs likely contribute to the higher FC concentrations at these sites. Most of the year, the WWTPs disinfect treated wastewater to reduce bacteria, but disinfection is not required from November to March when exposure to river water from recreational activity is low.

Figure 12: Median River FC Concentrations (#/100 mL), 2006-2015

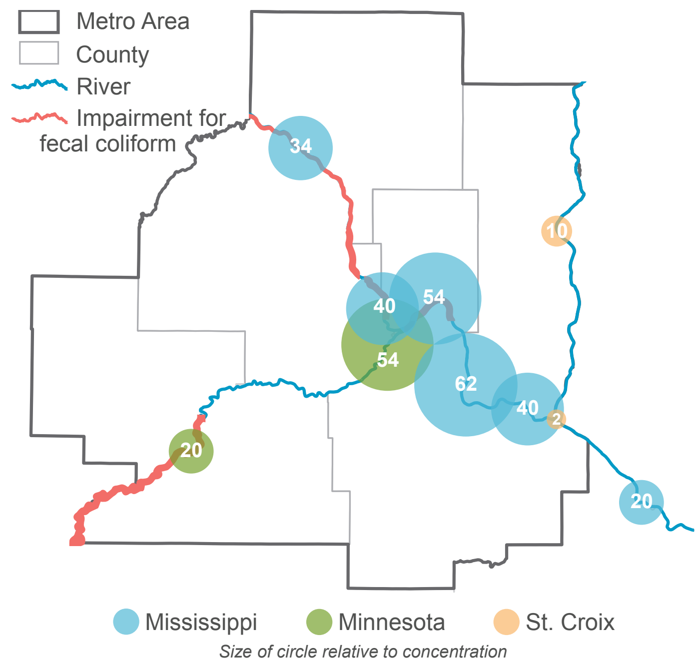
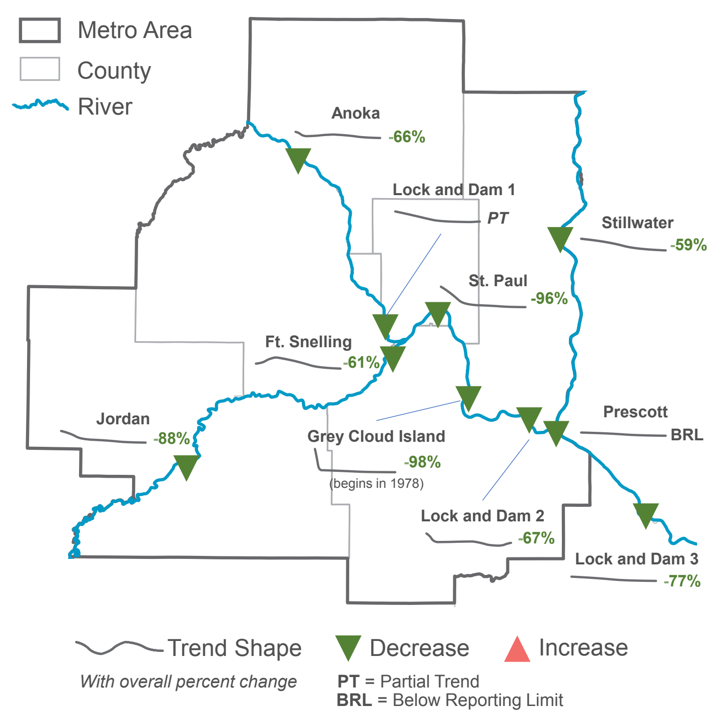


Figure 13: Flow-Adjusted FC Trends, 1976–2015



40-Year Trends. QWTREND analysis of long-term water quality trends (Figure 13) shows that FC concentrations have significantly decreased across all three regional rivers during the last 40 years, indicating an improvement in water quality. Reductions in FC concentrations ranged from 66-98% in the Mississippi River and 61-88% in the Minnesota River. In the St. Croix River, a 59% reduction was noted at Stillwater, and FC concentrations also decreased at Prescott. Although decreases in FC concentrations varied from site to site along the three rivers, the greatest decreases occurred in the Mississippi River reach between Saint Paul and Grey Cloud Island.

Decreasing FC concentrations in regional rivers during the last four decades can likely be attributed to separation of combined sewer overflow (CSO) systems in Minneapolis and Saint Paul (1985-1995), improved stormwater management via MS4 permits, and watershed-wide pollution control programs upstream that have reduced surface runoff and improved the management of feedlots, manure, and septic and sewage systems.

Although FC concentrations have significantly decreased in the three rivers, portions of the Mississippi and Minnesota rivers remain impaired due to excessively high FC concentrations (Figure 12).

Chloride (Cl)

Cl exists naturally at low levels in the metro area's surface waters and plays a vital role in biological functioning. However, high Cl concentrations can be hazardous to aquatic life and affect drinking water sources, infrastructure, vehicles, plants, soil, pets, and wildlife (MPCA, 2016d).

Recent Conditions. As the rivers enter the metro area, the recent 10-year median Cl concentrations (Figure 14) show that concentrations were highest in the Minnesota River (31 mg/L), intermediate in the Mississippi River (17 mg/L), and lowest in the St. Croix River (6 mg/L).

Cl concentrations generally increased from upstream to downstream as the rivers moved through the region. The highest Cl concentrations were evident near the central urban areas of Minneapolis and Saint Paul (43 mg/L near Fort Snelling in the Minnesota River and 36 mg/L near Grey Cloud Island in the Mississippi River), where winter road salt usage is a significant source of Cl.

Increases in Cl concentrations in the Mississippi River at Grey Cloud Island and Lock and Dam 2, and in the Minnesota River at Fort Snelling also reflect Cl contributions from MCES WWTPs, where

Figure 14: Median River Cl Concentrations (mg/L), 2006-2015

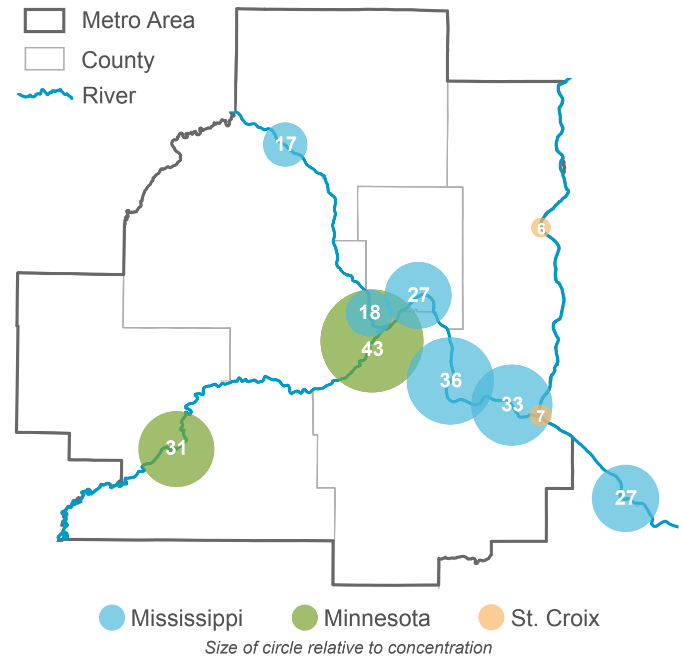
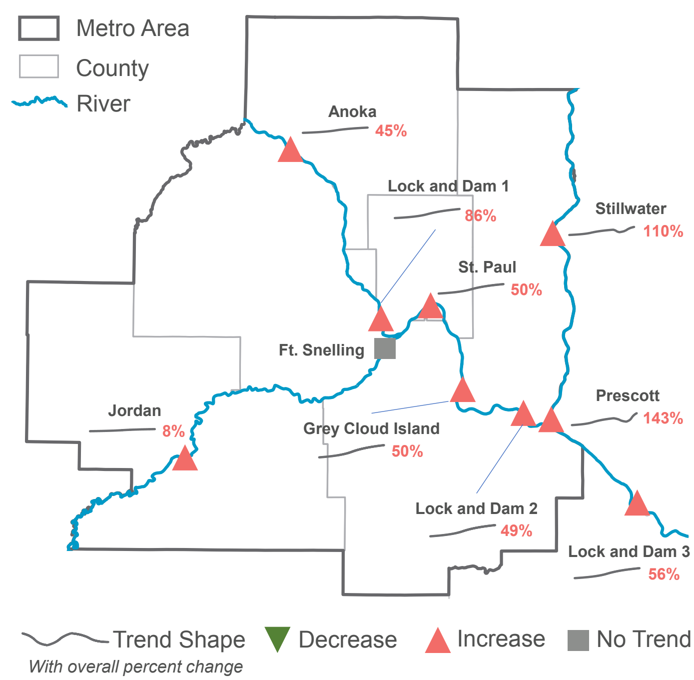


Figure 15: Flow-Adjusted Cl Trends, 1985–2015



salts from residential water softeners serve as the primary Cl source. In addition, Cl concentrations in the Mississippi River were influenced by the Minnesota and St. Croix rivers. A notable increase in the Mississippi River Cl concentration occurred downstream from the Minnesota River confluence, while a slight decrease occurred downstream from the St. Croix River confluence.

31-Year Trends. QWTREND analysis of long-term trends (Figure 15) shows that, with the exception of the Minnesota River at Fort Snelling, Cl concentrations have significantly increased across all three rivers during the last 31 years, indicating declining water quality.

Increases in Cl concentrations ranged from 45-86% in the Mississippi River, where the greatest increase (86%) occurred at Lock and Dam 1. Within the river reach from Anoka to Lock and Dam 1, numerous Mississippi River tributaries have been listed by the MPCA (2016a) as impaired due to excessive Cl concentrations. High Cl concentrations in these streams and direct storm sewer discharges to the Mississippi River from Minneapolis and Saint Paul likely reflect increased salt usage for winter maintenance activities in largely urbanized watersheds.

The relatively high percentage increases in Cl concentrations in the St. Croix River (110-143%) simply reflect small absolute increases in Cl concentrations that are the lowest of all metro area river concentrations. In the Minnesota River, an 8% increase in Cl concentrations was noted at Jordan, but no trend was apparent at Fort Snelling.

Summary

Recent Water Quality Conditions and Spatial Changes

The water quality of metro area rivers is affected by contributions from point and nonpoint sources within the metro area and from upstream watersheds. The patterns of the recent 10-year median concentrations in the rivers (summarized in Table 1) differ by parameter, since each parameter is affected by a different combination of point and nonpoint sources.

The pattern of the 10-year median concentrations of TSS, TP, and NO_3 highlights the impact that the upstream watersheds have on river water quality in the metro area. Their median concentrations showed clear differences between the three rivers as they entered the metro area, with concentrations consistently being higher in the Minnesota River, intermediate in the Mississippi River, and lower in the St. Croix River. This pattern is likely due to upstream differences in ecoregion type, land cover, and land use within the three contributing watersheds (Figure 2).

Other parameters, such as FC and Cl, also show differences between the rivers as they enter the metro area, but additionally highlight the impact that the metro area has on river water quality. The highest recent 10-year median FC and Cl concentrations were in the core of the metro area, specifically in the Mississippi River near Grey Cloud Island, and in the Minnesota River

Table 1. Patterns in Recent Water Quality Conditions in Metro Area Mississippi, Minnesota, and St. Croix Rivers (10-year median concentrations, 2006-2015)

River	Mississippi River						Minnesota River		St. Croix River	
Site	Anoka	Lock and Dam 1	Saint Paul	Grey Cloud Island	Lock and Dam 2	Lock and Dam 3	Jordan	Fort Snelling	Stillwater	Prescott
River Mile	*871.6*	*847.7*	*839.1*	*826.7*	*815.6*	*796.9*	*39.4*	*3.5*	*23.3*	*0.3*
Flow (cfs)	5,950	6,452	9,995	10,247	10,700	15,900	3,305	3,535	3,800	4,070
TSS (mg/L)	9	9	20	20	25	23	48	35	6	2
TP (mg/L)	0.061	0.056	0.09	0.103	0.12	0.103	0.14	0.167	0.037	0.032
NO_3 (mg/L)	0.93	0.66	1.67	1.94	2.02	1.62	2.94	3.02	0.24	0.58
FC (#/100mL)	34	40	54	62	40	20	20	54	10	2
Cl (mg/L)	17	18	27	36	33	27	31	43	6	7

Lowest Median — *Highest Median*

at Fort Snelling. Urban areas commonly serve as sources of FC and Cl. FC is typically associated with animal and human waste products, which tend to be more concentrated in populated regions due to WWTP and stormwater inputs. Cl sources include de-icers such as road salt and WWTP discharges, due primarily to salt usage in residential water softeners.

Long-term Water Quality Trends

The statistical model QWTREND was used to analyze long-term (1976-2015) flow-adjusted water quality trends in the metro area Mississippi, Minnesota, and St. Croix rivers. Table 2 summarizes water quality trends in these three rivers. QWTREND analysis showed that regional river water quality has improved for some parameters (TSS, TP, and FC) but declined for others (NO_3 and Cl) during the last four decades.

Overall, the water quality trends observed in this report are similar to those observed by past studies of water quality trends in the metro area Mississippi, Minnesota, and St. Croix rivers. These studies have used MCES data from the same monitoring sites, although the periods of record and statistical methods used for trend analysis differ.

Factors Contributing to Water Quality Changes

As indicated in this study, water quality in the metro area Mississippi, Minnesota, and St. Croix rivers has changed dramatically during the last four decades. Although influenced to some extent by natural processes, these changes largely reflect human activities related to agriculture and urban development.

Decreasing trends in TSS, TP, and FC concentrations indicate an improvement in water quality. Regulations on point source discharges and subsequent state-wide investments in wastewater treatment technology have greatly contributed to these decreasing trends. In the metro area, MCES investments in secondary treatment (post 1966) and advanced secondary treatment (post 1984) at WWTPs have substantially improved regional river water quality (USEPA, 2000), especially in the Mississippi and Minnesota rivers, where the Metro, Blue Lake, and Seneca WWTPs are the largest point source contributors.

Secondary treatment at MCES WWTPs has been especially effective at reducing TSS and FC concentrations, while advanced secondary treatment has effectively reduced NH_3 and TP concentrations. The elimination of combined sewer overflow (CSO) discharges to the metro Mississippi River has also yielded significant water quality benefits. Additional pollution reduction efforts include MS4 permits and the application of BMPs to address urban stormwater runoff, implementation of TMDL plans to address water quality impairments, application of BMPs to address agricultural runoff, and legislation to limit the use of phosphorus in detergents and lawn fertilizers.

Conversely, increasing trends in NO_3 and Cl concentrations indicate deteriorating water quality. Excessive nitrogen concentrations in surface waters

Table 2: Summary of Flow-Adjusted Water Quality Trends in the Metro Area Mississippi, Minnesota, and St. Croix Rivers, 1976-2015

River	Mississippi River						Minnesota River		St. Croix River	
Site	Anoka	Lock and Dam 1	Saint Paul	Grey Cloud Island[1]	Lock and Dam 2	Lock and Dam 3	Jordan	Fort Snelling	Stillwater	Prescott
River Mile	871.6	847.7	839.1	826.7	815.6	796.9	39.4	3.5	23.3	0.3
Downward Trend										
TSS (mg/L)	-56%	-74%	-41%	-43%	-34%	-42%	-37%	-51%	-48%	-75%
TP (mg/L)	-44%	43%	-46%	-59%	-36%	-37%	-44%[3]	-51%	-26%	-32%
FC Bacteria (#/100mL)	-66%	PT	-96%	-98%	-67%	-77%	-88%	-61%	-59%	BRL
Upward Trend										
NO_3 (mg/L)	204%	187%	223%	302%	PT	181%	PT[3]	21%	24%	67%
Cl (mg/L)[2]	45%	86%	50%	50%	49%	56%	8%	NT	110%	143%

(1) Period of record for Grey Cloud Island begins in 1978
(2) Period of record for Chloride begins in 1985
(3) Period of record begins in 1979

Decreasing Trend (green) (red) *Increasing Trend* are a major statewide concern. Increasing NO_3 concentrations in regional rivers may be linked to

(1) changes in land management, agricultural practices, and climate;

(2) increasing usage of fertilizers on agricultural croplands and urban lawns;

(3) expansion of livestock and poultry production;

(4) increasing population (MPCA, 2013).

Although advanced secondary treatment at the MCES WWTPs has substantially reduced NH_3 concentrations, NO_3 concentrations have increased as a result. Increasing Cl concentrations at all metro area river monitoring sites (except Fort Snelling) reflect the increasing use of salt for winter de-icing activities and for water softening, primarily by residential households.

Current Issues and Improvement Needs

Although concentrations of TSS, TP, and FC have significantly decreased in metro area rivers during the last four decades, water quality impairments for turbidity/TSS, eutrophication/nutrients, and FC bacteria still exist in portions of the three rivers. Clearly, additional improvements are needed to meet water quality standards that protect aquatic life and benefit recreational use.

To address current water quality impairments, the MPCA and local partners are implementing TMDL plans that identify and reduce the sources of these pollutants. Continued monitoring will be key to determining whether management actions effectively address these current water quality impairments.

Increasing nitrogen (TN and NO_3) concentrations in metro area rivers are a significant regional and state-wide concern, as high nitrogen concentrations can impact drinking water sources, harm fish and aquatic life, and contribute to the oxygen-depleted dead zone in the Gulf of Mexico via the Mississippi River. Currently, no water quality impairments exist in regional rivers, based upon the drinking water standard for NO_3. However, future development of a NO_3 standard that protects aquatic life and/or the need to reduce NO_3 loads to the Gulf of Mexico will likely drive actions to reduce nitrogen concentrations in the state's surface waters, including metro area rivers.

Cl concentrations have significantly increased in metro area rivers during the last 31 years. As such, Cl is an emerging regional pollutant, largely due to the impacts of urbanization. Although there are currently no water quality impairments for Cl in metro area rivers, 39 metro area waterbodies have Cl impairments, including 16 streams that eventually drain into the major rivers. Since Cl does not degrade in the environment, it will continue to accumulate over time, especially in groundwater and lakes, unless mitigation actions are taken in the coming years. To address the current Cl impairments in metro area waterbodies, the MPCA has completed a TMDL study and developed a metro area chloride management plan.

Recommendations

Many partners are working to protect and restore Minnesota's water resources. Continued collective efforts will be needed to support state, regional, and local water resources management and pollution control programs. The following recommendations are provided in support of these efforts.

Water Quality Concerns and Recommendations for Action

Passage of the Clean Water Act in 1972 resulted in major advances in wastewater treatment technology to address point sources of pollution via NPDES permits, and the application of best management practices to address urban nonpoint sources of pollution through MS4 permits. These advances have resulted in marked improvements in regional river water quality.

However, water quality impairments still exist for DO, turbidity/TSS, eutrophication/nutrients, and FC bacteria; and NO_3 and Cl are significant issues. Unregulated nonpoint sources of pollution must be better managed to achieve water quality standards and goals that improve and protect the water quality of regional rivers. The increasing trends in NO_3 concentrations across all three metro area rivers suggest that NO_3 management is a significant regional and state-wide issue. To help achieve reductions in the excessive nitrogen loads contributing to hypoxia in the Gulf of Mexico, Minnesota has established goals of a 20% reduction in nitrogen inputs to the Mississippi River by 2025 and a 45% reduction by 2040 (MPCA, 2014).

Achieving these goals will require nitrogen reductions from cropland sources, point sources, and other nonpoint sources, which contribute 78%, 9%, and 13%, respectively, of the nitrogen load to the Mississippi River in Minnesota during an average precipitation year. Further, establishment of a state water quality standard for NO_3 is needed to protect aquatic life in Minnesota waters. Such a standard may also lead to implementation of measures that reduce NO_3 contributions from point and nonpoint sources.

Although no Cl-related water quality impairments currently exist in metro area rivers, the increasing trends in Cl concentrations across all three rivers suggest that Cl management is a significant regional issue. Increasing Cl concentrations in the three rivers reflect increasing concentrations in contributing tributaries and stormwater discharges, with 16 tributaries exhibiting Cl impairments. The MPCA's chloride management plan (MPCA, 2016d) identifies methods for reducing chloride use in the metro area without impacting public safety. However, more education and outreach are needed, as citizens and municipalities can take actionable steps to help address this issue.

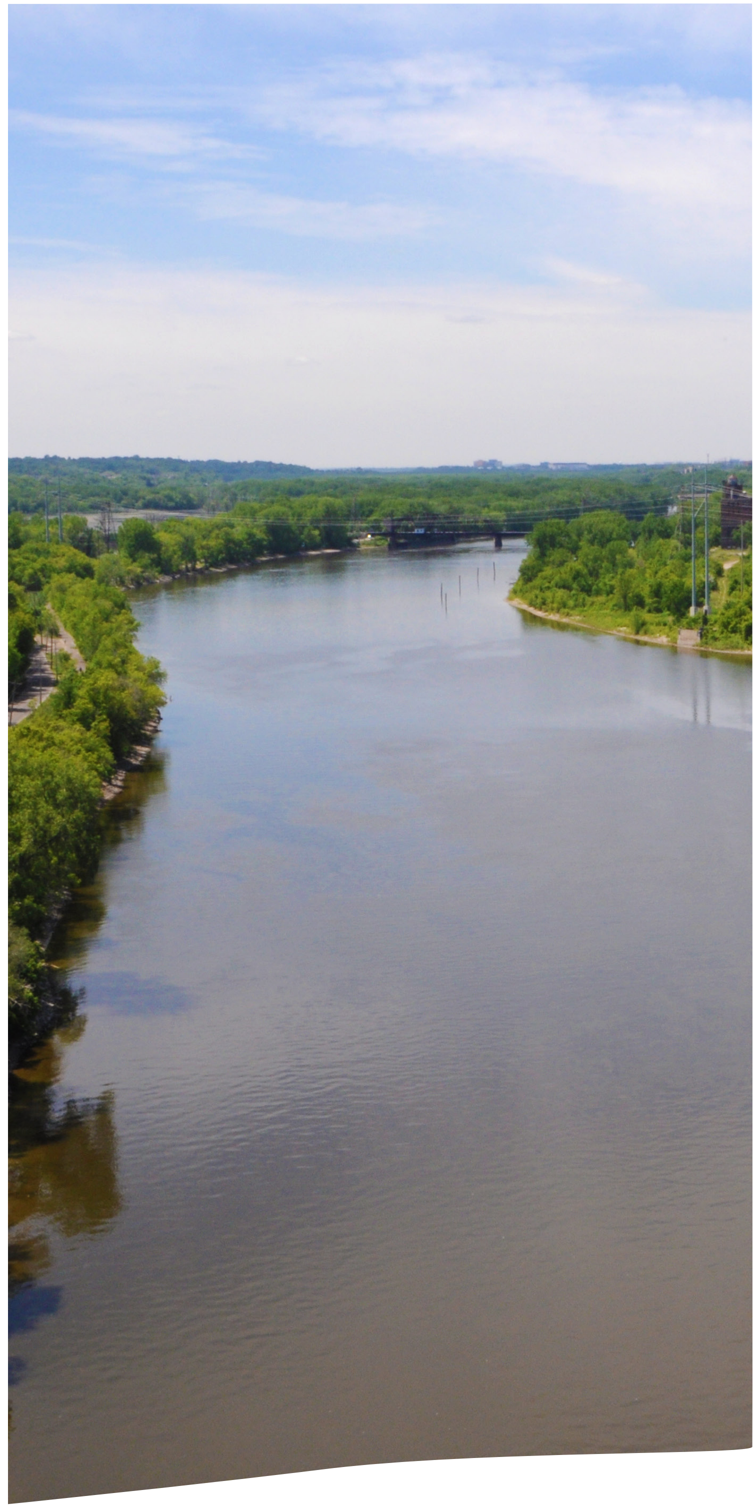
Although conventional water quality pollutants are evaluated in this study, emerging contaminants associated with wastewater treatment are not. Examples of these contaminants include pharmaceutical products, personal care products, and microplastics. Additional funding for research and river monitoring of emerging contaminants are needed to better evaluate this issue.

Monitoring Recommendations

Monitoring is a key tool to help water resources managers determine whether best management practices on the landscape are working to improve water quality. As such, continued long-term monitoring of metro area rivers is needed to evaluate ongoing changes and future improvements in water quality. Further investments are desirable to build strong working relationships with local, state, and federal agencies conducting water monitoring in Minnesota. The ability to capitalize on the unique expertise of each of these agencies will create a more comprehensive picture of river water quality.

Assessment Recommendations

Assessment of historical data for river flows, pollutant loads, and biota would provide a more complete picture of regional river health and water quality conditions. MCES and partners should determine whether water monitoring and assessment programs are positioned to evaluate the long-term impacts of climate change on Minnesota's water resources.



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