Comprehensive Water Quality Assessment of Select Metropolitan Area Streams

INTRODUCTION AND METHODOLOGIES

December 2014

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

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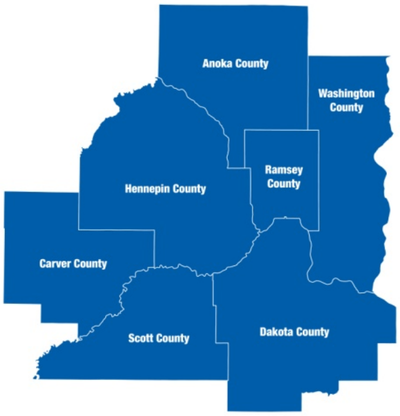

The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system, collects and treats wastewater, coordinates regional water resources, plans and helps fund regional parks, and administers federal funds that provide 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 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 Assessment of Select Metropolitan Area Streams* is the first major study conducted by the Metropolitan Council that examines the historical water quality of the 21 streams and stream segments monitored by Metropolitan Council Environmental Services (MCES).

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.

Protecting the Region's Water Resources

This work supports the regional polices established in the Metropolitan 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.

Cover Photo

The photo on the cover of this section depicts a fisherman seeking trout in the Vermillion River near Farmington. It was taken by Metropolitan Council staff.

Recommended Citations

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

Metropolitan Council. 2014. Introduction and Methodologies. In *Comprehensive water quality assessment of select metropolitan area streams*. Saint Paul: Metropolitan Council.

Please use the following to cite the entire report:

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

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Background

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.

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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. An enormous quantity of data has been collected from the streams, including solids, nutrients, chlorophyll, chloride, metals, macroinvertebrates, oxygen demand, bacteria, conductivity, temperature, ions (including hardness, sulfate, and alkalinity), and total organic carbon.

The study covers approximately 23 years of historical monitoring data (for the longest-term monitoring stations) of 21 streams or stream segments discharging to the three major rivers within the metropolitan area.

Study Focus

This study focuses on solids (primarily total suspended solids [TSS]), nutrients (primarily phosphorus [TP] and nitrate [NO_3]), flow, chloride (Cl), and macroinvertebrates (primarily aquatic insects), as these parameters are the primary concerns of local watershed management organizations, state agencies, cities, and other local partners.

Additional data will be assessed as staff time and budget are available. Future assessments will likely be released as small studies built upon the results and discussion included in the *Comprehensive Assessment of Select Metropolitan Area Streams.*

Study Goals

The study goals are to:

- Identify political and water management organization boundaries, regional parks, and special designations of streams (including Minnesota wild and scenic rivers and Minnesota state water trails) within each watershed.
- Identify watershed features (primarily topography, soils, and land cover) that may affect water quality.

- Identify permitted discharges (through the National Pollutant Discharge Elimination System), including wastewater treatment plants, feedlots, cooling water discharges, and industrial stormwater discharges.
- Identify stream reaches and lakes within each watershed vulnerable to groundwater pumping.
- Assess impaired stream segments and lakes (using the MPCA 2014 Impaired Waters List).
- Assess historical concentrations and loads of total suspended solids (TSS), total phosphorus (TP), total dissolved phosphorus (TDP), nitrate (NO_3), and chloride (Cl).
- Assess relationships between historical macroinvertebrate and water chemistry data.
- Compare water quality and flow of all streams monitored by MCES and identify any geographical trends.
- Identify improvements or declines in water quality based on trend analysis of flow-adjusted concentrations of TSS, TP, and NO_3.
- Draft recommendations for future study, actions, and partnerships for each stream.

MCES will assist watershed management organizations, cities, counties, and state and federal agencies to move forward with water quality restoration and protection efforts using the results and recommendations outlined in the *Comprehensive Assessment of Select Metropolitan Area Streams*, as well as the direction provided by Metropolitan Council policy documents, including *Thrive MSP 2040* and the *2040 Water Resources Policy Plan*.

Statutory and Policy Basis for Metropolitan Council Water Resource Monitoring and Assessment

The Metropolitan Council is the regional planning organization for the seven-county Twin Cities area. The Council operates the regional bus and rail system (Metropolitan Council Metro Transit), collects and treats wastewater through its Metropolitan Council Environmental Services (MCES), coordinates regional water resources (also MCES), 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.

A wide range of governmental organizations are responsible for planning, monitoring and managing water resources in the region – from the federal to the local level. A partial list of MCES's water resource partners includes the U.S. Environmental Protection Agency, the Board of Water and Soil Resources (BWSR), the Minnesota Pollution Control Agency (MPCA), the Minnesota Departments of Health (MDH), Agriculture (MDA) and Natural Resources (MnDNR), local governments, watershed and conservation organizations, and municipal water suppliers. All serve important roles and, together, make possible a broad front of cooperative, coordinated planning and action on behalf of water resources in the region.

The Metropolitan Council is responsible, under state law (Minnesota Statute 473.145), for preparing a comprehensive development guide for the metropolitan area. The Council's *Thrive*

MSP 2040, adopted in May 2014, provides a framework for a shared vision for the future of the region over the next 30 years. *Thrive* establishes the policy foundation used by the Council to develop its regional system and policy plans, as well as development policies and implementation strategies. Taken together, these constitute the comprehensive development guide that directs the orderly and economical development of the region. State statute specifies four metropolitan systems plans − for regional transportation, aviation, water resources, and regional parks. *Thrive's* regional vision includes five desired outcomes (stewardship, prosperity, equity, livability, and sustainability), as well as three principles (integration, collaboration, and accountability).

These outcomes and principles provide policy direction for the regional *2040 Water Resources Policy Plan* (WRPP). The Metropolitan Council has multiple roles and responsibilities that provide a unique regional perspective for planning and management, all aimed at protecting our region's water resources. The WRPP contains policy and associated implementation strategies related to assessment and monitoring of our region's water resources, of which the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams* is a product.

A list of relevant statutes, rules, and federal legislation providing direction for MCES water quality and assessment activities includes:

- Minn. Stat. 473.145: requiring preparation and adoption of a 30-year regional development guide.
- Minn. Stat. 473.157: requiring preparation and adoption of a regional water resources policy plan.
- Section 208 of the federal Clean Water Act: designating the Metropolitan Council as the area-wide waste treatment management agency to provide wastewater treatment and urban stormwater management to protect water quality in the region. The Council monitors and assesses water quality of area lakes, rivers and streams as part of this responsibility.

Table Intro-1 provides a summary of streams assessed in this study, including partnerships, relevant political information (for example, Council districts, counties, and watershed management organizations) and special designations (for example, designated trout streams), and regional parks within each stream watershed. Figures Intro-1 and Intro-2 show the locations of the stream watersheds within the seven-county metropolitan area and within the state of Minnesota, respectively.

History of MCES Water Quality Monitoring

This study is one of the latest in a long line of water monitoring activities in the Twin Cities metropolitan area. MCES, the Council's Environmental Services division, and its antecedent organizations have a long history of monitoring surface waters within the seven-county metropolitan area. Early monitoring, starting in the 1930s, focused on oxygen dynamics in the Mississippi River and related effects of discharge of untreated and treated wastewater from the cities of Saint Paul and Minneapolis.

In the 1970s, MCES began a comprehensive monitoring program to assess sediment, nutrients, bacteria, and oxygen dynamics at numerous locations in the metropolitan area's three major rivers – the Mississippi, the Minnesota, and the St. Croix – with the primary goal of assessing effects of discharge of treated wastewater effluent.

During the 1980s, increasing awareness of detrimental effects of urban and agricultural nonpoint source runoff on both tributary streams and the major rivers led MCES to design and implement a monitoring program focused on the metropolitan area tributary streams discharging to the region's three major rivers. The first MCES stream monitoring stations were installed in 1989 on Minnesota River tributaries as part of the NonPoint Source (NPS) program, which has historically been fully funded and staffed by MCES.

Additional stations were added on Mississippi River and St. Croix River tributaries during the 1990s through the Watershed Outlet Monitoring Programs (WOMP) I and II. These programs paired an MCES monitoring staff person with a local monitoring partner organization (called a "cooperator"), typically the local watershed management organization, conservation district, or city.

Organization of the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams* Study Report

The study report contains 23 sections which are available for separate download from the report website (metrocouncil.org/streams). The main sections of the study have been written for a technical audience, such as consultants, watershed management organization technical staff, city environmental staff, and academics. While the executive summaries, "Introduction and Methodologies," and "Glossary and Acronyms" sections apply to all 21 streams, each stream section is intended to provide sufficient information to stand alone as a technical resource for use by those interested in specific streams. Following the Governor's Executive Order 14-07 requiring all executive branch agencies to communicate using plain language, Metropolitan Council staff also created brief, easily readable fact sheets for all the streams studied.

The *Comprehensive Assessment of Select Metropolitan Area Streams* consists of the following sections and fact sheets:

- Technical Executive Summary plus accompanying Executive Summary fact sheet
- Introduction and Methodologies section
- Glossary and Acronyms section
- St. Croix River tributary stream sections, each with accompanying fact sheet
    - i. Browns Creek
    - ii. Carnelian-Marine Outlet
    - iii. Silver Creek
    - iv. Valley Creek
- Mississippi River tributary stream sections, each with accompanying fact sheet
    - i. Bassett Creek

ii. Battle Creek
iii. Cannon River
iv. Crow River (includes South Fork and Main Stem below confluence of South Fork and North Fork)
v. Fish Creek
vi. Minnehaha Creek
vii. Rum River
viii. Vermillion River

- Minnesota River tributary stream sections, each with accompanying fact sheet
  i. Bevens Creek (includes Upper and Lower monitoring stations)
  ii. Bluff Creek
  iii. Carver Creek
  iv. Credit River
  v. Eagle Creek
  vi. Nine Mile Creek
  vii. Riley Creek
  viii. Sand Creek
  ix. Willow Creek

Schedule of Additional Data Assessments

MCES does not plan to conduct an update of the entire comprehensive stream study, but other new data products and assessments will be available on the Council website. A schedule of planned assessments includes:

Annual web-based data and assessments:

- Water quality and daily average flow data for each station available for download via the MCES Environmental Information Management System (EIMS).
- Monthly and annual pollutant loads for each station available for download from the Council website.
- *Stream Water Quality Summary for the Twin Cities Metropolitan Area,* summarizing annual water quality concentrations for each station (posted on the Council website approximately June each year).
- *Regional Water Quality Assessment,* summarizing annual pollutant loads for streams, major rivers, and wastewater treatment plants (WWTPs) (posted approximately October each year).
- *Lake Water Quality Summary,* summarizing annual water quality grades for the region's lakes, many of which are located within the monitored streams' watersheds.

Longer-term and special web-based assessments:

- MCES plans to repeat the concentration trend analysis included in *Comprehensive Assessment of Select Metropolitan Area Streams* in approximately five years (2019). The updated trend analysis will be issued as a stand-alone report.
- Small special assessments using data collected by MCES but not included in this study. These smaller assessment reports will build upon the results of this study, and will be done as staff time and budgets allow.

Table Intro-1: Metropolitan Council Monitored Tributary Streams and Associated Organizational Metrics

Stream	Major River (Receiving Water)	8-Digit Hydrologic Unit Codes (HUC)[1] and Finer HUC Designation(s), if Applicable	Special Designations of Stream[2]	Start of Monitoring[3]	Monitoring Program[4]	Monitoring Cooperator(s) as of 2014[5]	Metropolitan Council Districts	Regional Parks within Watershed[6]	Special Designations of Receiving Water[7]	Watershed Management Organization(s)[8]	Counties within 7-County Metro Area	Counties outside 7-County Metro Area
Bassett Creek	Mississippi	Twin Cities 07010206 Bassett Creek 0701020605		2000	WOMP II	Bassett Creek WMC	1, 2, 3, 6, 7	Clifton E. French, **Theodore Wirth**	Mississippi NRRA and Critical Area; Mississippi River State Water Trail	Bassett Creek WMC	Hennepin	
Battle Creek	Mississippi	Twin Cities 07010206 City of St. Paul – Mississippi River 0701020608 Battle Creek 070102060804		1996	WOMP I	Ramsey Washington Metro WD	11, 12, 13	**Battle Creek–Indian Mounds**	Mississippi NRRA and Critical Area; Mississippi River State Water Trail	Ramsey Washington Metro WD	Ramsey, Washington	
Beltline Interceptor[9]	Mississippi	Twin Cities 07010206 City of St. Paul – Mississippi River 0701020608 Lake Phalen 070102060803		1995	WOMP I	Ramsey Washington Metro WD	11, 13	**Phalen-Keller**	Mississippi NRRA and Critical Area; Mississippi River State Water Trail	Ramsey Washington Metro WD	Ramsey, Washington	
Cannon River	Mississippi	Cannon 07040002	Minnesota Wild and Scenic River; Minnesota State Water Trail Several MCBS sites with outstanding biodiversity significance, including Lower Cannon (#25137)	1999	WOMP II	Dakota SWCD	16	**Lake Byllesby**, Miesville Ravine	Mississippi River State Water Trail	North Cannon River WMO, Cannon River Partnership	Dakota	Goodhue, Le Sueur, Rice, Steele, Waseca

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Crow River – Main Stem (Includes both North and South Forks)	Mississippi	Crow	07010204	Minnesota Wild and Scenic River (North Fork of Crow); Minnesota State Water Trail (North Fork and Main Stem of Crow)	1998	WOMP II	Wright SWCD	1	**Crow–Hassan, Lake Rebecca**	Mississippi NRRA and Critical Area; Mississippi River State Water Trail	Pioneer Sarah Creek WMC, Elm Creek WMC, North Fork Crow River WD, Middle Fork Crow River WD, Crow River Organization of Water (CROW Joint Powers)	Hennepin	Pope, Stearns, Kandiyohi, Meeker, Wright
Crow River – South Fork[10]	Mississippi	South Fork Crow	07010205	Minnesota State Water Trail	2001	WOMP I	Carver County	1, 4	Baylor		Pioneer Sarah Creek WMO, Carver County WMO, Crow River Organization of Water (CROW Joint Powers), Buffalo Creek WD	Carver, Hennepin	Kandiyohi, Meeker, Renville, McLeod, Sibley, Wright
Fish Creek	Mississippi	Twin Cities City of St. Paul – Mississippi River Harriet Island – Mississippi River	07010206 0701020608 070102060805		1995	WOMP I	Ramsey Washington Metro WD	11, 12, 13		Mississippi NRRA and Critical Area; Mississippi River State Water Trail	Ramsey Washington Metro WD	Ramsey, Washington	
Minnehaha Creek	Mississippi	Twin Cities Minnehaha Creek	07010206 0701020606		1998	WOMP II	Minnehaha Creek WD; USGS	1, 3, 4, 5, 6, 7, 8	Gale Woods, Morris T. Baker, Carver, Lake Minnewashta, Lake Minnetonka, Noerenberg Gardens, **Minneapolis Chain of Lakes, Nokomis Hiawatha, Minnehaha**	Mississippi NRRA and Critical Area; Mississippi River State Water Trail	Minnehaha Creek WD	Carver, Hennepin	

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Rum River	Mississippi	Rum	07010207	Minnesota Wild and Scenic River; Minnesota State Water Trail Several MCBS sites with outstanding biodiversity significance, including Cedar Creek Natural History Area (#30037)	1996	WOMP I and Major River[11]	Anoka Conservation District; MCES major river program	9	Lake George, **Rum River Central**	Mississippi NRRA and Critical Area; Mississippi River State Water Trail	Lower Rum River WMO, Upper Rum River WMO	Anoka	Aitkin, Crow Wing, Morrison, Mille Lacs, Kanabec, Benton, Isanti, Chisago, Sherbourn e
Vermillion River	Mississippi	Rush-Vermillion Vermillion River	07040001 0704000102	Portions are Designated Trout Stream; Several MCBS sites with outstanding biodiversity significance, including Vermillion Outlet (#19039)	1995	WOMP I and Major River[11]	Dakota SWCD (Hastings station) MCES (Empire and Farmington through the MCES major river program)	4, 15, 16	Whitetail Woods	Mississippi NRRA and Critical Area; Mississippi River State Water Trail	Vermillion River Joint Powers Board	Dakota, Scott	
Bevens Creek – Lower	Minnesota	Lower Minnesota Bevens Creek	07020012 0702001207		1989	NPS	MCES	4		Minnesota River State Water Trail	Carver County WMO	Carver	Sibley
Bevens Creek – Upper	Minnesota	Lower Minnesota Bevens Creek	07020012 0702001207		1992	NPS	MCES	4			Carver County WMO	Carver	Sibley
Bluff Creek	Minnesota	Lower Minnesota Minnesota River City of Shakopee – Minnesota River	07020012 0702001211 070200121102		1989	NPS	MCES	3, 4		Minnesota Valley NWR; Minnesota River State Water Trail	Riley Purgatory Bluff Creek WD; Lower Minnesota River WD	Carver, Hennepin	

Stream	Major River (Receiving Water)	8-Digit Hydrologic Unit Codes (HUC)[1] and Finer HUC Designation(s), if Applicable		Special Designations of Stream[2]	Start of Monitoring[3]	Monitoring Program[4]	Monitoring Cooperator(s) as of 2014[5]	Metropolitan Council Districts	Regional Parks within Watershed[6]	Special Designations of Receiving Water[7]	Watershed Management Organization(s)[8]	Counties within 7-County Metro Area	Counties outside 7-County Metro Area
Carver Creek	Minnesota	Lower Minnesota Carver Creek	07020012 0702001210		1989	NPS	MCES	4		Minnesota Valley NWR; Minnesota River State Water Trail	Carver County WMO; Lower Minnesota River WD	Carver	
Credit River	Minnesota	Lower Minnesota Minnesota River Credit River	07020012 0702001211 070200121107	Drains MCBS site with outstanding biodiversity significance, Murphy-Hanrehan (#70009)	1989	NPS	MCES	4, 15, 16	**Murphy Hanrehan**, Cleary Lake	Minnesota River State Water Trail	Scott County WMO; Lower Minnesota River WD	Dakota, Scott	
Eagle Creek	Minnesota	Lower Minnesota Minnesota River Eagle Creek – Minnesota River	07020012 0702001211 070200121106	Designated Trout Stream	1999	WOMP II	Lower Minnesota River WD; Scott SWCD	4		Minnesota Valley NWR; Minnesota River State Water Trail	Lower Minnesota River WD	Scott	
Nine Mile Creek	Minnesota	Lower Minnesota Minnesota River Nine Mile Creek	07020012 0702001211 070200121108		1989	NPS	MCES	3, 5	**Bryant Lake, Hyland–Bush–Anderson Lakes**	Minnesota River State Water Trail; Minnesota Valley NWR	Nine Mile Creek WD; Lower Minnesota River WD	Hennepin	
Purgatory Creek[9]	Minnesota	Lower Minnesota Minnesota River City of Shakopee – Minnesota River	07020012 0702001211 070200121102		2014	WOMP II	Riley Purgatory Bluff Creek WD	3, 5		Minnesota Valley NWR; Minnesota River State Water Trail	Riley Purgatory Bluff Creek WD; Lower Minnesota River WD		

Stream	Major River (Receiving Water)	8-Digit Hydrologic Unit Codes (HUC)[1] and Finer HUC Designation(s), if Applicable		Special Designations of Stream[2]	Start of Monitoring[3]	Monitoring Program[4]	Monitoring Cooperator(s) as of 2014[5]	Metropolitan Council Districts	Regional Parks within Watershed[6]	Special Designations of Receiving Water[7]	Watershed Management Organization(s)[8]	Counties within 7-County Metro Area	Counties outside 7-County Metro Area
Riley Creek	Minnesota	Lower Minnesota Minnesota River Riley Creek	07020012 0702001211 070200121103		1999	WOMP II	City of Eden Prairie; Barr Engineering Company	3, 4		Minnesota Valley NWR; Minnesota River State Water Trail	Riley Purgatory Bluff Creek WD; Lower Minnesota River WD	Carver, Hennepin	
Sand Creek	Minnesota	Lower Minnesota Sand Creek	07020012 0702001208		1989	NPS	MCES	4	Cedar Lake Farm, Doyle-Kennefick (planned)	Minnesota Valley NWR; Minnesota River State Water Trail	Scott County WMO	Scott	Rice, Le Sueur
Willow Creek[12]	Minnesota	Lower Minnesota Minnesota River Black Dog Lake – Minnesota River	07020012 0702001211 070200121109		1999	WOMP II	Lower Minnesota River WD; Dakota County SWCD	4, 5, 15		Minnesota River State Water Trail	Black Dog WMO, Lower Minnesota River WD	Dakota, Scott	
Browns Creek	St. Croix	Lower St. Croix Big Marine Lake – Saint Crow River Browns Creek	07030005 0703000509 070300050907	Designated Trout Stream	1998	WOMP I	Browns Creek WD; Washington Conservation District	11, 12		Lower St. Croix National Scenic Riverway; St. Croix River State Water Trail	Browns Creek WD	Washington	
Carnelian Marine Outlet[12]	St. Croix	Lower St. Croix Big Marine Lake – Saint Crow River Big Marine Lake	07030005 0703000509 070300050906		1995	WOMP I	Carnelian - Marine St. Croix WD; Washington Conservation District	11, 12	Big Marine	Lower St. Croix National Scenic Riverway; St. Croix River State Water Trail	Carnelian - Marine St. Croix WD	Washington	

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Silver Creek	St. Croix	Lower St. Croix Big Marine Lake – Saint Crow River Silver Creek – Saint Croix River	07030005 0703000509 070300050908	MCBS site of outstanding biodiversity significance: Fairy Falls (#82096)	1998	WOMP I	Carnelian - Marine St. Croix WD; Washington Conservation District	12	Pine Point	Lower St. Croix National Scenic Riverway; St. Croix River State Water Trail	Carnelian - Marine St. Croix WD	Washington	
Valley Creek	St. Croix	Lower St. Croix Lake Saint Croix Valley Branch	07030005 0703000512 070300051203	Designated Trout Stream	1999	WOMP II	Valley Branch WD; Washington Conservation District; Science Museum of Minnesota - St. Croix Watershed Research Station	11, 12		Lower St. Croix National Scenic Riverway; St. Croix River State Water Trail	Valley Branch WD	Ramsey, Washington	

[1] Hydrologic Unit Code (HUC) designated by the USGS. The table lists the 8-digit HUC plus 10- and 12-digit HUCs as necessary to define the stream watershed.

[2] State Wild and Scenic River and State Water Trails designated by MnDNR. MCBS (Minnesota County Biological Survey) administered by the MnDNR. Designated Trout Stream as listed in Minn. Rules Chapter 6264.0050

[3] Start of stream monitoring based on first sample entered in the Metro Council's Environmental Information Monitoring System (EIMS). Some streams (for example, Vermillion, Rum) are also sampled as part of the Met Council's river monitoring program and thus may have a longer data record.

[4] NPS (NonPoint Source): Funded and staffed solely by MCES; WOMP I (Watershed Outlet Monitoring Program One): Funded solely by MCES, staffed by MCES and monitoring cooperator; WOMP II (Watershed Outlet Monitoring Program Two): Funded by Clean Water Land and Legacy Amendment funds (via the Minnesota Pollution Control Agency) and MCES and staffed by MCES and monitoring cooperator.

[5] WMC = Watershed Management Commission; WD = Watershed District; WMO = Water Management Organization; JPO = Joint Powers Organization; U.S.G.S. = United States Geological Survey; SWCD = Soil and Water Conservation District.

[6] Regional Parks defined as those parks created by the 10 park implementing agencies (cities, counties, park districts) and the Metropolitan Parks and Open Space Commission; streams flow directly through those regional parks listed in bold type.

[7] Mississippi NRRA (Mississippi National River Recreation Area) administered by National Park Service. Mississippi River Critical Area administered by MnDNR. Minnesota NWR (National Wildlife Refuge) administered by U.S. Fish and Wildlife Service. Lower St. Croix National Scenic Riverway administered by National Park Service. State Water Trail as designated by MnDNR.

[8] WMC = Watershed Management Commission; WD = Watershed District; WMO = Water Management Organization; JPO = Joint Powers Organization; U.S.G.S. = United States Geological Survey; SWCD = Soil and Water Conservation District.

[9] Station data assessment not included in this report.

[10] Station will be discontinued in 2015.

[11] The Rum and Vermillion rivers are also monitored through the MCES major river program, with the Rum sampled at the convergence with the Mississippi River and the Vermillion at Empire and Farmington.

[12] Station discontinued in 2009.

Figure Intro-1: Location of Stream Watersheds Within the Seven-County Metropolitan Area

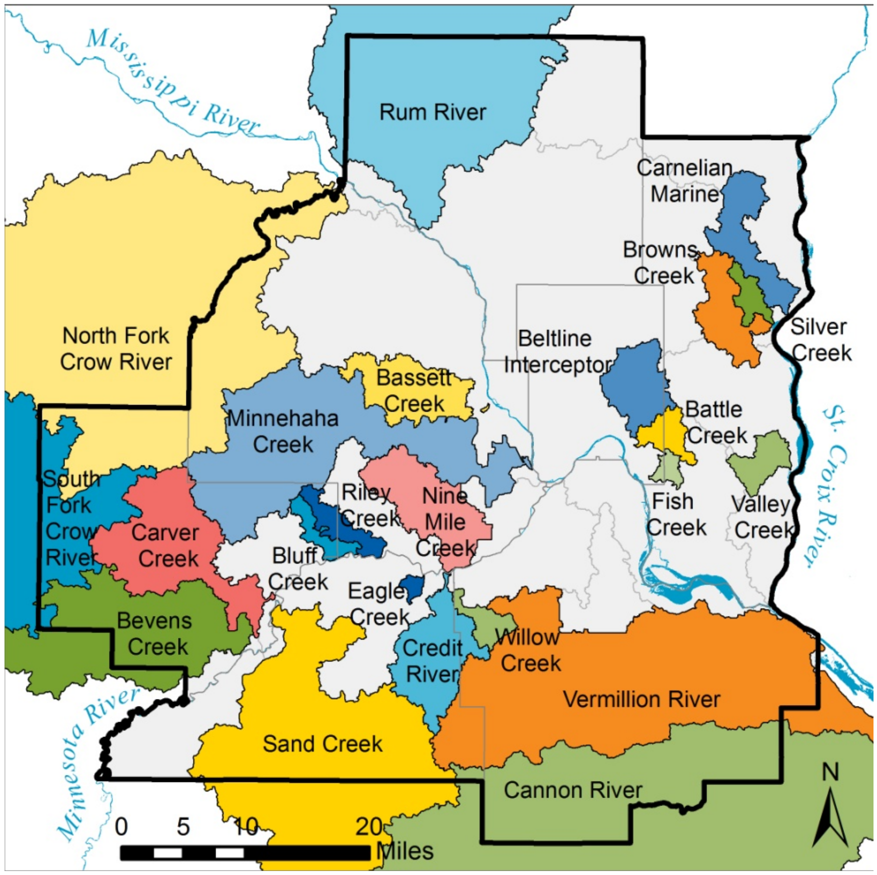
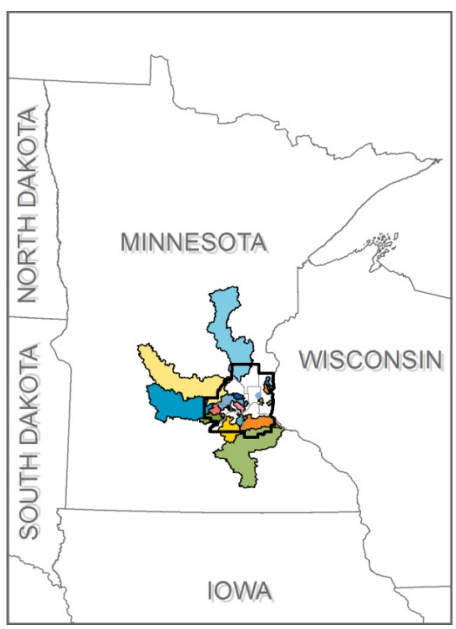


Figure Intro-2: Location of Stream Watersheds Within the State of Minnesota



Non-MCES Data and Sources

Water Quality Standards and Impaired Waters List

The federal Clean Water Act requires the MPCA to designate beneficial uses for all waters of the state (including wetlands, lakes, streams, and rivers) and to develop associated water quality standards. Water quality standards are used to protect beneficial uses, evaluate water quality data to assess quality of state's waters, identify waters that are impaired or need protection, identify water bodies that are not impaired and thus need protection, and set effluent limits for discharge permits governing wastewater treatment plants. Water quality standards are adopted in two Minnesota Rules (Chapter 7050, Waters of the State; and 7052, Lake Superior Basin Standards).

Water quality standards typically include all or part of the following (MPCA, 2014a):

- Identification of waterbody beneficial use: how people, aquatic communities, and wildlife use the waterbody.
- Establishment of a numeric standard: allowable concentrations of specific pollutants in a waterbody to protect the beneficial uses.
- Establishment of narrative standard: non-numerical statements of unacceptable conditions for a waterbody.
- Identification of non-degradation conditions: extra protection established for high-quality or unique waters.

This study was prepared in a unique period of Minnesota's water management history, a period when the MPCA was actively working to promulgate new standards for a number of pollutants addressed in this study, including TSS, TP, Cl, and NO_3. The MPCA provided MCES staff with recommended draft standards for assessment of each stream in this study. Standard values vary from stream to stream due to varying beneficial uses (for example, coldwater trout streams) and varying River Nutrient Regions (RNR), geographic areas used to set TSS and TP standards. A summary of water quality standards used in this study is listed in Table Intro-2.

Every two years the MPCA assesses available water quality data to compile a list (called the Impaired Waters List) of those waters not meeting their established water quality standards. The Impaired Waters List consists of three components: the 303(d) List, the Inventory of Impaired Waters, and Appendix A, (which lists waterbodies that are part of the statewide mercury TMDL). MCES used the 2014 Impaired Waters List (MPCA, 2014b) and associated geospatial data to map impaired reaches for each stream plus impaired lakes within each watershed. The appropriate impaired waters map is included in each stream section.

Table Intro-2: Stream Beneficial Uses, River Nutrient Region (RNR) Classifications, and Pollutant Draft Standards

Stream	Major River Basin	Use Classification[1] for Domestic Consumption (Class 1) and Aquatic Life and Recreation[1] (Class 2)	River Nutrient Region (RNR)[2] of Monitoring Station	Cl Draft Stnd[3] (mg/l)	TSS Draft Stnd[4] (mg/l)	TP Draft Stnd[5] (ug/l)	NO_3 DW Stnd[6] (mg/l)
Bassett Creek	Mississippi	2B	Central	230	30	100	10
Battle Creek	Mississippi	2B	Central	230	30	100	10
Cannon River	Mississippi	2B	Central[4]	230	30	100	10
Crow River – Main Stem (Includes both North and South forks)	Mississippi	2B	Central[3]	230	30	100	10
Crow River – South Branch	Mississippi	2B	South[3]	230	65	150	10
Fish Creek	Mississippi	2B	Central	230	30	100	10
Minnehaha Creek	Mississippi	2B	Central	230	30	100	10
Rum River	Mississippi	2B	Central[3]	230	30	100	10
Vermillion River Vermillion River[7] Vermillion River – South Branch[7]	Mississippi	2B 1B, 2A 1B, 2A	Central	230 230 230	30 10 10	100 100 100	10 10 10
Bevens Creek – (Upper and Lower)	Minnesota	2B	Central	230	30	100	10
Bluff Creek	Minnesota	2B	Central	230	30	100	10
Carver Creek	Minnesota	2B	Central	230	30	100	10
Credit River	Minnesota	2B	Central	230	30	100	10

Stream	Major River Basin	Use Classification[1] for Domestic Consumption (Class 1) and Aquatic Life and Recreation[1] (Class 2)	River Nutrient Region (RNR)[2] of Monitoring Station	Cl Draft Stnd[3] (mg/l)	TSS Draft Stnd[4] (mg/l)	TP Draft Stnd[5] (ug/l)	NO_3 DW Stnd[6] (mg/l)
Eagle Creek[7]	Minnesota	1B, 2A	Central	230	10	100	10
Nine Mile Creek	Minnesota	2B	Central	230	30	100	10
Riley Creek	Minnesota	2B	Central	230	30	100	10
Sand Creek	Minnesota	2B	Central	230	30	100	10
Willow Creek	Minnesota	2B	Central	230	30	100	10
Browns Creek[7]	St. Croix	1B, 2A	Central	230	10	100	10
Carnelian Marine Outlet	St. Croix	2B	Central	230	30	100	10
Silver Creek	St. Croix	2B	Central	230	30	100	10
Valley Creek[7]	St. Croix	1B, 2A	Central	230	10	100	10

[1] Minn. Rules 7050.0470 and 7050.0430.

[2] Watershed includes more than one River Nutrient Region (RNR). Listed RNR is for watershed at monitoring station or as designated by MPCA, 2010.

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

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

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

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

[7] Trout stream identified in Minn. Rule 7050.0470.

Topography

In unaltered watersheds, topography drives the flow patterns of runoff within a watershed. In altered and urbanized watersheds, topography combined with artificial drainage networks, like storm sewers and culverts, determine the directions of runoff flow. Combined with soil information, watershed topography can also be an indicator of gully, ravine, and streambank erosion potential.

MCES used the U.S. Geological Survey (USGS) National Elevation Dataset 1/3 arc-second (10-meter) digital elevation model to create the topography maps included in each stream section (downloaded from http://nationalmap.gov/elevation.html; July 7, 2011). Included in each stream section topography discussion is an estimate of percentage of steep and very steep slopes in the watershed. The MnDNR classifies steep slopes as slopes over 12% and very steep slopes as slopes over 18% (MnDNR, 2010). The percent steep and very steep slopes combined with knowledge of soil erodibility can be used as an indicator of potential for ravine and gully erosion. Slopes were calculated using the USGS National Elevation Dataset (30-meter) digital elevation model (downloaded from http://datagateway.nrcs.usda.gov; November 23, 2011) for the study area.

Also included in the topography section is information about stream gradient. Stream gradient is the vertical drop of a stream with distance. Stream gradient is a major factor in streambank erosion, sediment transport, and biological habitat. The stream gradient was calculated using the USGS National Elevation Dataset 1/3 arc-second (10-meter) digital elevation model.

Topography, including a longitudinal stream profile, is shown on the elevation map included in each stream section.

Watershed Boundaries and Areas

Watershed area is a crucial determinant of streamflow and pollutant concentration and load. In unaltered lands, watershed area is primarily a factor of land topography, while in urbanized lands topography and storm sewer drainage determine watershed areas. Watershed boundaries for this study were initially obtained from the MnDNR (MnDNR, 2009). The boundaries were modified when MCES had specific knowledge of natural or man-made diversions into or away from the stream, or of internally-drained (landlocked) areas not contributing to the stream.

It is important to note that the watershed boundaries shown in this report do not match the watershed boundaries shown on the Board of Water and Soil Resources' (BWSR) Twin Cities Metropolitan Area Watershed Districts and Management Organizations map (BWSR, 2014). Watershed district and management organization boundaries are nominally based both on topography and jurisdictional boundaries.

For this study, each watershed was subdivided into a monitored and unmonitored portion based on the USGS National Elevation Dataset 1.3 arc-second (10-meter) digital elevation model. The monitored portion of the watershed is that area upstream of the monitoring station, while the unmonitored portion of the watershed is that area downstream of the monitoring station but upstream of the confluence with the major river. As long as the unmonitored portion of the watershed is a small percentage of the total, data collected at the monitoring station should be representative of the stream as a whole.

Land Cover

The land cover indicates the physical land type or material coverage of land (for example, water, forest, agriculture, impervious surface), while land use (for example, mixed use development, single family home, institutional) documents how people are using the land. Land cover data is used as the scientific metric categorizing the surface of a watershed and has a profound influence on water quality.

Higher percentages of urban and agricultural land tend to lead to degraded stream water quality. Urban development increases an area's impervious coverage, which may result in increased runoff volume to surface waters and potentially a larger pollutant load of pollutants to streams. Higher fractions of impervious surfaces can also result in higher stream flow velocity, which may erode banks more quickly and carry higher levels of sediment and other particulate pollutants. Urban areas may also contribute metals, road salt, and petrochemicals to streams.

Agricultural land cover can impact streams through increased runoff volume due to subsurface drain tiles discharging to streams, increased TSS concentrations due to soil loss from fields, and negatively impact macroinvertebrate and fish populations due to elevated pesticide and herbicide concentrations in field runoff.

The location of different land covers in a watershed also has an effect on water quality, as a forested or grass buffer along a stream will likely filter runoff and stabilize the streambanks, leading to higher water quality.

Land cover data used for this study was created by the Minnesota Department of Natural Resources (MnDNR) by merging two datasets—the Minnesota Land Classification System (MLCCS) and the 2001 National Land Cover Database (NLCD) - in order to provide uniform data both within and without of the seven-county metropolitan area (B. Richardson, Information Technology for Minnesota Government [MN.IT], 2014, personal communication). The MLCCS is produced by the MnDNR and was used as the primary dataset; it is based completely on land cover, not land use, and classifies urban land by percent impervious. In areas where older aerial photos were used to determine land cover and the land is in a developing area, the MLCCS classification may not match the 2014 land cover. However, a quality check using 2010 aerial photography shows that these areas are small. For the merged dataset, the MLCCS data from 2008 was simplified to level 2 (the CARTO field in the original MLCCS data).

Where MLCCS data was not available (primarily outside the seven-county metropolitan area), 2001 NLCD data was used to classify land cover. The NLCD is produced by the Multi-Resolution Land Characteristics (MRLC) Consortium based primarily on 2001 Landsat data. The hybrid MLCCS-NLCD coverage contains the following twelve classes: 5-10% Impervious, 11-25% Impervious, 26-50% Impervious, 51-75% Impervious, 76-100% Impervious, Agricultural Land, Forest (all types), Open Water, Barren Land, Shrubland, Grasses/Herbaceous, and Wetlands (all types).

Land cover for each watershed is shown on the MLCCS-NLCD Land Cover map in each stream section.

For watersheds with a large percentage of agricultural land, more detailed data on crop types was accessed through the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) 2009 Minnesota Cropland Data Layer (downloaded from http://nassgeodata.gmu.edu/CropScape/; November 8, 2011).

Precipitation

The analysis of precipitation-weighted loads required MCES to use 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.

Estimation of Agricultural Tile Drainage

Agricultural area potentially drained by subsurface tile drainage was estimated for the MPCA study “Nitrogen in Minnesota Surface Waters (MPCA, 2013b) and used in this study. A spatial dataset prepared by David Mulla and Jake Galzki at the University of Minnesota (D. Mulla, personal communication, 2014) was used to estimate draintiled acres for those areas categorized as agricultural in the hybrid MLCCS-NLCD. This dataset was estimated by considering landscape factors that would benefit from enhanced drainage, including:

- Soil Survey Geographic (SSURGO) classified slopes of 0 to 3 percent
- SSURGO drainage class of Poorly or Very Poorly Drained
- NASS 2009 Crop Data Layer crops classified as likely under drainage (corn, soybeans, sugarbeets, or wheat)

Soils and Geology

A stream’s geologic setting and soils contribute greatly to its flow and water quality. In this study, each watershed’s geology and soils are briefly described in the individual stream sections, but are not mapped.

Minnesota’s surficial geology (in this case, referring to the earth materials underlying the soil surface) was primarily laid down during the Wisconsin Age of the Pleistocene which began about 75,000 years ago (Ojakangas and Matsch, 1982). Various glacial lobes covered the stream watershed areas at different times. As the glaciers advanced and retreated, they left behind rocks and sediment that form present day topography. The ground moraine left by retreating glaciers tends to be even and gradually changing, while along the margins of the glaciers, end moraines built up in more severe irregular patterns (Ojakangas and Matsch, 1982). Glacier melt rivulets carried sediment away and formed well-sorted outwash plains. Also as the glaciers retreated and thawed, they left behind lakes, sometimes due to deposition and melting of ice blocks, sometimes because end moraines created dammed lakes (Zumberge, 1952). These lakes built up and eventually overtopped and drained, forming the streams in the seven-county metropolitan area. Stream path and gradient were determined by the moraine and outwash patterns of the retreating glaciers.

Streams tributary to the Minnesota and St. Croix rivers tend to have steep drops or deep valleys upstream of their confluence with the rivers. The Minnesota and St. Croix river valleys were carved deeply by glacial rivers that carried tremendous volumes of water. These deep major river valleys determine the depth to which tributary streams can erode, and over time the streams outlets have deepened, eroding back towards their headwaters until reaching resistive bedrock (Schwartz and Thiel, 1963). Some of the streams, especially in the Minnesota River Valley, are still actively downcutting, contributing high concentrations and high loads of sediment within the streams.

The makeup of the surficial and bedrock geology also affects the level of groundwater contributions to the streams. If the groundwater table sits at the stream elevation, groundwater will equalize with the stream water level and contribute to the streamflow (Schwartz and Thiel, 1963). If the water table is below a stream, groundwater may still contribute to the stream through spring flow at the border of unconsolidated glacial drift and solid impervious bedrock layers or through fractures in bedrock.

Soil is the uppermost layer of the Earth's surface, consisting typically of organic materials, clay, and rock particles. A watershed's soils also influence how much water runs off the landscape into a stream and can be a contributor of pollutants. The Natural Resources Conservation Service (NRCS) has developed two statewide data sets for Minnesota: the U.S. General Soil Map (STATSGO2) and the Soil Survey Geographic (SSURGO). STATSGO2 is distributed on a state wide basis and is mapped at a scale for regional or statewide analysis and comparison. SSURGO is distributed on a county-wide level and is much more detailed than STATSGO2. It is intended to be used locally by farmers and other landowners to make management decisions on their land (Penn State, 2009). Because this report is a study on regional stream trends the STATSGO2 coverage was used to describe watershed soils (downloaded from http://SoilDataMart.nrcs.usda.gov; October 25, 2011). For any future detailed reports or watershed models it is recommended that the SSURGO coverage be used.

The soils data can be used to classify areas by soil type, hydrologic soil group, drainage class, hydric soil status, erosion potential, and many other parameters. This study provides information on hydrologic soil group, which is an indicator of the runoff potential of a soil. Soils are grouped into one of four groups, A, B, C, or D based on their runoff potential. Table Intro-3 summarizes the four soil groups.

Soils situated where the groundwater is very high (less than 24 inches from the surface) may have a dual hydrologic soil group classification A/D, B/D, or C/D. This indicates that based on the soil's native properties the soil would have low-moderately high runoff potential (depending on the first letter classification), but because the water table is so close they will not drain well and ordinarily have high runoff potential. However if the soil is drained its runoff potential will switch to that of the native soil group. Soils in urban areas may have been modified and compacted during development, in which case the mapped hydrologic soil group may not be a good indicator of runoff potential.

Table Intro-3: Hydrologic Soil Groups (NRCS, 2009)

	Hydrologic Soil Group A	Hydrologic Soil Group B	Hydrologic Soil Group C	Hydrologic Soil Group D
Description	Low runoff potential	Moderately low runoff potential	Moderately high runoff potential	High runoff potential
Soil makeup	<10% clay, >90% sand or gravel	10-20% clay, 50-90% sand	20-40% clay, <50% sand	>40% clay, <50% sand
Saturated hydraulic conductivity	>5.67 in/h	≤5.67 to >1.42 in/h	≤1.42 to >0.14 in/h	≤0.14 in/h

Major Point Sources

Point sources, such as domestic and industrial wastewater treatment plants (WWTPs), were the first source of pollutants regulated by the Clean Water Act, and can be a major source of pollutants to a stream. Point sources in Minnesota are permitted by the MPCA. Point source types included in this study include industrial stormwater and wastewater discharges, cooling, potable water treatment, dewatering discharges, domestic wastewater discharges (WWTPs), and animal feedlots.

Industrial wastewater, cooling, potable treatment, dewatering, and domestic wastewater discharges are all permitted through the joint National Pollutant Discharge Elimination System/State Disposal System (NPDES/SDS) program by the MPCA. This permit program requires treatment of wastewater prior to discharge and sets effluent limits based on the WWTP type and receiving waterbody. Monitoring of discharged effluent is required to ensure the permit is being met.

Domestic WWTPs are categorized into 4 classes - A, B, C, and D. In general, Class A and B WWTPs are typically large-scale facilities incorporating primary (initial settling), secondary (aerobic biological processes using activated sludge to degrade waste, plus secondary settling of solids), and tertiary (phosphorus and nitrogen removal) treatment, plus disinfection. Class A and B WWTPs continuously discharge treated effluent to receiving waters. Class D WWTPs typically are small facilities consisting of stabilization ponds which are discharged to the receiving water only once or twice per year. Class C WWTPs may be small versions of Class A or B WWTPs, or stabilization ponds (similar to Class D). Domestic WWTPs located within the stream watersheds are listed in Table Intro-4.

Industrial stormwater is surface runoff from industrial facilities and may contain metals, oil, grease, and other chemicals not found in typical residential stormwater. For this report, industrial stormwater is considered a point source because it usually enters receiving waters through limited discharge points. Industrial stormwater is regulated through the NPDES/SDS stormwater permit for industrial activity. The permit requires a site-specific stormwater pollution prevention plan, contaminant prevention and control measures including structural and non-structural BMPs (best management practices). Occasional monitoring of all stormwater discharge points is also required.

Point source data were provided by the MPCA (M. Graziani, personal communication, 2011). Data are shown on the Public and Impaired Waters and Potential Pollution Sources map included in each stream section.

Feedlots

Feedlots are fenced fields or buildings intended for raising animals where manure may accumulate and potentially can cause bacterial and nutrient contamination of surface waters if feedlot runoff is not contained and treated. Feedlot size is measured in animal units (AU). A 1,000-pound beef cow is considered one AU; other animal species are converted to AUs based on manure production compared to the 1,000-pound beef cow. State feedlot regulations govern manure collection, storage, and disposal. Any feedlot with 50 or more animal units (10 in a shoreland zone) is regulated by state rules and must register, but only feedlots with over 1,000 AUs are required to obtain a state permit. For smaller feedlots, enforcement occurs at the county level (MPCA, 2014c). Animals from feedlots with over 1,000 AUs are prohibited from accessing streams, but feedlots with fewer than 1,000 AUs have no such restriction. Animals entering streams can dislodge and erode streambanks, destroy buffer vegetation, and deposit manure directly into the water. However all livestock operations are required to operate in a manner that does not result in water pollution.

Feedlot information, including size and location, was provided by the MPCA (M. Graziani, personal communication, 2011). Feedlot locations are shown on the Public and Impaired Waters and Potential Pollution Sources map for each watershed.

Table Intro-4: Permitted Wastewater Treatment Plants Discharging to MCES-Monitored Streams[1]

Stream[2,3]	Major River Basin	Permit #	Permit Holder	Design Flow (mgd)	Phosphorus Removal[4]	Class[5]
Bevens Creek	Minnesota	MN0024392	Norwood Young America WWTP	0.908	No P limit	B
Bevens Creek	Minnesota	MN0025585	Hamburg WWTP	0.063	None	D
Cannon River	Mississippi	MN0030121	Faribault WWTP	7	2012	A
Cannon River	Mississippi	MN0024368	Northfield WWTP	5.2	2001	A
Cannon River	Mississippi	MN0051284	Owatonna WWTP	5	2011	A
Cannon River	Mississippi	MN0022993	Cannon Falls WWTP	0.92	2005	B
Cannon River	Mississippi	MN0031241	Lonsdale WWTP	0.687	2004	B
Cannon River	Mississippi	MN0025208	Waterville WWTP	0.4	2008	B
Cannon River	Mississippi	MNG550017	Morristown WWTP	0.21	NA	B
Cannon River	Mississippi	MN0021776	Walnut Grove WWTP	0.203	NA	B
Cannon River	Mississippi	MN0024112	Medford WWTP	0.14	NA	B
Cannon River	Mississippi	MN0041114	Elysian WWTP	0.13	NA	D
Cannon River	Mississippi	MNG580014	Ellendale WWTP	0.1003	NA	D
Cannon River	Mississippi	MN0021008	Geneva WWTP	0.069	NA	D
Cannon River	Mississippi	MN0065668	Nerstrand WWTP	0.042	NA	C
Cannon River	Mississippi	MN0022195	Dennison WWTP	0.025042	NA	D
Cannon River	Mississippi	MNG580084	Kilkenny WWTP	0.0228	NA	D
Cannon River	Mississippi	MN0041106	Lazy U Community Mobile Home Park	0.0218	NA	D

Stream[2,3]	Major River Basin	Permit #	Permit Holder	Design Flow (mgd)	Phosphorus Removal[4]	Class[5]
Cannon River	Mississippi	MN0068713	Meriden Township WWTP	0.0161	NA	D
Cannon River	Mississippi	MN0049514	MNDOT Straight River Rest Area	0.012	NA	D
Cannon River	Mississippi	MN0068802	Hope - Somerset Township WWTP	0.0102	NA	C
Carver Creek	Minnesota	MN0053457	Carver WWTP	0.361	After 2013 permit expiration	B
Carver Creek	Minnesota	MN0023108	Cologne WWTP	0.325	1 mg/l since 1996	B
Credit River	Minnesota	MN0066826	Credit River Township - Territory	0.0669	No surface water discharge	C
Crow River Main Stem	Mississippi	MN0040649	Buffalo WWTP	3.6	2009	B
Crow River Main Stem	Mississippi	MN0023973	Litchfield WWTP	2.37	2004	A
Crow River Main Stem	Mississippi	MN0051250	Delano WWTP	2.199	2005	A
Crow River Main Stem	Mississippi	MN0020940	Watertown WWTP	1.262	No reduction	B
Crow River Main Stem	Mississippi	MN0052752	Green Lake SSWD WWTP	0.889	After 2013 permit expiration	A
Crow River Main Stem	Mississippi	MN0020168	Paynesville WWTP	0.887	1999 and 2010	C
Crow River Main Stem	Mississippi	MN0066966	Annandale/Maple Lake/Howard Lake WWTP	0.827	2009	B
Crow River Main Stem	Mississippi	MN0024228	Montrose WWTP	0.781	2004	B
Crow River Main Stem	Mississippi	MN0049204	Cokato WWTP	0.726	After 2015 permit expiration	C
Crow River Main Stem	Mississippi	MN0024082	Maple Lake WWTP	0.461	1995; joined Annandale /	B

Stream[2,3]	Major River Basin	Permit #	Permit Holder	Design Flow (mgd)	Phosphorus Removal[4]	Class[5]
					Maple Lake / Howard Lake WWTP in 2010	
Crow River Main Stem	Mississippi	MN0051926	Howard Lake WWTP	0.369	1995; joined Annandale / Maple Lake / Howard Lake WWTP in 2010	B
Crow River Main Stem	Mississippi	MN0023574	Grove City WWTP	0.224	NA	C
Crow River Main Stem	Mississippi	MN0022659	Atwater WWTP	0.2	NA	D
Crow River Main Stem	Mississippi	MN0063762	Greenfield WWTP	0.2	NA	B
Crow River Main Stem	Mississippi	MN0054127	Dassel WWTP	0.188	NA	B
Crow River Main Stem	Mississippi	MN0051381	Belgrade WWTP	0.167	NA	D
Crow River Main Stem	Mississippi	MN0025909	Brooten WWTP	0.133	NA	D
Crow River Main Stem	Mississippi	MN0023990	Loretto WWTP	0.061	NA	C
Crow River Main Stem	Mississippi	MN0024295	New Germany WWTP	0.052	NA	D
Crow River Main Stem	Mississippi	MNG580150	Darwin WWTP	0.05	NA	D
Crow River Unmonitored	Mississippi	MN0020222	Saint Michael WWTP	2.445	2002	B
Crow River Unmonitored	Mississippi	MN0064190	Otsego East WWTP	1.65	2000	A
Crow River Unmonitored	Mississippi	MN0029629	Rogers WWTP	1.602	1996	B
Crow River Unmonitored	Mississippi	MN0024627	Rockford WWTP	0.651	2007 and 2012	B
Crow River Unmonitored	Mississippi	MN0066753	Meadows of Whisper Creek WWTP	0.02	NA	B
Minnehaha	Mississippi	MN0054399	Laketown	0.004	NA	D

Stream[2,3]	Major River Basin	Permit #	Permit Holder	Design Flow (mgd)	Phosphorus Removal[4]	Class[5]
Creek			Community WWTP			
Rum River	Mississippi	MN0020362	Cambridge WWTP	1.92	P reduction required before 2015	A
Rum River	Mississippi	MN0024147	Milaca WWTP	0.679	No reduction	D
Rum River	Mississippi	MNG550008	Isanti WWTP	0.657	2010	C
Rum River	Mississippi	MN0024538	Princeton WWTP	0.635	2012. Additional reduction in future	C
Rum River	Mississippi	MN0021407	St Francis WWTP	0.54	Limited discharge to surface water	C
Rum River	Mississippi	MN0022870	Braham WWTP	0.2851	2004 and 2010	B
Rum River	Mississippi	MNG580050	Onamia WWTP	0.21	NA	D
Rum River	Mississippi	MN0023809	Isle WWTP	0.2	NA	
Rum River	Mississippi	MN0042196[6]	Castle Towers WWTP[6]	0.12	NA	B
Rum River	Mississippi	MN0069795[7]	MCES – East Bethel Regional Water Reclamation / Reuse Center[7]	0.47	2014	B
Rum River	Mississippi	MNG580017	Foreston WWTP	0.0489	NA	D
Rum River	Mississippi	MNG580167	Pease WWTP	0.039	NA	D
Rum River	Mississippi	MN0058475	Bethel WWTP	0.0375	NA	D
Rum River	Mississippi	MN0052132	Village Green North Mobile Home Park	0.03	NA	C
Rum River	Mississippi	MN0059480	ISD 15 - Cedar Creek Community School	0.022	NA	D
Rum River	Mississippi	MN0054518	Isanti Estates LLC	0.02	NA	C
Rum River	Mississippi	MN0033723	MDNR Father	0.0086	NA	D

Stream[2,3]	Major River Basin	Permit #	Permit Holder	Design Flow (mgd)	Phosphorus Removal[4]	Class[5]
			Hennepin State Park			
Sand Creek	Mississippi	MN0020150	New Prague WWTP	2.5	2005	A
Sand Creek	Mississippi	MNG550016	Montgomery WWTP	0.968	2004	B
Sand Creek	Mississippi	MN0042251	Riverbend Mobile Home Park WWTP	0.06	NA	C
Sand Creek Unmonitored	Mississippi	MN0020869	Jordan WWTP	1.289	1999 and 2003	B
Silver Creek	Mississippi	MN0063665	Carnelian Hills Community - May Township	0.022	NA	D
Crow River South Fork	Mississippi	MN0055832	Hutchinson WWTP	5.43	2009	A
Crow River South Fork	Mississippi	MN0025259	Willmar WWTP	5.04	2010	A
Crow River South Fork	Mississippi	MN0022233	Glencoe WWTP	2.6	Future permit will include reduction	A
Crow River South Fork	Mississippi	MN0021571	Winsted WWTP	0.82	2012	C
Crow River South Fork	Mississippi	MN0025445	Hector WWTP	0.66	No P limit	B
Crow River South Fork	Mississippi	MN0021202	Mayer WWTP	0.435	2002	A
Crow River South Fork	Mississippi	MN0023957	Lester Prairie WWTP	0.364	2007	A
Crow River South Fork	Mississippi	MN0022951	Brownton WWTP	0.196	Consistently over 3 mg/l	B
Crow River South Fork	Mississippi	MN0050211	Buffalo Lake WWTP	0.165	NA	C
Crow River South Fork	Mississippi	MNG580164	Silver Lake WWTP	0.139	NA	D
Crow River South Fork	Mississippi	MNG580077	Stewart WWTP	0.114	NA	D
Crow River South Fork	Mississippi	MN0023841	Kandiyohi WWTP	0.112	NA	C
Crow River	Mississippi	MNG580056	Cosmos	0.09	NA	D

Stream[2,3]	Major River Basin	Permit #	Permit Holder	Design Flow (mgd)	Phosphorus Removal[4]	Class[5]
South Fork			WWTP			
Crow River South Fork	Mississippi	MN0021954	Lake Lillian WWTP	0.0535	NA	D
Crow River South Fork	Mississippi	MN0069388	Blomkest Svea Sewer Board WWTP	0.04	NA	D
Crow River South Fork	Mississippi	MN0066605	Cedar Mills WWTP	0.00915	NA	C
Vermillion River	Mississippi	MN0045845	MCES - Empire WWTP	29	P-removal commenced 2006; Effluent diverted to Mississippi R. 2008	A
Vermillion River	Mississippi	MN0056219	Elko New Market WWTP	0.362	Ceased operations in 2011	A
Vermillion River	Mississippi	MN0021946	Hampton WWTP	0.101	NA	D
Vermillion River	Mississippi	MN0025101	Vermillion WWTP	0.054	NA	C

[1] Data provided by MPCA (M. Graziani, personal communication, 2011).

[2] Facilities with design flow > 1 mgd shaded in gray.

[3] Stream names designated as “unmonitored” indicate WWTP discharges downstream of the monitoring station, in the unmonitored watershed area.

[4] Information provided by MPCA (S. Weiss, personal communication, 2013). Information was not tabulated for smallest facilities and thus labeled “NA.”

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

[6] Permit application indicates the City of East Bethel plans to divert the facility’s wastewater to the nearby MCES- East Bethel Water Reclamation/Reuse Facility (MN0069795) during permit cycle ending June 30, 2019. The Castle Towers Facility will be properly decommissioned and abandoned once the new lift station and force main to the MCES-East Bethel Facility is complete and wastewater from Castle Towers Facility has been successfully diverted.

[7] MCES East Bethel Regional Water Reclamation and Reuse Center started operation in 2014. The WRF (water reclamation facility) discharges to subsurface only, with no surface discharge.

Methodologies for MCES Sample Collection, Laboratory Analysis, and Data Assessment

This section briefly summarizes the methodologies used by MCES for flow measurement, sample collection, laboratory analyses, and data assessment. A full description of the methods used for sample collection, flow measurement, and laboratory analysis is included in the quality assurance program plan (QAPP) for the stream monitoring program (Metropolitan Council, 2011). This section covers only methods pertinent to topics covered in this study. The QAPP includes extensive information on all data collection, including information not included here.

Field Data Collection

Sample Collection Frequency and Methods

The MCES stream monitoring program includes collection of both baseflow grab samples and event-based composite samples. A baseflow grab sample is defined as a sample collected at one specific point in time during a period when the stream is flowing due to influences other than precipitation-based runoff – for example, groundwater or lake outflow. Grab samples are collected by dipping a jug or bottle into streamflow at a representation depth and location (typically the midpoint of stream width). An event-based composite sample is collected by automated equipment over the course of elevated flows that result from precipitation or snowmelt. Discrete portions of stream water are combined in one container, creating a sample that statistically represents the water quality occurring from that storm event.

Monthly grab samples are obtained during winter months if ice conditions allow. During the remainder of the year, baseflow grab sampling frequency may increase to twice per month. Depending on specific site conditions, additional grab samples might be obtained to help further characterize water quality. To ensure collection of a sample that accurately represents the whole-stream water quality, grab samples are generally collected from the stream thalweg (deepest points), where water is well mixed. The sample bottle is capped, stored in a cooler with ice packs, and transported to the MCES laboratory within 48 hours.

Event-based, flow-weighted composite samples are collected by the automatic samplers during all storm runoff events in the open-water (ice-free) season. About 10-15 storm events per year are collected by composite sampling, although this number can vary depending upon rainfall frequency and distribution. Samples are collected by the automatic sampler on an equal-flow increment (EFI) basis. With EFI sampling, the datalogger is programmed to trigger the autosampler to collect discrete sub-samples representing equal volumes of stream flow. For example, an autosampler may be programmed to collect a sub-sample for every 100,000 cubic feet of stream discharge. If a storm runoff event had a total of 1,000,000 cubic feet of discharge, the autosampler would collect 10 discrete sub-samples. The discrete sub-samples can be collected in separate 1,000-ml plastic containers in the automatic sampler during the runoff event, then mixed thoroughly and combined into a 5-gallon plastic container, to create a composite sample. As an alternative, a composite sample can be directly created by placing a 5-gallon glass container in the automatic sampler to receive all of the discrete flow-weighted sub-samples collected during the runoff event. The composite sample is placed in a cooler with ice and transported to the MCES laboratory, for analysis within 48 hours.

Flow

Stream flow measured by MCES is recorded at 15-minute intervals by Campbell CR10X dataloggers, based upon the 15-minute stage measurements and a stage-discharge rating curve that is programmed into the datalogger. The rating curve is developed by fitting a curve to paired in-stream measurements of stage and flow, under a variety of flow conditions. Velocity (or current) meters, such as the SonTek/YSI Meter and USGS Price Meter, are used to measure water velocity at a specific point in the stream channel. Stream flow (discharge) can be calculated by making regularly spaced velocity measurements across a stream or river transect, coupled with measurements of the cross-sectional stream channel geometry at the same transect locations. The velocity meters are factory-calibrated.

Instantaneous stream flow measurements over a wide range of flow conditions are paired with concurrent measurements of stream stage to develop and calibrate site specific rating curves.

At two monitoring stations (Eagle Creek and Valley Creek), acoustic Doppler current meters are used to directly measure stream flow at 15-minute intervals. YSI Incorporated's SonTek Argonaut®-SW is used at Eagle Creek, and YSI Incorporated's SonTek Argonaut®-SL is used at Valley Creek. Using pulsed acoustic Doppler technology, both units combine velocity and water level data with channel geometry to compute total flow in real time.

Aquatic Life Assessment with Associated Macroinvertebrates Methods

Biological monitoring is a method to assess the condition of water bodies by evaluating the health and condition of indicator species. These species usually are representative fish, macroinvertebrates, or algae that live in the assessed water body. These communities respond to anthropogenic (human-originated) stressors and integrate changes in the physical, chemical, and biological quality of their environment over time (Barbour et al. 1999; Karr and Chu, 1999). By measuring and describing the changes in the communities over time, scientists can identify disturbances and guide water policy decisions (Genet and Chirhart, 2004).

Macroinvertebrates include aquatic insects, worms, crustaceans, and bivalves. The presence or absence and relative abundance of certain macroinvertebrate species in the stream system are an important indicator of water quality. Chirhart (2003) identified many of the advantages of using these organisms to describe water quality:

- They spend most of their life cycle in relatively small areas – making them excellent indicators of site-specific ecological condition over time.
- They respond with a range of sensitivities to many kinds of stressors.
- They inhabit the sediment, water column, and submerged substrates of water bodies and reflect the biological integrity of the entire aquatic ecosystem.
- Sampling methods and analysis protocols are well developed and accepted.

An additional advantage to this approach is that macroinvertebrates are frequently sampled by watershed management organizations, volunteer groups, nonprofits, and other organizations. This allows for agency collaboration to form a large dataset.

MCES has been sampling for macroinvertebrates in streams since 2001. Macroinvertebrates were collected each fall with D-frame dipnets. All available habitats were sampled at each monitoring location until at least 300 individuals were collected. Samples were preserved in ethyl alcohol, processed to remove leaves, rocks and other debris, and then sub-sampled by MCES staff (during 2001-2008) or Rhithron Associates, Inc. (during 2009-2011). The macro-invertebrates were then identified. From 2001 to 2003, invertebrates were identified to family level by MCES staff. From 2004-2007 invertebrates were identified to genus-level and species-level, if possible, by students and staff at the University of Minnesota Entomology Department. From 2008-2011 invertebrates were identified to genus-level and species-level, if possible, by Rhithron Associates, Inc. Funding for the work by Rhithron was provided by the MPCA.

The macroinvertebrate data were analyzed through a series of statistical tests, or metrics. These metrics are well established (Barbour et al. 1996; Barbour et al. 1999; Yuan and Norton, 2003), and their results directly identify the condition of the water body. Typically, multiple individual metrics are used to understand and describe water quality. Alternatively, many well-suited metrics may be combined to develop a regional multi-metric index of biological integrity (IBI). An IBI is created using cumulative distribution functions and multiple regressions on the regional gradient of environmental conditions and the metric results (Barbour et al., 1999).

Individual Metrics

MCES selected three metrics for the initial assessment: Family Biotic Index (FBI), Percent Intolerant Taxa, and Percent POET Taxa. The FBI is a commonly used water quality assessment to evaluate the presence of pollution in the water. Each macroinvertebrate family is assigned a tolerance value that describes its ability to tolerate organic pollution (Hilsenhoff, 1988). The tolerance values range from 0-10, with low scores assigned to very sensitive families and higher scores assigned to more tolerant families. The tolerance values are used to calculate a weighted average tolerance value for the sample. This value is called the FBI and can be used to describe the water quality (Table Intro-5).

Table Intro-5: Evaluation of Water Quality Using Biotic Index Values (adapted from Hilsenhoff, 1982)

Biotic Index	Water quality	Degree of organic pollution
0.00– 3.50	Excellent	No apparent organic pollution
3.51 – 4.50	Very Good	Possible slight organic pollution
4.51 – 5.50	Good	Some organic pollution
5.51 – 6.50	Fair	Fairly significant organic pollution
6.51 – 7.50	Fairly Poor	Significant organic pollution
7.51 – 8.50	Poor	Very significant organic pollution
8.51 – 10.0	Very Poor	Severe organic pollution

The Percent Intolerant Taxa metric is another assessment used to evaluate the degree of pollution in the water. The presence of moderate numbers of intolerant taxa with tolerance values of two or less is an indicator of good aquatic health (Chirhart 2003). This metric is a percentage of individual taxa from the entire sample, not a weighted average as in the FBI.

The Percent POET Taxa is a richness metric that describes the diversity of the macroinvertebrate community. This metric measures the percent of macroinvertebrates that belong to the orders **P**lecoptera (stoneflies), **O**donata (dragonflies and damselflies), **E**phemeroptera (mayflies), and **T**richoptera (caddisflies) (Table Intro-6). A high percent POET value is indicative of good water quality.

Table Intro-6: Description of POET Characteristics (Chirhart, 2003)

Order	Characteristics
Plecoptera	• Among the most sensitive indicator organisms • Live in the interstitial spaces between rocks, woody debris, and vegetation • Require high levels of dissolved oxygen (DO) • Do not generally live in pools • If absent from riffles/runs, can indicate impairment resulting from low DO or siltation
Odonata	• Live in standing or slow moving waters • Can tolerate lower levels of DO • Somewhat tolerant to sedimentation, pollutants • Included in POET to help assess low flowing waters
Ephemeroptera	• Live in interstitial spaces between rocks, rock surfaces, sediment, and aquatic vegetation • Sensitive to low DO • Some individuals are sensitive to metals and other toxicants
Trichoptera	• More tolerant to pollution than Ephemeroptera and Plecoptera • In the presence of significant impairment they do not have a diverse community composition • Exploit a wide variety of habitat – both slow and fast moving waters

Macroinvertebrate Index of Biotic Integrity (M-IBI)

Individual metrics can be integrated in a multi-metric analysis to provide a holistic assessment of the stream. Each metric is independently important and clarifies one aspect of ecosystem health: species richness, community diversity, water quality, etc.

MCES analyzed the macroinvertebrate data using the MPCA Minnesota Statewide Macroinvertebrate Index of Biological Integrity (M-IBI). This region-specific, multi-metric analysis provides a robust evaluation of water quality and a method to allow the comparison of streams across the metropolitan area or the entire state of Minnesota (MPCA, 2014d). The statewide M-IBI separates the Minnesota's wadeable streams and rivers into nine classifications based on geographic location, land vegetation cover, water temperature, and reach type. Macroinvertebrate samples were collected from 1996 to 2011 by the MPCA in streams of varying ecological condition in each stream classification. Using these data, the MPCA defined multiple biologically meaningful metrics for each class that best corresponded to ecosystem condition. The biological integrity of a site, or M-IBI score, is determined by the summation of metric scores for each stream classification. The resultant M-IBI score is normalized to a range of 0-100. High scores correspond to low human disturbance and better water quality. Conversely, low scores correspond with more human disturbance and impaired water quality.

MPCA determines impairment status of stream using the impairment threshold value and confidence level (Table Intro-3). If the final M-IBI score exceeds the threshold value and the upper confidence level, the water quality at the site is high enough to sustain aquatic life. If the final M-IBI score is below the threshold value and the lower confidence level, the water quality does not support the aquatic community and may be declared impaired by the MPCA. If the final M-IBI score falls between the confidence levels it is difficult to confidently describe the water quality by biological assessment alone and it is necessary to incorporate other monitoring information, such as hydrology, water chemistry, or land use change in the evaluation (MPCA, 2014d). MCES used the thresholds and confidence levels as a guideline to evaluate the stream macroinvertebrate samples. MCES does not have the authority to determine the impairment status of streams.

Please see MPCA documentation (2014d) for further information regarding M-IBI methodology and development.

Some MCES macroinvertebrate samples did not meet the requirements for M-IBI analysis. M-IBI analysis requires organisms to be identified to genus- or species-level. The MCES macroinvertebrate samples collected prior to 2004 were indentified to family-level only. M-IBI analysis requires a subsample of 300 individuals. MCES macroinvertebrate samples with greater or less than 20% of the target subsample size were excluded to remove the possibility of sample bias.

MCES macroinvertebrate samples which met all M-IBI requirements were divided between Invertebrate Class 5 – Southern Streams and Invertebrate Class 9 – Southern Coldwater Streams (Table Intro-7). These samples were analyzed using their respective suite of metrics resulting in annual M-IBI scores.

Table Intro-7: MCES Streams and their MPCA 2014 M-IBI Classification and Thresholds

Classification	Threshold Value (90% Confidence Level)	MCES Streams
Class 5 – Southern Streams	37 (12.6)	Battle Creek, Bevens Creek, Bluff Creek, Carver Creek, Credit River, Fish Creek, Minnehaha Creek, Nine Mile Creek, Sand Creek, Vermillion River
Class 9 – Southern Coldwater Streams	43 (13.8)	Browns Creek, Eagle Creek, Silver Creek, Valley Creek

Note: Joel Chirhart of the MPCA calculated the M-IBI scores and provided guidance in data interpretation. Calculation and graphing of single metrics were completed in Microsoft Excel 2007, the box plots were graphed using SigmaPlot 12.5.

Laboratory Analytical Procedures

All laboratory analyses for the MCES stream monitoring program are performed by MCES Analytical (Lab) Services, located at the Metro WWTP in Saint Paul. The MCES laboratory is certified by the Minnesota Department of Health (the certifying agency for Minnesota); the MCES laboratory certification number is 027-123-172.

Analytical Methods

The analytical methods pertinent to this study are listed in Table Intro-8.

Table Intro-8: MCES Laboratory Analytical Methods for Stream Study Parameters

Laboratory Parameter	Certified Reference[1]
Chloride, Unfiltered (Cl)	SM 4500-Cl-E-97
Dissolved Oxygen (DO)	ASTM D888-92(A)
Nitrate Nitrogen, Filtered (NO_3)	SM 4500-NO3-H_00
Total Phosphorus, Filtered (TDP)	USEPA 365.4 (ATP)
Total Phosphorus, Unfiltered (TP)	USEPA 365.4 (ATP)
Total Suspended Solids (TSS)	SM 2540-D (ATP)
Volatile Suspended Solids (VSS)	SM 2540-E
[1]SM = Standard Methods for the Examination of Water and Wastewater ASTM = ASTM International; American Society for Testing and Materials USEPA = U.S. Environmental Protection Agency	

Quality Assurance/Quality Control

The data collected through the MCES stream monitoring program are vetted to meet the data quality assurance (QA) objectives outlined in the QAPP. Readers should reference the QAPP for detailed information about the MCES QA objectives.

Analytical sensitivity is the lowest concentration of a variable that can be reliably measured in a given sample. To ensure that analytical data are useful, the lowest reporting limit (LRL) for a given pollutant should be either well below the lowest expected ambient environmental concentrations or below any applicable regulatory action levels. Although the LRL can vary from sample to sample due to matrix interferences and other analytical issues, under most conditions the LRL is fixed for a given analytical method. The routine LRLs for water quality variables analyzed for this study are listed in Table Intro-9.

Table Intro-9: Lower Reporting Limits (LRLs) Reported by MCES Laboratory Services During September 2014

Laboratory Variable	LRL	Units
Chloride, Unfiltered	2.00	mg/L
Dissolved Oxygen	0.05	mg/L
Nitrate N, Unfiltered	0.05	mg/L
Nitrite N, Unfiltered	0.03	mg/L
Total Phosphorus, Unfiltered	0.05	mg/L
Total Phosphorus, Unfiltered, low level	0.01	mg/L
Total Suspended Solids	3.00	mg/L
Volatile Suspended Solids	3.00	mg/L

LRL levels have changed over time as the accuracy of instrumentation has improved. For example, LRL levels for nutrients were higher in the beginning years of the monitoring program.

Data Analysis Methods

Pollutant Load Calculations

Load calculations were completed using the computer model Flux32, a standard assessment tool developed by the United States Army Corps of Engineers (Walker, 1999). Flux32 allows the estimation of pollutant mass loads and flow-weighted mean concentrations using sample concentration data and continuous average daily stream flow records. Flux32 incorporates 8 statistical methods to identify relationships between daily average flow, season, and existing sample concentrations, and applies the selected relationship to estimate concentrations for unmonitored days, ultimately allowing estimation of annual, monthly, or daily mass loads. Loads were calculated for this study using the standard operating procedure developed by MCES (Metropolitan Council, 2012a; Metropolitan Council, 2012b). Pollutants analyzed include total phosphorus (TP), total dissolved phosphorus (TDP), nitrate (NO_3), ammonia nitrogen (NH3-N), total suspended solids (TSS), and chloride (Cl).

Load and Flow 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 5^{th}, 25^{th}, 50^{th}, 75^{th}, and 95^{th} percentiles, respectively.
- Multiply concentration and flow for each sampling event for period of record, to result in approximate daily mass loads included on the curve as points.
- Multiply water quality standard concentration and monitored flow to form a line indicating allowable load. Sample load points falling below the line meet the standard; those falling above the line exceed the standard.

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

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

Most of the draft standards proposed by MPCA have accompanying criteria that are difficult to show on the load duration curves. For example, for a water body to violate the draft TP river criteria, the water body must exceed the causative variable (TP concentration), as well as one or more response variables: sestonic (suspended) chlorophyll, biochemical oxygen demand ($BOD_{5)}$, dissolved oxygen (DO) flux, and/or pH (MPCA, 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.

Trend Analysis

Long-term changes in stream water quality can be affected by both natural processes (such as flow conditions) and human activities (such as agricultural practices and stormwater best management practices (BMPs)). Implementation of nonpoint-source pollution control measures and new technologies for wastewater treatment can reduce pollution loads and improve water quality in the receiving water bodies. However, those efforts can also be offset by increases in upland surface runoff and downstream flow due to seasonal, annual, and long-term climate changes. The shifting balance between this array of factors makes statistical identification of water quality trends challenging.

Because of the often counteracting effects of natural and human factors on water-quality conditions, it is important to consider two types of trends: non-flow-adjusted trends (the overall trends resulting from both natural and human factors) and flow-adjusted trends (the trends that would have occurred in the absence of natural stream flow variability) (Sprague et al. 2006).

While non-flow-adjusted trends describe the state of actual stream conditions, the flow-adjusted trends describe water quality trends with removed effects of flow and water volume on concentration. The flow-adjusted trends can be used to identify causative pollution control efforts and other factors.

QWTREND, which is short for Quality of Water Trend, is a statistical program developed by the USGS to analyze long-term water quality trends with adjusted flow (Vecchia, 2005). The program is a parametric time series model that accounts for seasonality, complex flow-related variability, and complex serial correlation structure to detect trends in concentration. The QWTREND model can be expressed as (MPCA, 2013b):

Log C(t) = Intercept + Time Series + Long Term + Intermediate Term + Seasonal + Trend + HFV

where

- *Log C(t)* = log-transformed concentration
- Intercept = intercept term
- Time Series = collection of autoregressive and moving-average time-series relations between stream-flow and concentration and within the concentration data
- Long Term = 5-year anomaly (5-year moving average log of stream flow)
- Intermediate Term = 1-year and seasonal (3-month) anomaly
- Seasonal = first- and second-order Fourier terms that describe seasonal variation
- Trend = user-supplied trend terms that explain long-term deviations not described by the previous terms
- HFV = high-frequency variability in the stream-flow, which is the daily stream flow after the long- and intermediate-term anomalies have been removed

At minimum, the following data are required to identify long-term water quality trends using QWTREND (Vecchia, 2000):

- 15 years of water quality records
- Average of at least 4 samples per year
- At least 10 samples within each quarter of the year
- Less than 10 percent of values below detection limit
- Complete daily flow record for the water quality measurement periods plus the precedent 5 years (if the 5-year anomaly option is used).

QWTREND was coded with R, free software for statistical and graphical analysis. QWTREND and R were used in this study to identify and assess water quality trends in the streams. The existence of trends was determined based on two statistical parameters: the Akaike Information Criteria (AIC) and the p-value. The parameters were calculated using the following equations:

$$AIC = (-2\ln L) + (2 * \text{Number of Parameters})$$

$$p = 1 - \text{pchisq}((-2\ln L)_{initial} - (-2\ln L)_{linear}, \text{number of trends}).$$

The AIC provides a relative measure of the goodness of fit of a statistical model, while the p-value is used to assess statistical significance of the identified trends against the critical p-value. Depending on study goals, scopes and characteristics of the streams and rivers, the critical p-value may range from 0.01 for a more conservative assessment to 0.1 (MPCA, 2013b). In this study, the critical p-value for a single trend was set at 0.05 compared to the one-trend model. For a two-trend model, the critical p-value was set at one-half of the single model and for a three-trend model, the value is set at one-third, and so on.

Potential Factors Influencing Water Quality Improvement and Decline

The trend analysis indicates the water quality in the majority of streams monitored by MCES has improved during the past five years. However, the analysis does not identify which actions, projects, structures, or practices have caused the improvements or declines. 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 or 10 years. In the meantime, MCES will continue to investigate the NO_3, TSS, and TP dynamics in streams entering the metropolitan area with local partners and state agency staff. A potential solution could be a comprehensive water quality simulation model, however, it is costly and without it MCES staff can only surmise what actions have resulted in the improvements or declines. It is likely that water quality improvements have occurred due to multiple projects and actions, implemented over time. Similarly, declines have likely occurred from multiple effects, ranging from increased impervious area to changes in agricultural land area.

Some examples of historical actions and projects that may have affected metropolitan area stream water quality include:

- Passage of the federal Clean Water Act in 1972. The federal Clean Water Act formed the foundation for the U.S. Environmental Protection Agency's implementation of pollution control programs such as establishing standards for industrial wastewater discharges to streams and rivers and establishing water quality standards for contaminants in lakes, streams, and rivers. The Clean Water Act has led the Minnesota Pollution Control Agency's to establish:
    - i. Minnesota-based water quality standards.
    - ii. TMDL (Total Maximum Daily Load) studies to determine sources of pollutants and appropriate practices to control pollutant discharges.
    - iii. National Pollutant Discharge Elimination System (NPDES) permit programs for industrial discharges and construction sites.
    - iv. General permit programs for MS4s (Municipal Separate Storm Sewer System), which are conveyance systems owned or operated by public entities (like cities, townships, counties, highway departments, etc.) and are designed for collecting and conveying stormwater.
- Changes in metropolitan area population, developed area, and impervious surface over time. For example, the federal decennial census data for the seven-county metropolitan area is as follows:

    1990: 2,288,721

    2000: 2,642,056 (+15% increase)

    2010: 2,849,567 (+8% increase)
- Implementation of state-wide reductions in wastewater treatment plant (WWTP) solids, ammonia, and phosphorus discharges. Most recently, the MPCA has negotiated either chemical or biological phosphorus removal from WWTP discharge through the NPDES permit system. While some WWTPs completed phosphorus reduction in the 1990s (or earlier), most WWTPs initiated phosphorus removal after 2000. Many of the small municipal WWTPs discharging to the streams covered in this study started phosphorus removal in the mid-2000s (see individual stream sections of the complete report for details).
- Passage of the Minnesota Phosphorus Lawn Fertilizer Law: Implemented in 2002, the law restricts the use of phosphorus fertilizers on lawns and turf within the seven county metropolitan area.
- Construction of numerous structural best management practices for nonpoint source and stormwater control by cities, counties, state agencies, water management organizations, soil and water conservation districts, private industries, and homeowners. Examples of

practices include ponds, bioinfiltration basins, rain gardens, vegetated swales, pervious pavers, permeable pavement, green roofs, iron-enhanced filters, stormwater reuse systems, and alum treatment facilities.

- Establishment of educational programs, for example:
  i. Northland NEMO (Nonpoint Education for Municipal Officials, established 1994) is a collaborative of organizations and partners in Minnesota and Wisconsin established in 1994, led by the University of Minnesota Extension and Minnesota Sea Grant Program, offers educational programming and resources to help local community officials make informed decisions about land use planning, development of protective water resources ordinances, and selection and installation of appropriate water quality practices.
  ii. Metro Watershed Partners (established in 1995 with a seed grant from the Metropolitan Council's Twin City Water Quality Initiative (TCQI) grant program), is a group of over 60 organizations, including the Metropolitan Council, state agencies, the Science Museum of Minnesota, Hamline University, and non-profits. Through collaborative education and outreach, the partners promote public understanding to inspire people to act to protect water quality in their watershed.
  iii. The East Metro Water Resource Education Program (EMWREP, formed 2006) is partnership to provide shared educational resources and staff to 18 units of government in the east metropolitan area. The shared education program provides information and training on the impacts of nonpoint source pollution on lakes, streams, rivers, and groundwater resources to enable communities to engage their citizens to protect and improve water quality.
- Establishment of grants to fund construction of water quality practices, for example:
  i. Section 319 (of the Clean Water Act) grants were established in 1987 and are administered annually through the MPCA to fund technical assistance, education, training, demonstration projects and monitoring. Approximately $3 million per year is available in Minnesota, with 43% required to be spent on TMDL implementation projects.
  ii. The Minnesota Environmental and Natural Resources Trust Fund (Trust Fund) was established in 1988 by Minnesota voters. Forty percent of the net proceeds of the Minnesota State Lottery are deposited to the Trust Fund each year, with the monies providing long-term, consistent, and stable funding for activities that protect and enhance Minnesota's environment and natural resources. Funding recommendations are made each year by the Legislative-Citizen Commission on Minnesota Resources (LCCMR) to the Minnesota Legislature. Since 1991, the Trust Fund has provided more than $360 million to more than 800 projects around the state.
  iii. Minnesota Clean Water, Land & Legacy Amendment was approved by voters in 2008 with the goal to protect drinking water sources; to protect enhance, and restore wetlands, prairies, forest, and fish, game, and wildlife habitat; preserve arts and cultural heritage; support parks and trails; and to protect, enhance, and restore lakes, rivers, streams, and groundwater.

iv. Thirty-three percent of the Legacy Amendment funds are allocated to the Clean Water Fund; these funds can only be spent to protect, enhance, and restore water quality in lakes, rivers, streams, and groundwater. For fiscal years (FY) 2014-2015, $194.9 million will be distributed by various state agencies through the Clean Water Fund.

v. Multiple water quality benefits are provided by the Outdoor Heritage Fund, which receives 33% of the Legacy Amendment funds to restore, protect, and enhance wetlands, prairies, forest, and habitat for fish, game, and wildlife. The Outdoor Heritage Funds recommendations are made by the Lessard-Sams Outdoor Heritage Council to the Minnesota Legislature. Annual budget for the Outdoor Heritage Fund is approximately $80 million.

vi. The Metropolitan Council has implemented two grant programs in the metropolitan area to fund water quality research, education, and implementation projects. The Twin Cities Water Quality Initiative (TCQI) grant program was instituted in 1994 and provided over $8 million. The Metro Environment Partnership (MEP) grant program was instituted in 1999 and provided over $7 million.

- Establishment, advocacy, and action of environmental nonprofits, including Friends of the Mississippi River, Minnesota Center for Environmental Advocacy, Great River Greening, Minnesota Erosion Control Association, Minnesota Environmental Initiative, Minnesota Green Roofs Council, and others.
- Changes in agricultural practices and programs over time have likely caused water quality improvements and water quality declines.

  Increased production of specific crops due to commodity prices and demand (for example, increased corn production for ethanol) may result in returning areas set aside for water quality protection (like vegetated stream and edge-of-field buffers) back to active crop production. Similarly, increased demand may result in increased artificial drainage (through draintiles or ditches), resulting in faster and greater flow to surface waters.

  On the other hand, educational programs have resulted in greater awareness of the potential impacts of poor farming practices on water quality. Feedlot programs administered by the MPCA and counties and farmer's manure management plans have resulted in improved manure management and water quality protection. Other factors for improving water quality due to agricultural management include general increases in funding and targeting of funds through programs like CREP (Conservation Reserve Enhancement Program); the increased role of nonprofits like The Nature Conservancy and Land Stewardship Project; funding of RIM (Reinvest in Minnesota) to create vegetative buffers along ditches and shorelands, and inspection and management of rural individual onsite septic systems.
- Enactment of the Metropolitan Surface Water Management Act in 1982. When first enacted, there were 46 watershed organizations (36 joint-powers watershed management organizations (WMOs) and 10 watershed districts (WDs)) in the metropolitan area. There are currently 33 watershed management organizations (due to

consolidation of some districts) made up of Watershed Districts, WMOs, and county joint-powers organizations. Each is required to prepare and implement local watershed management plans in order to protect surface water resources in the seven-county metropolitan area. The purposes of the watershed management programs required under the Metropolitan Surface Water Management Act are to:

i. Protect, preserve, and use natural surface and groundwater storage and retention systems;
ii. Minimize public capital expenditures needed to correct flooding and water quality problems;
iii. Identify and plan for means to effectively protect and improve surface and groundwater quality;
iv. Establish more uniform local policies and official controls for surface and groundwater management;
v. Prevent erosion of soil into surface water systems;
vi. Promote groundwater recharge;
vii. Protect and enhance fish and wildlife habitat and water recreational facilities; and
viii. Secure the other benefits associated with the proper management of surface and groundwater.

- Development of the Minnesota State Stormwater Manual by the Minnesota Stormwater Steering Committee in 2005 (and greatly expanded in 2013 by the MPCA and partners) and the Minnesota Urban Small Sites Best Management Practices Manual by the Metropolitan Council in 2001. Both manuals have provided guidance on land management and design, construction, and maintenance of structural practices like raingardens, green roofs, infiltration basins, and vegetated swales.
- Academic research conducted at the University of Minnesota and others.

Acknowledgements

This report represents over 25 years of effort by Metropolitan Council staff, local cooperators, state and federal agency staff, and others. While many individuals have provided input to this effort at various times, the following represent the most recent contributors to this stream assessment.

MCES Environmental Monitoring:

Kent Johnson, manager
Mike Ahlf, Cassie Champion, Scott Haire, Leigh Harrod, Tim Pattock
Mike Meyer (retired)

MCES Analytical (Lab) Services:

Dave Fuchs, manager
John Hubbling (retired)
Plus numerous lab staff

MCES Water Resources Assessment:

Judy Sventek, manager
Karen Jensen, Jen Kostrzewski, Joe Mulcahy, Terrie O'Dea, Emily Resseger, Hong Wang
Gary Oberts (retired)
Jim Larsen (currently of Metropolitan Council Community Development)

Other Metropolitan Council Staff:

Michelle Fure, Donna Harden, Leigh Homstad, Shawn Jacobson, Jeanne Landkamer, Cara Lee, Ed Lube, Lucinda Plaisance, Tomi Schuldt, Craig Skone, Jeff Syme, Linda White

Cooperators and Partners (Past and Present):

Anoka CD, Bassett Creek WMO, Barr Engineering Company, Browns Creek WD, Carnelian-Marine St. Croix WD, Carver County Environmental Services, City of Eden Prairie, Dakota County SWCD, Lower Minnesota River WD, Minneapolis Park and Recreation Board, Ramsey-Washington Metro WD, Riley Purgatory Bluff Creek WD, Science Museum of Minnesota – St. Croix Research Station, Scott SWCD, Valley Branch WD, Washington Conservation District, Wright SWCD

Others:

Minnesota Pollution Control Agency (MPCA): Wayne Anderson, Joel Chirhart, Dave Christopherson, Marco Graziani, Mark Tomasek, Dave Wall, Steve Weiss, Chris Zadak

Minnesota Department of Natural Resources: Dave Wright

U.S. Geological Survey (USGS): Dave Lorenz, Aldo (Skip) Vecchia

Science Museum of Minnesota – St. Croix Research Station: Jim Almendinger

Bassett Creek WMC: Laura Jester, Karen Chandler (Barr Engineering), Greg Wilson (Barr Engineering)

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METROPOLITAN COUNCIL

390 Robert Street North
St Paul, MN 55101-1805

651.602.1000
TTY 651.291.0904
public.info@metc.state.mn.us
metrocouncil.org