Lower Minnesota River Model:

Monitoring Program

Sponsored by the

Metropolitan Council
Lower Minnesota River Watershed District
Metropolitan Airports Commission
Minnesota Pollution Control Agency
U.S. Army Corps of Engineers
U.S. Geological Survey

Catherine E. Larson
Metropolitan Council Environmental Services
230 East Fifth Street
St. Paul, MN 55101-1626

651/602-1275
cathy.larson@metc.state.mn.us

Last Revised: January 12, 2006

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

1 OVERVIEW

This report describes the monitoring program conducted in support of the Lower Minnesota River Model. The goal of the modeling project is to build an assessment and management tool for water quality in the lower 40 miles of the Minnesota River. This reach is located within the Twin Cities Metropolitan Area (Metro Area) and extends from Jordan, Minnesota, to the river's confluence with the Mississippi River in St. Paul, Minnesota. Metropolitan Council Environmental Services (MCES) is coordinating the project with support from federal, state, and local partners.

The top priority is to develop a tool for setting effluent limitations for expanded wastewater treatment facilities and other point sources. Second is determining pollutant loads from the headwaters and tributaries and load reductions needed to meet water-quality standards. All or portions of the lower Minnesota River are listed as impaired due to low oxygen, turbidity, bacteria, mercury, and PCBs on Minnesota's list of impaired waters. The reach also contains excessive levels of sediment, nutrients, and algae. Modeling and monitoring will focus on the following water-quality measures, in order of priority: dissolved oxygen, ammonia, nutrients, and sediment. See the project proposal (MCES, 2004a) for more information on the modeling effort.

The model proposed for application to the lower Minnesota River is CE-QUAL-W2, a two-dimensional, laterally averaged, hydrodynamic and water-quality model supported by the U.S. Army Corps of Engineers (Cole and Wells, 2002). A variety of information is needed to develop and test the model, including river geometry, hydrology, and meteorology plus flow and water-quality data for the river, tributaries, and point sources. To adequately capture the dynamic nature of the Minnesota River, the model will be time variable and span multiple years. To support this structure, the monitoring program will be conducted over a period of three years: October 1, 2003 through September 30, 2006 (water years 2004-2006). Hopefully, this period will include a range of flows that provide information on variable loads and other temporal differences.

The monitoring program for the Lower Minnesota River Model was designed using the following sources:

- Sampling guidelines in the user manual for CE-QUAL-W2, V3.1 (Cole and Wells, 2002)
- Recommendations from Thomas W. Cole, one of the model's principal authors
- MCES experience with monitoring and modeling the Minnesota and Mississippi Rivers
- Advice from technical partners, including the Minnesota Pollution Control Agency (MPCA), U.S. Army Corps of Engineers (USACE), and U.S. Geological Survey (USGS)

MCES and partners will review the program as the modeling project progresses, and the monitoring plan will be periodically updated.

The monitoring program designed to support the model consists of three basic elements:

1. Base Monitoring Program. Routine monitoring conducted year-round over three years to meet model-recommended data requirements.
2. Summer Low-Flow Monitoring Program. More intensive monitoring to capture oxygen, algal, and nutrient dynamics under critical low-flow conditions in the summer.
3. Special Monitoring and Field Studies. Targeted work to address particular data needs or study specific issues in depth.

Subsequent sections of this report describe the three elements.

Throughout this report, locations along the Minnesota River will be given in river miles upstream of the mouth. For example, the USGS gaging station near Jordan is located at mile 39.4 or MI 39.4. Table 1 lists the major features along the river's lower 40 miles. Figures A.1 and A.2 in the appendix contain maps of the study area. Figure A.1 shows the secondary watersheds that drain to the lower Minnesota River along with the major highways, cities, and townships. Figure A.2 shows the locations of the four major point sources and 16 river and stream monitoring stations operated by or in cooperation with MCES. A more detailed project map is available on request. Navigation charts for the reach from mile 27 to the mouth can be found at the following Web site:

http://www.mvr.usace.army.mil/navcharts/umrnavcharts.asp

Table 1. Locations of major features on the lower Minnesota River

Feature	Location[1]
Bevens Creek	44.2 L
USGS Gaging Station	39.4
MCES Monitoring Station	39.4
Sand Creek	35.5 R
Carver Creek	34.1 L
Carver Rapids	33.5
Chaska Creek	31.6 L
East Chaska Creek, Two Outlets	30.3 & 30.0 L
MCES Monitoring Station	25.1
Bluff Creek	22.5 L
Riley Creek	22.3 L
Blue Lake Wastewater Treatment Plant	20.5 R
Purgatory Creek	19.6 L
Eagle Creek	15.8 R
Nine-Foot Navigation Channel, Upstream End	14.7
Credit River	13.7 R
MCES Monitoring Station	14.3
Nine Mile Creek	12.5 L
Willow Creek	11.0 R
Black Dog Generating Plant, Lyndale Outfall	10.7 R
Black Dog Generating Plant, Intake	8.8 R
MCES Monitoring Station	8.5
Black Dog Generating Plant, Cedar Outfall	7.6 R
Seneca Wastewater Treatment Plant	6.7 R
International Airport, Stormwater Outfall	4.1 L
International Airport, Main Stormwater Outfall	3.8 L
USGS Gaging Station	3.5
MCES Monitoring Station	3.5
International Airport, Stormwater Outfall	3.0 L

[1] Locations are given as approximate miles upstream of the mouth and left or right descending bank. Miles were interpreted from the USACE navigation charts and a canoeing and boating guide for the Minnesota River published by the Minnesota Department of Natural Resources.

2 BASE MONITORING PROGRAM

This section describes the monitoring program that will be routinely implemented year-round during the three-year study period (10/01/03-9/30/06). Section 3 describes a more intensive monitoring program that will replace the base program during the summer when river flows are less than 1,000 cfs for an extended period.

The base monitoring program includes five long-term river monitoring stations, seven point-source discharges, and 12 tributaries (Table 1). Table 2 lists the variables needed to support the model. Variables will be monitored at select stations according to Tables A.1 and A.2 in the Appendix. Flow and temperature will be monitored continuously or daily at the model boundaries:

- Upstream end of the model (Jordan, MI 39.5)
- Downstream end of the model (mouth represented by Fort Snelling, MI 3.5)
- Tributaries (12)
- Discharges (7)

Dissolved oxygen (DO) will be monitored continuously in the Minnesota River at Jordan (except in winter) and Fort Snelling and in the effluents of the Blue Lake and Seneca Wastewater Treatment Plants (WWTPs). Other variables will be measured weekly (key variables at key sites) or twice per month at a minimum. Instantaneous grab samples are collected at stations on the river and tributaries. In addition, event-based composite samples are collected at Jordan (MI 39.4) and the tributaries. At the WWTPs, 24-hour flow-weighted composite samples are collected from the effluent. MCES will collect the river, WWTP, and most tributary samples and perform all analytical tests. Local cooperators collect some of the tributary samples.

The following sections describe the four main elements of the base monitoring program:

- River Monitoring (Section 2.1)
- Tributary Monitoring (Section 2.2)
- Point-Source Monitoring (Section 2.3)
- BOD Monitoring (Section 2.4)

See Tables A.1 and A.2 in the appendix for monitoring recommendations for the CE-QUAL-W2 model and an outline of the base monitoring program for the Lower Minnesota River Model. Table A.1 outlines the program at the boundaries. Table A.2 outlines the program for intermediate river stations located between Jordan and Fort Snelling: Shakopee (MI 25.1), Savage (MI 14.3), and Black Dog (MI 8.5).

Table 2. Variables needed to support the model

Flow (MI 39.4, MI 3.5, tributaries, and dischargers)
Temperature
Conductivity
Dissolved Oxygen (DO)
pH
Total Dissolved Solids
Total Organic Carbon
Dissolved Organic Carbon
Biochemical Oxygen Demand (BOD5), 5-Day, Unfiltered
Carbonaceous Biochemical Oxygen Demand (CBOD5), 5-Day, Unfiltered
Biochemical Oxygen Demand (BOD5), 5-Day, Filtered (Only with 70-day tests)
Carbonaceous Biochemical Oxygen Demand (CBOD5), 5-Day, Filtered (Only with 70-day tests)
Biochemical Oxygen Demand (BOD), 70-Day, Unfiltered (Only at select sites)
Carbonaceous Biochemical Oxygen Demand (CBOD), 70-Day, Unfiltered (Only at select sites)
Biochemical Oxygen Demand (BOD), 70-Day, Filtered(Only at select sites)
Carbonaceous Biochemical Oxygen Demand (CBOD), 70-Day, Filtered (Only at select sites)
Total Phosphorus
Total Dissolved Phosphorus
Total Particulate Phosphorus (only at MI 39.4, MI 8.5, and MI 3.5; not requested for modeling)
Total Reactive Phosphorus
Soluble Reactive Phosphorus
Nitrite Nitrogen
Nitrate Nitrogen
Ammonium Nitrogen (total, not filtered)
Total Kjeldahl Nitrogen
Dissolved Kjeldahl Nitrogen
Total Suspended Solids
Volatile Suspended Solids
Pheophytin-Corrected Chlorophyll-a (all sites unless shown to be negligible)
Phytoplankton (only at MI 39.4 and MI 3.5; identification, counts, and biovolumes to genus)
Dissolved Silica
Light Readings, Sensor (river sites and boat runs only; as many sites as possible)
Ice and Snow Conditions

Note: Sulfide, dissolved iron, and dissolved manganese were dropped from the original program.

2.1 RIVER MONITORING, BASE PROGRAM

The Metropolitan Council (Council) and agencies that preceded it have monitored the water quality of large rivers in the Metro Area since 1927, when the Mississippi River was declared a public health hazard due to untreated wastewater discharges. Within the Metro Area, the Mississippi River merges with two major tributaries: the Minnesota and St. Croix Rivers. The river monitoring program evolved into its current network of more than 20 stations, including five on the lower Minnesota River.

Along with investigating problems and measuring progress toward resolving them, information from the monitoring program has been used to track trends and assess whether the rivers meet state and regional water-quality standards and goals. The monitoring network was designed to document the quality of water as it enters and leaves the metropolitan area and to gauge the effects of WWTP discharges and tributaries. The data allow us to develop models, such as the Lower Minnesota River Model, to simulate water quality in the rivers and predict responses to changes in loading rates from point and nonpoint sources.

The current river monitoring program has been in place, with few modifications, since the 1970s. The program includes continuous monitoring, grab sampling for conventional parameters, grab sampling for toxic contaminants, biological monitoring, and sediment-bed monitoring. A description of the river monitoring program is posted at the Web site

http://www.metrocouncil.org/environment/RiversLakes/Rivers/

The following sections describe the program as it applies to the Lower Minnesota River Model.

2.1.1 River Monitoring Network

Table 3 lists the five long-term monitoring stations maintained by MCES on the lower Minnesota River. The USGS has operated a stream-flow gaging station (0533000) at river mile 39.4 since 1935. To monitor flows and loads near the mouth for the modeling project and other work, the USGS installed a gaging station (05330920) at river mile 3.5 in January 2004 (see Section 4.1.3). The MPCA, Metropolitan Airports Commission, and Xcel Energy also conduct limited water-quality monitoring at select locations in the lower Minnesota River.

Table 3. MCES and USGS monitoring stations on the lower Minnesota River

General Area	Specific Location	River Mile	Programs
Jordan	Bridge at CR 45/CR 9; Mid-channel most times, Left bank in winter	39.4	Flow, Continuous (new), Grab (major site), Event, Biological, and Sediment
Shakopee	Foot bridge at old Hwy 101; Mid-channel most times, Right bank in winter	25.1	Grab (minor site)
Savage	Left bank from railroad swing bridge	14.3	Grab (minor site)
Black Dog	Right bank from land, just downstream of plant intake	8.5	Grab (major site)
Fort Snelling	Left bank, end of pier	3.5	Flow (new), Continuous, Grab (major site), Biological, and Sediment

2.1.2 River Monitoring Program

This section describes elements of the MCES river monitoring program that were in place before the modeling project began. The next section describes modifications to the program to support the Lower Minnesota River Model.

Continuous Monitoring. MCES operates a continuous monitor at river mile 3.5 in Fort Snelling State Park. Water is pumped from one meter below the surface at the end of a pier on the left bank to a shelter where equipment is housed. The monitor continuously measures five parameters: dissolved oxygen, temperature, pH, specific conductance, and turbidity. Every 15 minutes, the measurements are aggregated to mean values, transmitted, and stored on a computer. The equipment is maintained and calibrated typically twice per week and more often as needed.

Grab Sampling. MCES collects water samples from one meter below the surface at five locations on the lower Minnesota River: three major sites and two minor sites (Table 3). Samples are collected from bridges, piers, or shore. A number of variables are monitored at the three major sites located at Jordan (MI 39.4), Black Dog (MI 8.5), and Fort Snelling (MI 3.5), including most of the variables needed to develop the model (Table 2). A limited set of variables is monitored at the two minor sites at Shakopee (MI 25.1) and Savage (MI 14.3): temperature, DO, pH, ammonium nitrogen, and turbidity. CBOD5 tests are also run on water samples from MI 25.1.

The five sites are monitored weekly during the open-water season (roughly March through October) and semi-monthly during the winter (roughly November through February). Different groups of variables are measured at different frequencies; for example, DO, pH, temperature, ammonium, and turbidity are measured weekly, but most nutrients, solids, BOD, and chlorophyll are measured every other week. Temperature is always measured in the field; DO and pH are measured in the field when temperatures are above 10°C.

Event Sampling. MCES collects flow-weighted composite samples during runoff events at Jordan (MI 39.4). Event sampling was implemented at this site to compare river and tributary loads. See the stream monitoring program (Section 2.2.2) for more information on event sampling.

Water Chemistry. Analytical tests of water samples are conducted by MCES Laboratory Services. The laboratory is certified under the State of Minnesota laboratory certification program, which is overseen by the Minnesota Department of Health.

Biological Monitoring. Biological monitoring is conducted once every summer at Jordan (MI 39.4) and Fort Snelling (MI 3.5). Four groups of organisms are monitored with different sampling equipment: phytoplankton with a Van Dorn sampler, periphyton with a periphytometer, macroinvertebrates with artificial substrates or a Ponar dredge, and zooplankton with a plankton net or sampler. Taxonomic identification, organism counts, and diversity-index calculations are performed on these four biological groups. Organisms are identified to the genus level. Current velocity, incubation dates, light attenuation, and water depth are also recorded.

Sediment-Bed Monitoring. MCES periodically monitors the sediment bed at Jordan (MI 39.4) and Fort Snelling (MI 3.5). Left, right, and mid-channel samples are collected at each site. Samples were last collected at Jordan in September 2000 and Fort Snelling in November 1999. A combination of toxicity testing, biological monitoring, and chemical monitoring is conducted to assess potential toxicity to sediment-dwelling organisms. Of interest to the modeling project, total organic carbon and particle sizes are measured in sediment samples, and alkalinity, hardness, ammonium, and metals are measured in the interstitial pore water.

2.1.3 Modifications to Support the Model

This section contains a list of modifications to the MCES river monitoring program to collect information to develop and test the Lower Minnesota River Model.

Stations. Frequent monitoring near the upstream and downstream boundaries of the model is needed to compile inputs to the model. The MCES long-term monitoring stations near Jordan (MI 39.4) and Fort Snelling (MI 3.5) will meet this requirement. Less frequent data are needed at intermediate locations to test the model by comparing measured concentrations against model-estimated concentrations. The three MCES stations near Shakopee (MI 25.1), Savage (14.3), and Black Dog (MI 8.5) should be adequate for testing the model at normal to high flows. Additional stations are recommended during the summer at low river flows (Section 3.1).

Flow. Continuous flow data are needed for both upstream and downstream boundaries of the model. Jordan (MI 39.4) was selected as the upstream boundary because of the excellent long-term monitoring programs already in place, including a stream-flow gaging station operated by the USGS. In January 2004, the USGS installed a stream-flow gaging station at Fort Snelling (MI 3.5) near the mouth of the Minnesota River (Section 4.1.3). Stage, velocity, depth, current direction, water temperature, and precipitation are monitored at the Fort Snelling station.

Continuous water quality. Daily or continuous monitoring at the upstream and downstream boundaries is also recommended for the following variables: temperature, conductivity, DO, and pH. Since the early 1970s, MCES has operated a continuous monitor at Fort Snelling (MI 3.5) at which these four variables are measured. Turbidity was added in 1991. A USGS study of mixing characteristics (Section 4.1.4) revealed some vertical differences in DO concentrations at this location, especially during low flows in summer. Under summer low flows, MCES hopes to install one or two probes at deeper locations near the Fort Snelling station to collect continuous temperature readings as indicators of vertical differences. Maintaining a DO probe at a deep location would be too difficult.

In spring 2004, continuous monitoring equipment was installed at the MCES station at Jordan (MI 39.4), and the equipment began recording the four variables at the end of May. Initially, the monitor was set to hourly intervals, but this was switched to 15-minute intervals to match the Fort Snelling monitor. During the first year, only 64 days of data were recorded due to a problem in how the station was reconfigured after bridge construction. This problem was resolved during the winter of 2004-05, and the monitor began operating again on April 4, 2005. River water is pumped to the station; so winter monitoring is not feasible with this setup. In 2005 a probe was installed below the water surface to obtain continuous temperature data during the winter.

In addition to monitoring cooling-lake discharges from Black Dog Lake, Xcel Energy continuously monitors temperature upstream of the discharges near mile 11.5 (Section 2.3.2). As part of a supplemental environmental study, Xcel Energy will also collect some DO and pH measurements at this location. The Metropolitan Airports Commission is required to monitor the river at low flows (Section 2.3.3).

Total dissolved solids (TDS). At the boundaries, either frequent TDS monitoring or a proven relationship between TDS and conductivity is needed. Historically, TDS has been monitored semi-monthly at both Jordan (MI 39.4) and Fort Snelling (MI 3.5), and conductivity has been monitored monthly at Jordan and continuously at Fort Snelling. Sufficient data should exist to develop a relationship between TDS and conductivity, so frequent TDS monitoring is not needed.

Field measurements. It is recommended that measurements of temperature, DO, pH, and conductivity be made in the field whenever possible. These variables will be monitored continuously at Jordan (MI 39.4) and Fort Snelling (MI 3.5). At all five long-term stations, temperature, DO, and pH are measured whenever grab samples are collected (i.e., weekly in summer, every other week in winter). Conductivity will be measured at least semi-monthly at all five sites. DO and pH are measured in the laboratory when river temperatures are below 10°C.

Grab samples. The river monitoring program for the lower Minnesota River was modified to measure all model-recommended variables at least twice per month at the five long-term stations. At the boundaries, Jordan and Fort Snelling, variables listed as minimum requirements in the CE-QUAL-W2 users manual (Cole and Wells, 2002) will be monitored weekly. See Tables A.1 and A.2 in the appendix for a list of the variables and sampling frequencies at each site.

Sampling protocol. Grab samples are collected at a single point, one meter below the surface at the five locations listed in Table 3. A study of mixing characteristics by the USGS (Section 4.1.4) recommended a change in sampling protocol to capture vertical and lateral differences under certain flows. Suggested protocols include equal width increment, equal discharge, and depth integrated. MCES plans to proceed as follows:

- At flows less than 1,500 cfs, collect vertical profiles of field measurements (temperature, DO, pH, conductivity, and turbidity) at mid-channel at all stations if vertical differences are indicated.
- At flows less than 1,500 cfs, collect vertical profiles of field measurements at the quarter points at all stations if lateral differences are indicated.
- Collect some near-bottom water samples to compare water chemistry to samples from one meter below the surface.
- Collect some depth-integrated samples of chlorophyll *a* to compare results with discrete samples.
- Hold off on adopting other sampling protocols until more information on vertical and lateral differences is collected.

Boat runs. In order to collect light measurements and vertical profiles when algal activity is high and DO may vary from top to bottom, field measurements and grab samples will be collected from a boat at the five long-term stations during the summer at low river flows. Due to high flows and staff shortages, no boat runs were conducted in 2004. Several boat runs were made in 2005, mainly in July and August.

Event samples. Event-based composite samples are collected at Jordan (MI 39.4), and all modeling variables in Table 2 are recommended for analysis. Measurements of BOD5, CBOD5, and soluble reactive phosphorus are subject to conditions but will be analyzed as often as possible. Problems collecting event samples occurred in 2004 after the station was reconfigured for a new bridge. This problem was resolved in October 2005 with the first reliable composite sample collected on 8/19/05. While the station was down, additional grab samples were collected during events. Event monitoring is not needed at the downstream boundary; however, a solid relationship between turbidity (continuously monitored) and total suspended solids (grab sampled) will be needed for modeling suspended-solids transport.

Ultimate BOD. Ultimate BOD and CBOD will be monitored four times per year (seasonally) at the five stations. The tests are typically run for 70 days. It is important for BOD5 and CBOD5 tests to be run on the same sample so ultimate-to-5-day ratios can be developed for the model.

Phytoplankton. During April through September, phytoplankton samples will be collected every other week at Jordan (MI 39.4) and Fort Snelling (MI 3.5). During October through March, monthly samples will be collected for a total of 18 samples per year at each site. A qualified contractor was hired to conduct identifications, enumeration, and biovolumes to the species level. In 2004, phytoplankton samples were only collected at Fort Snelling. Organic carbon (unfiltered and filtered) and chlorophyll *a* were also requested so carbon-to-chlorophyll ratios could be used as a backup for estimating biomass. Unfortunately, tests for total organic carbon were run on decanted samples until 2006, so particulate organic carbon cannot be estimated.

Periphyton. Depending on substrate and light conditions, periphyton may be important at times in the lower Minnesota River, but phytoplankton are considered the dominant form. Currently, there are no plans to increase periphyton monitoring beyond the annual samples collected by MCES at Jordan (MI 39.4) and Fort Snelling (MI 3.5).

Snow and ice cover. The CE-QUAL-W2 model has the ability to simulate ice formation and breakup. Ice cover is an important factor in the exchange of oxygen between the atmosphere and river. Field observations would be helpful to test the model simulation. Ice and snow conditions in the immediate vicinity of the five stations are noted on field sheets when grab samples are collected every other week in the winter. Use of satellite images to estimate ice cover has also been discussed. From December 2003 to February 2004 (roughly), the entire 40-mile reach was likely frozen with the exceptions of small patches near the Black Dog outfalls (MI 10.7 and MI 7.6). In contrast, the current winter ('05-'06) has been mild with a mostly open river.

2.2 TRIBUTARY MONITORING, BASE PROGRAM

MCES coordinates an extensive stream monitoring program to assess water quality and quantify pollutant loads from minor watersheds in the Metro Area. The program currently includes nine tributaries to the lower Minnesota River. Carver County Environmental Services and the Riley-Purgatory-Bluff Creek Watershed District have adopted the program in large part and applied it to other streams in the study area. A total of 12 tributaries that discharge directly to the lower Minnesota River will be monitored during the study years 2004-2006 (Table 4). The quality assurance program plan for stream monitoring (MCES, 2003) describes the program in detail. The following sections describe the program as it applies to the Lower Minnesota River Model.

Table 4. Descriptions of monitored tributaries

Tributary	Monitoring Location (stream mi)	Confluence Location[1] (river mi)	Shed Area (mi^2)	Dominant Land Use	Monitoring Program (agency, year started)
Bevens Creek	2.0 & 5.0	44.2 L	131[2]	Rural	MCES, 1989
Sand Creek	8.2	35.5 R	255[2]	Rural	MCES, 1989
Carver Creek	1.7	34.1 L	84[2]	Rural	MCES, 1989
Chaska Creek	1.0	31.6 L	16[4]	Mixed	Carver County, 1998
E. Chaska Creek[5]	~0.25 & 2	30.3, 30.0 L	12[4]	Mixed	Carver County, 2003
Bluff Creek	3.5	22.5 L	9[2]	Mixed	MCES, 1990
Riley Creek	1.3	22.3 L	13[2]	Mixed	MCES & Partners, 1999
Purgatory Creek	~2.5	19.6 L	36[3]	Mixed	Watershed District, 1997
Eagle Creek	0.8	15.8 R	3[2]	Mixed	MCES & Partners, 1999
Credit River	0.9	13.7 R	51[2]	Mixed	MCES, 1989
Nine Mile Creek	1.8	12.5 L	38[2]	Urban	MCES, 1989
Willow Creek	1.0	11.0 R	10[2]	Urban	MCES & Partners, 1999

[1] Source: USACE Navigation Charts and MDNR, 2003 [2] Source: MCES, 2003
[3] Source: Bonestroo *et al.*, 2001 [4] Source: Carver County [5] Also known as Hazeltine-Bavaria

2.2.1 Stream Monitoring Network

In 1987 the Metropolitan Council and MPCA agreed to study nonpoint-source pollution in six tributaries of the Minnesota River within the Metro Area. The agreement followed a wasteload allocation study of the lower Minnesota River conducted by the MPCA (1985), which concluded that the water-quality standard for dissolved oxygen could not be met without pollutant load reductions from both point and nonpoint sources. During the period 1989-1991, stage-recording and water-sampling equipment were deployed at Bevens Creek, Sand Creek, Carver Creek, Bluff Creek, Credit River, and Nine Mile Creek. Baseflow grab samples and event-based composite samples are collected at each site.

At the same time, equipment was installed to collect event-based composite samples from the Minnesota River near Jordan (MI 39.4) to compare headwater loads to those of the tributaries. Stage recording by the USGS and grab sampling by MCES were already in place at Jordan. Due to bridge construction near the station at Carver Creek, stage recording and event sampling were stopped in late May 2003 and resumed in September 2004; grab sampling continued during this period with some instantaneous flow measurements.

In 1990 the Minnesota Legislature mandated that the Metropolitan Council develop target pollutant loads for Metro-Area watersheds (MN Statute 473.157). The objectives were to help achieve federal and state water-quality standards, provide effective water pollution control, and help reduce unnecessary investments in advance wastewater treatment. Baseline information on stream water quality was needed before targets could be developed. To collect this information, the Council, with the help of local organizations, began monitoring three additional tributaries to the lower Minnesota River in 1999: Riley, Eagle, and Willow Creeks. These stations are part of a Watershed Outlet Monitoring Program (WOMP), which is supported in part with funding from the Minnesota Legislature through the MPCA. Under this program, monitoring is conducted on streams throughout the Metro Area by watershed management organizations, watershed districts, soil and water conservation districts, and other government agencies through cooperative cost-sharing agreements with the Metropolitan Council. The monitoring program was modeled after the program implemented earlier on the six Minnesota River tributaries.

From 1998 to 2002, Carver County Environmental Services monitored Chaska Creek in cooperation with the Minnesota Department of Agriculture (Carver County, 2004). The County monitored flow and collected base-flow grab samples and a few event-based composite samples. In 2003, Carver County entered an agreement with the Lower Minnesota River Watershed District (LMRWD) and City of Chaska to implement WOMP-like monitoring at Chaska Creek and East Chaska Creek through 2007. Automated monitoring stations were deployed on the two streams in July and August 2003. East Chaska Creek is also known as Hazeltine-Bavaria Creek.

On Chaska Creek, the station is located near the intersection with U.S. Highway 212, approximately one mile from the Minnesota River. Monitoring on East Chaska Creek is more complex. At high flows, East Chaska Creek is diverted near County Road 17 and routed directly to the Minnesota River to control flooding in the City of Chaska (Greg Aamodt, Carver County, per- personal communication). Three stations are required on East Chaska Creek to measure loads: an automatic sampling station upstream of the diversion (EC-2) and level recorders near the mouths of the natural and constructed channels (EC-3 and EC-1, respectively). The sampling station is approximately two miles from the Minnesota River, and the recorders are both approximately a quarter mile from the river. Grab samples are collected at all three sites, and all samples (grab and composite) are analyzed by MCES Laboratory Services.

At high flows, most of East Chaska Creek is diverted directly to the Minnesota River via the constructed channel; however, the natural channel still receives some flow from downtown Chaska (Greg Aamodt, Carver County, personal communication). At flows near or above flood stage, a lift station pumps this localized flow over a flood dike built to protect the city. At low-to-normal flows, the city splits the flow of East Chaska Creek roughly in half between the natural and constructed channels via a culvert controlled with a screw weir at the diversion near County Road 17. Both channels enter the Minnesota River near river mile 30, approximately a quarter to half mile apart.

From 1997 to 2000, the Riley-Purgatory-Bluff Creek Watershed District collected monthly field measurements at several stations on Purgatory Creek (Barr, 2001). Samples were not collected for water-quality analyses. In August 2003, the District switched to a WOMP-like program that includes water chemistry (Chris Bonick, Barr Engineering Company, personal communication). The nearest station to the mouth of Purgatory Creek is located where the creek crosses Pioneer Trail. Monitoring is expected to continue at this location beyond 2006. The Council’s WOMP includes stations near the mouths of Riley and Bluff Creeks within the District.

Table 4 lists the locations of the monitoring stations as miles upstream of the confluence with the Minnesota River. Stations were installed some distance from the outlets to minimize flooding and ease maintenance. Flows and water quality are not expected to change greatly between the stations and outlets on Credit River and Bevens, Carver, Chaska, Purgatory, and Eagle Creeks. Following are notes on features between the stations and mouths on other tributaries that may affect flow and water quality:

- The Sand Creek station is located 8.2 miles upstream of the outlet. Downstream of the station, the Jordan WWTP discharges to the creek, and the creek flows through the large Louisville Swamp.
- East Chaska Creek: See description of flow diversion earlier in this section.
- Bluff Creek flows through Rice Lake between the station and outlet.
- Riley Creek flows through Grass Lake between the station and outlet.
- Nine Mile Creek splits downstream of the station. Maps (MDNR, 2003, and others) show the eastern branch flowing directly to the Minnesota River and the western branch possibly interacting with one or two small floodplain lakes before reaching the river.
- Willow Creek flows through an underground culvert beginning at the toe of the river terrace. The box culvert starts approximately a half-mile south and upstream of the monitoring station. The creek continues flowing north in the culvert for another mile, traveling underneath the Burnsville landfill, and then discharges directly into the Minnesota River through a very large pipe.

In addition to these major tributaries, there are numerous minor tributaries to the lower 40 miles of the Minnesota River. Many of these smaller tributaries drain lakes and wetlands in the floodplain, which are replenished by springs, stormwater, or streams. The Water Management Plan for the LMRWD (1999) lists a total of 47 streams in the District, which extends from Carver, Minnesota, to the mouth.

2.2.2 Stream Monitoring Program

This section describes the MCES stream monitoring program that was in place before the modeling project began. See MCES (2003) for further details. The programs at Chaska, East Chaska, and Purgatory Creeks are similar. Section 2.2.3 describes modifications to the program to support the Lower Minnesota River Model.

Continuous Monitoring. Automated measurements of water stage, in conjunction with site-specific rating curves, are used to estimate flow rates in all streams. Temperature and conductivity were continuously monitored at some stations, and this capability was implemented at additional stations for the modeling project. Data loggers record the stage, temperature, and conductivity at 15-minute intervals during the open water season. During a typical year at each site, continuous measurements are recorded on at least 260 days (roughly, mid-March to mid-November).

Field Measurements. In the past, field measurements with portable equipment were generally used to calibrate the continuous temperature and conductivity probes or to measure temperature where continuous equipment was not installed. DO was not measured in the field or laboratory, and pH was measured in the laboratory only. Portable equipment has been increasingly used for in-situ measurements of temperature, conductivity, DO, pH, and turbidity.

Water Samples. Two types of water samples are collected at the stream sites for chemical analysis: composites and grabs. During runoff events, flow-weighted composite samples are collected with automatic samplers. Samplers are programmed to collect discrete samples representing equal volumes of stream flow; that is, sampling is conducted on an equal-flow increment (EFI) basis. Subsamples are then composited into a single sample for laboratory analysis. During baseflow conditions and occasionally during events, instantaneous grab samples are collected and analyzed.

Event-based composite sampling is conducted during the open-water season (roughly mid-March through mid-November), and baseflow grab sampling is conducted year round. Monthly grab samples are collected in the winter when conditions allow. The grab-sampling frequency may increase to twice a month in warmer months. During a typical year at each site, a minimum of 12 grab and 10-15 composite samples are collected. Fewer event samples (up to five) are collected from Chaska and East Chaska Creeks.

Water Chemistry. The following variables are analyzed in most samples:

Total organic carbon
Total alkalinity
Chemical oxygen demand
Turbidity
Total suspended solids
Volatile suspended solids
Total Kjeldahl nitrogen
Nitrate nitrogen
Nitrite nitrogen
Ammonium nitrogen
Total phosphorus
Total dissolved phosphorus
Total sulfate
pH
Conductivity
Hardness

Analysis of the following variables is dependent on stream and sample conditions as well as holding-time constraints. These analyses are conducted on roughly half or fewer of the samples:

BOD, 5-day
CBOD, 5-day
Soluble reactive phosphorus
Fecal coliform bacteria
Total chloride

Total metals have been analyzed in a few samples, mainly from Nine Mile Creek. Occasionally, chlorophyll tests have been run on samples, especially when concentrations are suspected to be high.

2.2.3 Modifications to Support the Model

Before considering changes to the stream monitoring program to support the Lower Minnesota River Model, the relative contributions of flows and loads to the river by the tributaries were as sessed. Monitoring should put the most effort into defining major inputs to the model, and the Metro-Area tributaries are small compared to the Minnesota River. The combined watershed area of the 12 monitored tributaries is only 658 square miles or roughly 4% of the watershed area of the Minnesota River near Jordan (16,200 square miles). Further, Bevens Creek, with a watershed area of 131 square miles, discharges to the Minnesota River upstream of Jordan, so it actually resides in the larger watershed. However, in the model, it is the size of the loads and not the size of the watershed that matters.

The stream monitoring programs have been operated for a number of years, and annual flows and loads have been compiled that can be compared to headwater flows and loads at Jordan (Metropolitan Council, 2004; MCES, 2004b; MCES, 2004c; and Greg Aamodt, Carver County, personal communication). Table 5 lists the relative contributions of flow, phosphorus, and suspended solids by the tributaries as average percentages of the annual flow or load of the Minnesota River at Jordan for the periods of record. The periods of record used in the table are 1989-2003 for the original six streams (some years may be missing), 2001-2003 for the three WOMP sites, and 1999-2003 for Chaska Creek.

In general, tributary flows and loads follow the same order of size, large to small, as the watershed areas. On average, the three tributaries contributing the largest phosphorus and suspended-solids loads to the lower Minnesota River are Sand Creek (5.29% and 4.49%), Bevens Creek (2.51% and 1.63%), and Carver Creek (1.53% and 0.96%). These three creeks enter the Minnesota River upstream of mile 34. Of the monitored streams, only Credit River, Nine Mile Creek, and Willow Creek enter the river in the navigation zone, where oxygen levels are lowest, and they enter near the upper end of the channel between miles 13 and 15. Credit River and Nine Mile Creek have contributed the fourth and fifth largest phosphorus and solids loads. Clearly, the watershed contributing the greatest loads to the lower Minnesota River—and the one most important to monitor—is the Minnesota River Basin upstream of Jordan.

Table 5. Mean annual flows, phosphorus loads, and suspended-solids loads of 12 tributaries as a percent of the flow and loads of the Minnesota River at Jordan (MI 39.4)

Tributary	**Watershed Area (mi^2)**	**Loading Record (years)**	**Flow (% Jordan)**	**Phosphorus Load (% Jordan)**	**Suspended-Solids Load (% Jordan)**
Sand Creek	255	14	2.43 %	5.29 %	4.49 %
Bevens Creek	131	14	1.07 %	2.51 %	1.63 %
Carver Creek	84	14	0.55 %	1.53 %	0.96 %
Credit River	51	13	0.36 %	0.40 %	0.25 %
Nine Mile Creek	38	13	0.49 %	0.39 %	0.35 %
Purgatory Creek	36	-	-	-	-
Chaska Creek	16	5	0.16 %	0.14 %	0.04 %
Riley Creek	13	3	0.10 %	0.13 %	0.18 %
E. Chaska Creek	12	-	-	-	-
Willow Creek	10	3	0.13 %	0.06 %	0.03 %
Bluff Creek	9	12	0.08 %	0.13 %	0.15 %
Eagle Creek	3	3	0.21 %	0.04 %	0.01 %

Data Sources: Karen Jensen, Steve Kloiber, and Leigh Harrod, MCES, and Greg Aamodt, Carver County

Another angle to consider is the maximum load that might be contributed by each tributary as compared to the headwaters at Jordan. From the monitoring records, 2002 stands out as the year (or one of the years) when Metro-Area tributaries contributed the highest phosphorus and suspended-solids loads compared to the Minnesota River at Jordan. In 2002 the eastern portion of the Minnesota River Basin, particularly the Metro Area, received more precipitation than the western portion. Also, nine of the 12 tributaries were monitored in 2002, providing a fairly complete picture.

Table 6 lists the tributary loads in 2002 as metric tons and as percentages of the loads of the Minnesota River at Jordan. Again, Sand, Bevens, and Carver Creeks delivered the highest percentages of phosphorus (7.36%, 5.37%, and 2.75%, respectively) compared to the load at Jordan. The three creeks also contributed the highest suspended-solids loads in 2002. Note that individual storm events may deliver even higher tributary contributions compared to the load at Jordan.

Nine of the 12 monitored tributaries appear to contribute relatively small phosphorus and solids loads (less than one percent each and probably less than five percent combined) to the lower Minnesota River compared to the loads at Jordan. Because Sand, Bevens, and Carver Creeks represent the largest tributary flows and loads to the lower Minnesota River, MCES initially implemented the base monitoring program described in Section 2 and Table A.1 for these three streams to the degree possible. In May 2005, MCES decided to drop Bevens Creek from the base monitoring program and add Credit River and Nine Mile Creek. Bevens was dropped because it enters upstream of the model's boundary at Jordan; Credit and Nine Mile were added to better define loads from the eastern, more developed watersheds. The stream monitoring programs described in the previous section and implemented before the modeling project were judged adequate for describing model inputs for the remaining tributaries.

Table 6. Phosphorus and suspended-solids loads of 12 Metro-Area tributaries compared to loads at the Minnesota River near Jordan in 2002

	Shed Area (mi^2)	**Total Phosphorus**		**Suspended Solids**	
		Load (mt)	**% Jordan**	**Load (mt)**	**% Jordan**
Jordan	16,200	995		661,000	
Sand	255	73.5	7.36 %	52,300	7.96 %
Bevens	131	53.7	5.37 %	26,200	3.99 %
Carver	84	27.5	2.75 %	12,000	1.82 %
Credit[1]	51	-	-	-	-
Nine Mile	38	8.84	0.89 %	3,130	0.48 %
Purgatory	36	-	-	-	-
Chaska	16	3.81	0.38 %	831	0.13 %
Riley	13	1.74	0.17 %	1,350	0.21 %
East Chaska	12	-	-	-	-
Willow	10	1.05	0.11 %	460	0.07 %
Bluff	9	1.73	0.17 %	1,460	0.22 %
Eagle	3	0.71	0.07 %	139	0.02 %

Data Sources: Karen Jensen, Steve Kloiber, and Leigh Harrod, MCES, and Greg Aamodt, Carver County

[1] Annual loads were not available for 2002; however, Credit River loads were very similar to Nine Mile Creek in 2003.

Following are notes on the implementation of the base monitoring program for tributaries. The four tributaries currently targeted for more intensive monitoring are Sand Creek, Carver Creek, Nine Mile Creek, and Credit River.

Flow. Continuously monitored at all 12 tributaries during most of the open-water season.

Temperature. Before the modeling project began, equipment to continuously monitor temperature was operating at all streams except Bevens, Carver, Chaska, and East Chaska Creeks. Temperature was measured when water samples were collected at Bevens and Carver Creeks. Temperature probes for continuous monitoring were added to the Bevens station in December 2003 and to the Carver station in November 2004 after it was redeployed. Temperature is not monitored at the Chaska and East Chaska Creeks.

Conductivity. Before the modeling project began, equipment to continuously monitor specific conductance was operating only at Nine Mile, Willow, and Eagle Creeks. This equipment was added to the Sand and Bevens stations in December 2003 and to the Carver station in November 2004 after the station was redeployed. In summer 2005, new temperature and conductivity probes for continuous monitoring were added to the stations at Credit River and Nine Mile Creek. At all stations, conductivity is measured in the field or lab when samples are collected.

Dissolved oxygen. DO was not a component of the stream monitoring program but is one of the most important inputs to the model. Daily or continuous data are recommended for loading sources in the model. Daily or continuous DO monitoring requires a high level of maintenance that exceeds current field resources, so it was not implemented. Instead, DO will be measured at the four targeted tributaries in the field or lab whenever the stations are visited. Data will later be examined to see if a relationship to temperature (e.g., percent saturation) or another variable can be developed.

pH. Daily or continuous pH measurements are also recommended, but pH is a secondary parameter. No continuous pH monitoring is implemented at the stream stations, and in the past, pH was only measured in the lab with grab and composite samples. In-situ measurements are recommended to better represent ambient conditions, so field measurements will be taken at the four targeted tributaries whenever the stations are visited. At all stations, pH is measured in the field or lab when water samples are collected.

Field measurements. A portable meter for measuring temperature, conductivity, dissolved oxygen, and pH was purchased for the modeling project to collect in-situ measurements at least at the four targeted tributaries whenever the stations are visited. The meter was incorporated into the program in November 2003.

Diurnal measurements. DO and pH may exhibit diurnal fluctuations, which depend on temperature changes and algal activity. The model developer initially recommended some diurnal measurements in the streams. However, the threat of vandalism at most stations makes it risky to deploy unattended sondes. Also, the stream program would need to borrow or purchase sondes with logging capability. Due to interactions with lakes, the highest levels of algal activity are suspected in Carver Creek (Winkler and Miller Lakes), Nine Mile Creek (Normandale Lake), Bevens Creek (Washington Lake), and Sand Creek. Due to the logistical problems and relatively small stream inputs, diurnal DO and pH measurements will not be collected in the streams.

Water chemistry. Some analytical tests were added to samples from the four targeted tributaries to complete the suite of modeling variables in Table 2. Measurements of BOD5, CBOD5, and soluble reactive phosphorus are subject to conditions but will be analyzed as often as possible. If not enough volume is available in composite samples to analyze both BOD5 and CBOD5, BOD5 will be tested. BOD5 is the more reliable test, as the nitrification inhibitor in the CBOD5 test is suspected to be a source of oxygen demand. Some chlorophyll *a* tests have been conducted in the past, and concentrations have typically been low. It is suspected that phytoplankton populations are low in the streams; however, a number of chlorophyll *a* samples will be analyzed to confirm this assumption.

Ultimate BOD. Ultimate BOD and CBOD will be monitored four times per year (seasonally) at the four targeted tributaries. The tests are typically run for 70 days. It is important for 5-day BOD and CBOD tests to be run on the same sample so ultimate-to-5-day ratios can be developed for the model.

Algal biomass. There are currently no plans to measure phytoplankton or periphyton biomass.

Winter. Monthly grab samples are collected during the winter when conditions allow. Samples are collected twice per month at the four targeted tributaries. During the winter of 2003-04, all streams monitored by MCES were running except the upper site on Bevens Creek (mile 5). Accurate stage data are difficult to collect, so winter flows are generally estimated.

Sand Creek. The monitoring station at Sand Creek is located 8.2 miles upstream of the mouth. The intervening reach contains the City of Jordan and its WWTP and the large Louisville Swamp. A number of concurrent grab samples (~12) will be collected at the station and mouth to compare water quality.

Bevens Creek. Bevens Creek enters the Minnesota River at mile 44.2, or nearly five miles upstream of the river monitoring station near Jordan (MI 39.4). Flow and water quality is intensely monitored at Jordan, making it an ideal upstream boundary for the model. If the model begins at Jordan, monitoring data from Bevens Creek are not needed for model development and calibration. However, the Council and other partners have an interest in including Bevens Creek in model projections. Perhaps this could be accomplished by adjusting inputs for the Minnesota River near Jordan, which would also require information on flow and loading from the creek.

Jordan. The MCES stream monitoring program also includes the collection of flow-weighted composite samples from the Minnesota River near Jordan during storm events. Some analytical tests were added to complete the list in Table 2.

2.3 POINT-SOURCE MONITORING, BASE PROGRAM

The lower 40 miles of the Minnesota River receives inputs from approximately 36 permitted discharges. The modeling proposal (MCES, 2004a) provides a list of the discharges and descriptions of the four largest point sources. Table 7 provides brief descriptions of the four major point sources.

Table 7. Descriptions of major point sources

Blue Lake Wastewater Treatment Plant operated by MCES

- Step-fed activated sludge with single-stage nitrification
- Operated to optimize phosphorus removal
- Aerated polishing pond and cascade effluent aeration
- Average wet-weather design flow = 42 mgd
- Discharges to river mile 20.5

Black Dog Generating Plant operated by Xcel Energy

- Four-unit, 538-megawatt, coal- and gas-fired facility
- Open-cycle cooling system: water is pumped from the river, passed through condenser chambers once, and discharged to a cooling lake (Black Dog Lake)
- Withdraws from river mile 8.8 at a maximum permitted rate of 597 cfs
- Discharges from the cooling lake to the river at miles 10.7 and 7.6

Seneca Wastewater Treatment Plant operated by MCES

- Conventional activated sludge with single-stage nitrification
- Operated to optimize phosphorus removal
- Cascade effluent aeration with pure oxygen injection as required
- Average wet-weather design flow = 38 mgd
- Discharges to river mile 6.7

International Airport operated by the Metropolitan Airports Commission

- Process wastes (e.g., deicing compounds) in combination with stormwater
- Glycol recovery plan in place
- Recent improvements, including two stormwater detention ponds
- Discharges to river miles 4.1, 3.8, and 3.0 (predominantly mile 3.8)

Permits for all facilities discharging to the lower Minnesota River require some level of effluent monitoring and reporting to the MPCA. These data will be evaluated for use in the model. In addition, monitoring programs at the four largest point sources were evaluated and supplemented, as needed, to support the model. The following sections describe the monitoring programs in place for the four largest point sources during the study period 2004-2006.

2.3.1 Blue Lake and Seneca Wastewater Treatment Plants

Blue Lake and Seneca are the third and fourth largest wastewater treatment plants (WWTPs) in Minnesota and can deliver sizable loads of nutrients, BOD, and other pollutants, as well as oxygen, to the lower Minnesota River. For example in 2002, effluent flow from each facility added, on average, approximately one percent to the flow of the Minnesota River near Jordan. River flows near Jordan averaged 4,067 cfs, which was near the long-term mean of 4,477 cfs. Pollutant-load contributions by the two WWTPs in 2002 were sometimes greater than flow contributions. Effluent phosphorus loads added 5.27% (Blue Lake) and 2.31% (Seneca) to the river load near Jordan in 2002—contributions similar to phosphorus loads from Bevens and Carver Creeks, respectively (Table 6). Annual nitrate loads were 1.58% (Blue Lake) and 1.83% (Seneca) of the load at Jordan. On the other hand, suspended-solids loads from the WWTPs were negligible compared to river loads (e.g., less than 0.1% in 2002). CBOD and DO loads were not compared.

WWTP loading rates are relatively stable compared to the highly variable loading rates in the river. When river flows become low and afford less dilution, the portion of loads contributed by WWTPs increases. At river flows less than 4,000 cfs, the percentages of loads contributed by Blue Lake and Seneca are expected to be higher than in 2002. At very low flows (<500 cfs), WWTP loads could be quite significant. Given the potential load contribution, adequate effluent monitoring at the two WWTPs is important for describing loading inputs to the model. Also, the model is being developed for WWTP facility planning and wasteload allocation, so accuracy is important.

Before the modeling project began, extensive effluent monitoring had been in place at the two WWTPs for many years. Monitoring is conducted by MCES to meet permit requirements and control the treatment process. Of the list of variables needed to define loads to the model (Table 2), the following have been routinely monitored in the effluents of both WWTPs:

Variable	**Sampling Frequency**
Flow	Continuous
Temperature	Daily
Dissolved oxygen	Continuous
pH	Daily
CBOD, 5-day	Blue Lake, 3/week; Seneca, 5/week
Total phosphorus	5/week
Nitrate nitrogen	5/week
Nitrite nitrogen	5/week
Ammonium nitrogen	5/week
Total Kjeldahl nitrogen	5/week
Total suspended solids	5/week

Data for continuously monitored variables are summarized to 1-minute intervals when stored. For analytical testing, 24-hour flow-weighted composite samples are collected.

For the modeling project, the Industrial Waste Section of MCES will collect two additional 24-hour flow-weighted composite samples each month from the effluents of both facilities. Samples will be analyzed for all variables listed in Table 2 except total particulate phosphorus, chlorophyll *a*, algal biomass, and light (Note: We later decided to collect some chlorophyll samples to test the assumption that effluent concentrations were low). The routinely measured variables (e.g., CBOD5 and ammonia) will also be analyzed in these samples, so relationships may be developed with other variables. If sample volume is not adequate for both BOD5 and CBOD5 tests, BOD5 will be analyzed, as this test is more reliable than CBOD5. Samples for 70-day BOD and CBOD will be collected four times per year (seasonally) along with 5-day BOD and CBOD to construct ultimate-to-5-day ratios. Due to the large volume needed for the 70-day tests, grab samples will be collected.

2.3.2 Black Dog Generating Plant

The Black Dog Generating Plant withdraws water from the Minnesota River near mile 8.8 for cooling condensers. After passing through the condenser chambers once, the water is dis charged to Black Dog Lake, which serves as a cooling lake. The water then flows back to the Minnesota River at either end of the lake (miles 10.7 and 7.6). The primary concern for the model is how Black Dog's cooling system affects the hydrodynamics and temperature of the river. The withdrawal and discharge rates can represent a sizable portion of the river flow. For example, Figure 1 compares the withdrawal rates and river flows in 1998, when the mean river flow (6,226 cfs) was somewhat above normal. The withdrawal rates represented 0-26% of the river flow in 1998. The portion withdrawn increases during times of low river flows and high-energy use. During the 1988 drought, the withdrawal rate approached 100% of the river at times (MCES, 2004a).

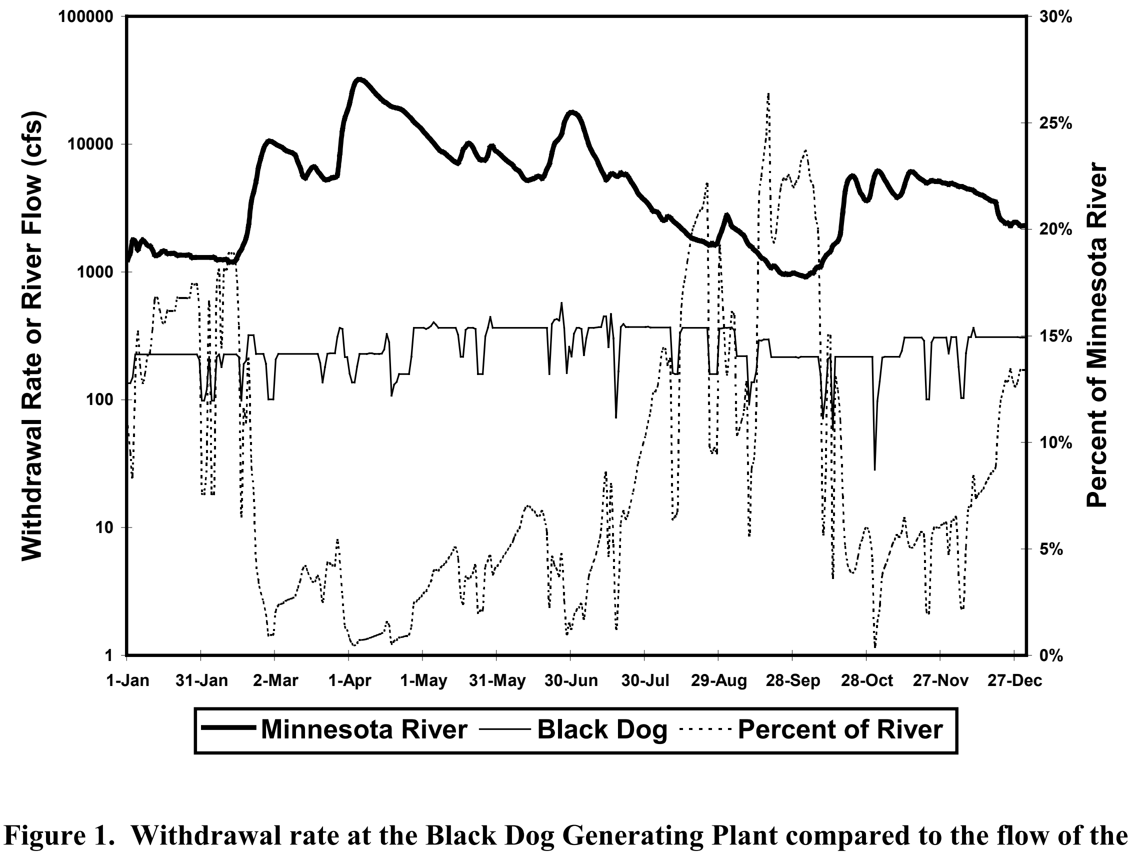

Figure 1. Withdrawal rate at the Black Dog Generating Plant compared to the flow of the Minnesota River near Jordan in 1998.

To comply with the discharge permit for the Black Dog Generating Plant, Xcel Energy continuously monitors flow and water temperature year-round in the two cooling-lake discharges. Water temperature is also monitored continuously at a location on the Minnesota River just upstream of the facility (mile 11.5 near the I35W bridge). The flow and temperature data are aggregated to hourly values (mean flow and maximum temperature) and stored on a process computer (Jim Bodensteiner, Xcel Energy, personal communication). Strip charts may be available if more temporal resolution is needed for the model.

Some monitoring is conducted at the intake for the water appropriations permit and plant operations. Personnel take a daily reading of river elevation from a staff gauge at the intake screenhouse (Jim Bodensteiner, Xcel Energy, personal communication). Water temperature is recorded hourly at the inlet to each condenser within the facility. Daily intake flow is estimated from the pumping time, pump capacity, and design curves.

Two of four coal-fired units were recently converted to gas, and operational changes may potentially increase the volume of heat released to the Minnesota River. For this reason, the current discharge permit requires a supplemental study pursuant to Section 316A of the Clean Water Act. Xcel Energy is required to study the thermal effects on the water quality and aquatic health of the Minnesota River through monitoring and modeling. A work plan was submitted to the MPCA in July 2003, monitoring will be conducted over three years (2004-2006), and a final report is due by May 1, 2007.

The 316A demonstration will focus on biological monitoring of fish and invertebrates, but some DO monitoring is also included (Jim Bodensteiner, Xcel Energy, personal communication). Since fall 2003, DO and pH have been measured in situ with a portable meter on a monthly basis at three locations:

- Minnesota River near the I35W bridge (river mile 11.5)
- Black Dog intake (river mile 8.8)
- Black Dog outfall near Cedar Ave (river mile 7.6)

In addition, 24-hour monitoring of DO and pH on at least an hourly basis will be conducted occasionally (e.g., in 2004, on one day in June and one day in September). Continuous DO monitoring on a semi-permanent basis was considered at the two outfalls and river mile 11.5, which would benefit model development. To date, this has not been implemented.

As part of the summer low-flow monitoring program in the base program, weekly water-quality monitoring is planned for the two outfalls (Section 3.3). At normal to high river flows, it was initially thought that permit-required monitoring and the supplemental study at Black Dog would address the model's data requirements. However, more than river flow and temperature may be affected by the cooling system at Black Dog. Algal activity and deposition in Black Dog Lake may alter water quality, as may the use of biocide at the facility. The effects likely depend on residence times in the cooling lake and the amounts of water withdrawn and discharged to the river. Some additional monitoring at the outfalls may be desirable during certain river flows and seasons. For example, from Figure 1, if the outfalls had been sampled during June-September 1998 whenever river flows were less than 1500 cfs, the data would have represented 30-40% of the time when the facility was withdrawing 10% or more of the river. To explore the possible effects, some samples will be collected from the two discharges and an upstream river site in the summer when river flows are less than 2,000 cfs. Five sets of samples were collected in August and September 2005.

To improve habitat in Black Dog Lake, Xcel Energy is permitted to draw down water every 2-3 years between mid-May and mid-July. During the drawdowns, DO concentrations must be maintained above 4 mg/L. Due to high flows, there were no drawdowns in 2004 and 2005.

2.3.3 Minneapolis/St. Paul International Airport

The Metropolitan Airports Commission (MAC) owns and operates the Minneapolis/St. Paul International Airport, which is permitted to discharge combined waste- and stormwater to the Minnesota River at three outfalls near river miles 4.1, 3.8, and 3.0. Discharge monitoring through 2002 revealed high levels of CBOD5 from de-icing and anti-icing alcohols (propylene and ethylene glycol). The airport is permitted to discharge up to 900 tons of CBOD5 per year. While the airport discharges more CBOD5 during the de-icing season (November 1 – April 15), summer loads may also be substantial. During 1997-2000, mean summer CBOD5 loads ranged from 800 to 1200 lb/day. This problem led to subsequent improvements.

An airfield improvement plan, currently being implemented, includes a number of construction projects that will improve the recovery of aircraft de-icing fluids and reduce CBOD loads to the river. Two new stormwater detention ponds are already in place above the main discharge at river mile 3.8 (outfall 020). The vast majority of flow and loads are discharged at this outfall. The outfall at river mile 4.1 is now active only at high flows, receiving stormwater that normally flows to outfall 020. The discharge at river mile 3.0 is unchanged but is relatively small.

Of the variables needed for the model (Table 2), the following are monitored at the three outfalls as required by the airport's discharge permit (1993, modified in 2004):

Variable	**Sampling Frequency**
Flow	Continuous
Temperature	Weekly
Dissolved oxygen	Annually but more may be requested
CBOD, 5-day	Daily
CBOD, 40-day	May be requested
Total phosphorus	Annually
Ammonium nitrogen	Weekly
Total Kjeldahl nitrogen	Annually
Total suspended solids	Weekly (monthly during the deicing season)
Total alkalinity	Monthly

The MPCA can request additional DO monitoring and 40-day CBOD tests (e.g., during a synoptic river survey to support a wasteload allocation study). For laboratory analyses, 24-hour composite samples are collected.

During normal to high river flows, permit-required monitoring appears adequate to describe loads to the model. The only additional base-program variables that will be monitored by the Industrial Waste Section of MCES are 70-day BOD and CBOD in conjunction with BOD5 and CBOD5 in grab samples from the main outfall (020). These tests are needed to develop ultimate-to-5-day ratios comparable to other loading sources. The ultimate BOD samples are 24-hour, flow-weighted, composite samples collected four times a year (seasonally). Until February 14, 2005, no ultimate BOD samples had been collected due to construction and startup of the new detention ponds. Additional samples may be collected in 2005 and 2006 to make up for this period.

Weekly water-quality monitoring of airport outfall 020 will be conducted by MCES as part of the summer low-flow monitoring program (Section 3.3). In addition to discharge monitoring, the MAC is required to monitor the Minnesota River at two locations during June through September when river flows near Jordan are less than 1,000 cfs (Table A.2). The two sites are located upstream and downstream of the airport outfalls at approximately river mile 4.0 (I494 bridge) and between miles 0.1 and 0.4. Under these conditions, the MAC will conduct weekly monitoring of DO, 5-day CBOD, temperature, pH, and ammonium nitrogen at mid-depth and mid-channel between 10:30 am and 12:30 pm. This period corresponds to the time of the daily average DO concentration. The downstream sample is not required when backwater interference is apparent. See Section 3 for more information on summer low-flow monitoring.

2.4 BOD MONITORING, BASE PROGRAM

Analytical tests for biochemical oxygen demand require more resources (e.g., space, staff, time, and supplies) than most analyses. This is especially true for the extended ultimate BOD test, which is typically run for 70 days by MCES Laboratory Services. For this reason, additional information on BOD monitoring is provided in this section.

2.4.1 Model Data Requirements

Monitoring data are needed to track organic matter, its decay, and resulting oxygen demand in the model. Analytical results for organic carbon (OC) and BOD serve as measures for organic matter and its associated oxygen use during decomposition. Thomas Cole, a CE-QUAL-W2 model developer, provided guidance on OC and BOD monitoring for the Lower Minnesota River Model.

Organic matter in the river comes from two general sources: externally from allochthonous sources (e.g., discharges and tributaries) and internally from autochthonous sources (e.g., phytoplankton). The two sources are tracked separately in the CE-QUAL-W2 model. External sources of organic matter are tracked as CBOD. To distinguish one loading source of organic matter from another, the model allows any number of CBOD groups with different decay rates. Internal sources are tracked as organic matter divided into four fractions: labile dissolved, refractory dissolved, labile particulate, and refractory particulate organic matter.

Separate tracks for external and internal sources of organic matter has led to different data requirements for the development and calibration phases of modeling. In compiling model inputs for the boundaries (i.e., tributaries, discharges, and upstream/downstream ends of the modeled reach), BOD measurements are preferred. Specifically, total BOD is preferred; it is not necessary to measure the carbonaceous and nitrogenous fractions (CBOD and NBOD). OC measurements are not needed to describe the boundaries but may provide a valuable check on consistency.

During the calibration phase, measurements of total and dissolved organic carbon (TOC and DOC) are preferred for testing how well the model simulates the four fractions of organic matter. For particulate organic matter, subtracting DOC from TOC provides a realistic estimate. CBOD can also serve as a surrogate for organic matter, but it is a second choice.

Ratios of ultimate BOD to 5-day BOD must be described for each boundary, tributary, and discharge in the model. The ratios are used within the model to estimate ultimate BOD from the more frequently measured 5-day BOD inputs. For this work, it will be important to build a database of paired 5-day and 70-day BOD measurements for key loading sources. For each sampling site and date, 5-day and 70-day BOD tests should be run on as near to the same water as possible. Ultimate BOD tests will also help define BOD decay rates in the river and the fractions of labile and refractory organic matter.

To measure the entire oxygen demand related to organic matter, BOD tests should be run on unfiltered samples. When it's desirable to distinguish between oxygen demand related to dissolved and particulate matter, BOD tests should also be run on filtered samples. For example, BOD tests on both filtered and unfiltered samples would help quantify the BOD associated with particulate forms such as algae and detritus.

2.4.2 BOD Monitoring Plan

In the base monitoring program, BOD5, CBOD5, TOC, and DOC will be monitored at least twice per month in samples from the following 11 sites (Tables A.1 and A.2):

- Five long-term river monitoring stations (MI 39.4, MI 25.1, MI 14.3, MI 8.5, and MI 3.5)
- Blue Lake and Seneca WWTPs
- Four targeted tributaries (Sand, Carver, Nine Mile, and Credit)

As often as possible, the four variables will also be measured in event-based composite samples collected at Jordan (MI 39.4) and the four targeted tributaries. TOC, BOD5, and CBOD5 are measured in some grab and composite samples from additional tributaries as part of stream monitoring programs. More frequent CBOD5 monitoring of the WWTP and airport discharges is required by permits. The CE-QUAL-W2 user manual (Cole and Wells, 2002) recommends weekly OC and BOD monitoring at the boundaries (TOC at a minimum), so weekly TOC monitoring was requested at Jordan (MI 39.4) and Fort Snelling (MI 3.5). However, based on recommendations in the previous section, BOD5 monitoring at these two sites may be more valuable.

While all four variables are not needed for modeling, they provide consistency checks against each other. If resources become limited, BOD and OC monitoring could be scaled back using the guidelines in the previous section. BOD5 and CBOD5 tests will be run only on unfiltered samples, except when run with filtered 70-day BOD tests. The nitrification inhibitor in the CBOD5 test has been shown to be a potential source of BOD, so the total BOD5 test is more reliable. If sample volume is not adequate for both tests, total BOD5 will be measured. A nitrification inhibitor is not used in the 70-day test; instead, nitrification is tracked with nitrate sampling. At the conclusion of the test, CBOD is estimated by subtracting NBOD from total BOD.

Four times per year, 70-day BOD and CBOD tests will be run on both filtered and unfiltered samples from the 11 sites listed above plus the main airport stormwater outfall (020). Over the three-year monitoring program, this should provide 12 sets of ultimate BOD measurements for each location. From concurrent samples, both filtered and unfiltered, 5-day BOD and CBOD tests will be conducted so ultimate-to-5-day BOD ratios can be calculated. TOC and DOC are also requested on the same samples as the 70-day BOD tests. Sampling will target the four seasons (winter, mid-January to mid-February; spring, April; summer, July or August; fall, October). Attempts will be made to capture different discharge and river conditions, but special efforts will be made to collect samples in summer when river flows are low. The Water Quality Section of MCES will coordinate sampling with the Industrial Waste Section and Laboratory Services. Laboratory Services requests advanced notice of at least four weeks for ultimate BOD tests.

The Blue Lake and Seneca WWTPs normally discharge high quality effluent with CBOD5 concentrations much below permit limitations (summer monthly average concentrations of 12 and 15 mg/L, respectively). Model projections will probably involve scenarios with effluent CBOD5 concentrations near the current permit limits, so effluent sampling at poorer performance levels, if possible, would provide valuable information.

From the modeling perspective, dilution and seeding of samples can introduce error to BOD measurements and should be avoided if possible. However, dilution cannot be avoided in some effluent samples when the oxygen demand is high, and seeding cannot be avoided when chlorination kills too many microorganisms. Seeding is required by Standard Methods when effluent samples have been chlorinated.

In June 2005, MCES Laboratory Services notified the modeling team that organic carbon results labeled as unfiltered were actually derived from decanted samples. They are working to resolve this problem so they can deliver results for unfiltered (total) organic carbon for the remaining months of the program. The results for filtered (dissolved) organic carbon were not affected by this problem.

3 SUMMER LOW-FLOW MONITORING PROGRAM

The Lower Minnesota River Model will be used to evaluate the following water-quality impairments in order of priority: low oxygen levels, eutrophication, and high turbidity. DO concentrations are generally lowest and algal levels are highest during the summer when river flows are low. While turbidity related to inorganic solids is low during drought periods, turbidity related to algae may be high. Therefore, more intensive monitoring is recommended during summer low flows to capture information needed to support oxygen, nutrient, and algal dynamics in the model. This section describes the summer low-flow monitoring program.

The program will be implemented during an 8- to 12-week period in summer (June 1 through September 15) when river flows near Jordan are expected to drop below 1,000 cfs for an extended period. The flow target of 1,000 cfs was selected for the following reasons:

- Travel time between mile 25 and the mouth is expected to increase to more than two days, which will amplify important processes such as algal growth, settling, and sediment fluxes.
- The combined flow of the Blue Lake and Seneca WWTPs is currently ~75 cfs. River flow at 750 cfs provides a 10:1 dilution (5:1 at 375 cfs). A low dilution ratio is needed to detect any effects of the high quality effluent (e.g., CBOD5 < 4 mg/L) discharged by the two WWTPs.
- At these flows, the Black Dog Generating Plant has withdrawn greater than 20% of the river flow for cooling water on some days. The facility's operation may affect hydraulics, temperature, and water quality in the river.
- Records indicate an increase in the frequency of DO concentrations less than 6 mg/L.
- The summer 7Q10 flow upstream of the Blue Lake WWTP was 314 cfs for the period 1936-2001, and the summer 7Q30 was 377 cfs (Carol Sinden, MPCA, personal communication). These flow statistics affect the application of the DO and ammonia standards.

Sampling frequency will increase to weekly during the summer low-flow monitoring program, and the number of river monitoring stations will double from five to ten. All water samples from the river will be collected from a boat. In addition to the Blue Lake and Seneca WWTPs, MCES will monitor the discharges at the airport's main stormwater outfall (020) and Black Dog's two cooling-lake outfalls. See Table 8 for a list of monitoring stations during the summer low-flow program.

The following sections describe the four elements of the summer low-flow monitoring program:

- River Monitoring (Section 3.1)
- Tributary Monitoring (Section 3.2)
- Point-Source Monitoring (Section 3.3)
- BOD Monitoring (Section 3.4)

Table 2 lists the variables needed to support the model. These variables will be monitored at all stations unless noted. In addition to the summer low-flow monitoring program, the MPCA plans to conduct one or two synoptic surveys of the Lower Minnesota River when river flows are less than 1,500 cfs (Section 4.2.2). During the weeklong synoptic surveys, DO, temperature, pH, and conductivity will be monitored continuously using sonde-equipped buoys at four locations within the lower 21 miles of the river. In addition, daily grab samples will be collected for laboratory analysis at two of the four sites.

Table 8. Monitoring stations during the summer low-flow monitoring program

Site	Description
Mile 39.4 Jordan	- MCES long-term monitoring station - Upstream boundary of model - Roughly two miles downstream of Bevens Creek
Mile 25.1 Shakopee	- MCES long-term monitoring station - Downstream of Sand, Carver, Chaska, and East Chaska Creeks - Upstream of Blue Lake WWTP (mile 20.5)
Mile ~16.8 Bloomington	- Pedestrian bridge (~mile 16.8) or Bloomington Ferry bridge (~mile 17.4) - WLA model predicts a sharp decline in water quality between miles 20 and 15 - Downstream of Blue Lake WWTP and Bluff, Riley, & Purgatory Creeks
Mile 14.3 Savage	- MCES long-term monitoring station - WLA model predicts declining water quality in this reach - Downstream of Eagle Creek
Mile ~10.8 I35W/Lyndale	- Downstream of Credit River, Nine Mile Creek, and Willow Creek - Upstream of Black Dog Generating Plant (2 outfalls and 1 intake)
Mile 8.5 Black Dog	- MCES long-term monitoring station - Two miles downstream of Black Dog's Lyndale outfall (mile 10.7) - Directly downstream of Black Dog's intake point
Mile ~7.2 Hwy 77/Cedar	- Downstream of Black Dog's Cedar outfall (mile 7.6) - Upstream of Seneca WWTP (mile 6.7)
Mile ~5.0 Six Mile Cut	- Downstream of Seneca WWTP - Upstream of airport stormwater outfalls (miles 4.1, 3.8, and 3.0)
Mile 3.5 Ft. Snelling	- MCES long-term monitoring station - Directly downstream of primary airport outfall (#020 at mile 3.8)
Mile ~0.5 Mouth	- Downstream boundary of model - Downstream of all airport outfalls
12 Tributaries	- Twelve direct tributaries monitored by MCES and local organizations: Bevens, Sand, Carver, Chaska, East Chaska, Bluff, Riley, Purgatory, Eagle, Credit, Nine Mile, and Willow
5 Major Discharges	- Blue Lake and Seneca WWTPs - Black Dog Generating Plant, two cooling-lake discharges - International Airport, main stormwater outfall 020

3.1 RIVER MONITORING, LOW FLOW PROGRAM

MCES will collect weekly grab samples from a boat at the 10 river sites listed in Table 4. The summer low-flow monitoring program concentrates on the channelized section below Savage for the following reasons:

- Velocities drop in this reach, decreasing reaeration rates and increasing settling rates.
- This reach receives discharges from the Seneca WWTP, Black Dog Generating Plant, and International Airport.
- The model used in the wasteload allocation study (MPCA, 1985) predicted that the greatest impacts by point sources would occur in this reach, including two DO sag points: just upstream of the Seneca WWTP (MI 6.7) and at the mouth (MI 0.0).
- This reach is easily accessible by boat. Above Savage, the river is more difficult to access and navigate by boat.
- All of the major tributaries enter upstream of mile 10.8; however, their relative contribution to flow and loads during dry conditions will be low.

Currently, MCES plans to collect discrete grab samples at mid-channel and one meter below the surface. MCES will evaluate its sampling protocol based on the results of the mixing study conducted by the USGS (Section 4.1.4) and their own investigations (Section 2.1.3). The two most important locations for accurate representation of flow and water quality are the upstream and downstream boundaries near Jordan and the mouth.

Continuous monitoring of DO, temperature, pH, and conductivity was recommended somewhere between Interstate 35W (MI 11.5) and the Seneca WWTP (MI 6.7) to capture the DO sag, if any, downstream of the Blue Lake WWTP during summer low-flow conditions. In addition to monitoring cooling-lake discharges from Black Dog Lake, Xcel Energy continuously monitors temperature upstream of the discharges near the I35W freeway bridge (Section 2.3.2). As part of a supplemental environmental study, Xcel Energy will also collect some DO and pH measurements at this location. Adding continuous DO monitoring to this site during summer low-flow conditions would provide valuable information.

In addition to monitoring waste/stormwater discharges from the international airport, the MAC is required to monitor the Minnesota River at two locations in the summer (June-September) when river flows near Jordan are less than 1,000 cfs (Section 2.3.3). One location is upstream of the outfalls at the I494 bridge near river mile 4.2, and the other is downstream of the outfalls somewhere between river miles 0.1 and 0.4. Monitoring will be done at mid-channel and mid-depth. The following variables will be monitored weekly: water temperature, DO, pH, 5-day CBOD, and ammonium nitrogen. Monitoring at both locations will occur on the same day sometime between 10:30 AM and 12:30 PM, when DO concentrations typically approach the daily average concentration. The downstream sample is not required when backwater interference is apparent.

3.2 TRIBUTARY MONITORING, LOW FLOW PROGRAM

Flows in the 12 monitored tributaries are likely to be low during summer drought conditions. The exceptions may be after occasional and localized storm events. Table 9 provides baseflow estimates near the outlets of the monitored tributaries from a groundwater-inflow study conducted by the USGS on September 8, 2003 (see Section 4.1.6) and stream monitoring programs for the period 8/23/03-9/10/03. In both sets, the combined flow of the tributaries represented less than 5% of the flow of the Minnesota River near Jordan, and no one tributary exceeded 1.5% of Jordan's flow. Eagle Creek, with the smallest watershed, receives substantial ground-water inflows and exhibited the highest baseflow in late summer 2003.

Table 9. Baseflow estimates for tributaries in summer 2003

Tributary	USGS Seepage Study September 8, 2003		Stream Monitoring 8/23/03-9/10/03	
	Flow (cfs)	% Jordan	Flow (cfs)[1]	% Jordan
Jordan	527		493 (9/10)	
Bevens	3.46[1]	0.7 %	2.48	0.5 %
Sand	0.08	0.0 %	2.31	0.5 %
Carver	2.75	0.5 %	-	-
Chaska	0.50	0.1 %	2.1	0.4 %
East Chaska	0.20	0.0 %	-	-
Bluff	0.64	0.1 %	0.68	0.1 %
Riley	0.84	0.2 %	1.20	0.2 %
Purgatory	1.87	0.4 %	0.96	0.2 %
Eagle	7.92	1.5 %	6.82	1.4 %
Credit	1.78	0.3 %	2.25	0.5 %
Nine Mile	1.03	0.2 %	1.46	0.3 %
Willow	0.00	0.0 %	0.27	0.1 %
Others	1.86	0.4 %	-	-
Total	22.93	4.4 %	20.53	4.2 %

[1] Average daily flow monitored by MCES or local organizations.

Because inputs from the monitored tributaries are expected to be relatively steady and low, stream monitoring will not be intensified during summer low flow conditions. It will continue as described in Section 2.2. In general, grab samples will be collected every other week, and if a rain event occurs, flow-weighted composite samples will be collected. The parameters used to trigger event sampling can be adjusted to meet modeling needs.

The synoptic river survey proposed by the MPCA (Section 4.2.2) must be coordinated with MCES and local partners to ensure that samples are collected on monitored streams at least once during the survey. Grab samples or composite samples collected over equal time intervals could be collected during the survey, if arranged ahead of time. The synoptic survey covers the lower 21 miles of the river. The monitored streams that enter the Minnesota River downstream of mile 21 are Purgatory Creek, Eagle Creek, Credit River, Nine Mile Creek, and Willow Creek.

Table 10 lists tributary flows measured during a synoptic survey of the lower 25 miles on August 12, 1980 when the river flow at Jordan was 733 cfs (MPCA, 1985). The combined flow contrib uted by the tributaries was less than 10% of the flow at Jordan. The outlets of two lakes that are not currently monitored, Blue Lake and Long Meadow Lake, had the highest flows along with Eagle Creek. The two outlets may be worth tracking in the synoptic survey. Note that an outlet from the formerly landlocked Prior Lake was constructed near Blue Lake in 1983.

Table 10. Tributary flows during synoptic survey on August 12, 1980 (MPCA, 1985)

Tributary	River Mile And Bank	Flow (cfs)	Percent of Jordan
Minnesota River at Jordan	39.4	733	
Camp Creek	23.0 R	3.3	0.5 %
Bluff Creek/Rice Lake	22.5 L	0.6	< 0.1 %
Riley Creek/Grass Lake	22.3 L	1.3	0.2 %
Blue Lake	20.0 R	11.0	1.5 %
Purgatory Creek	18.3 L	3.4	0.5 %
Eagle Creek	15.8 R	10.9	1.5 %
Credit River	13.7 R	7.1	1.0 %
Nine Mile Creek	12.5 L	9.1 + 0.8	1.4 %
Black Dog Creek	6.7 R	2.4	0.3 %
Tributary	5.0 R	1.1	0.2 %
Lower Long Meadow Lake	4.5 L	17.3	2.4 %
South Gun Club Lake	3.2 R	1.8	0.2 %
North Gun Club Lake	2.5 R	1.9	0.3 %
Total		72.0	9.8 %

3.3 POINT-SOURCE MONITORING, LOW FLOW PROGRAM

Samples will be collected every week by the Industrial Waste Section of MCES from the following five point-source discharges:

- Blue Lake WWTP
- Seneca WWTP
- International Airport, main outfall 020
- Black Dog Generating Plant, outfall near Lyndale Ave
- Black Dog Generating Plant, outfall near Cedar Ave

The samples should be 24-hour, flow-weighted composites. All variables listed in the parameter column of Table A.1 should be analyzed with the exception of total particulate phosphorus, algal biomass, and light. Note that chlorophyll *a* should be measured in discharges from the airport, Black Dog, and Blue Lake WWTP due to the ponds or lakes at these sites. These samples are in addition to the permit-required discharge monitoring programs described in Section 1.3.

Note that effluent aeration to increase DO concentrations to at least 16 mg/L is required at Seneca when river flows fall below 1,200 cfs for seven consecutive days during the summer months (June through September). The effectiveness of effluent aeration on raising river DO concentrations was studied by MCES in September 1998; however, river temperatures had started to drop, so conditions were not ideal (MCES, in progress).

3.4 BOD MONITORING, LOW FLOW PROGRAM

Ultimate BOD and CBOD tests will be run on unfiltered and filtered samples every other week at the nine sites: six river monitoring stations (MI 39.4, MI 25.1, MI 14.3, MI ~10.8, MI ~7.2, and MI 3.5) and three major discharges (Blue Lake WWTP, Seneca WWTP, and airport outfall 020). In an 8-12 week program, this will provide a minimum of four and maximum of six ultimate BOD sets for each site. Tributary loads during drought conditions should be low, so no 70-day BOD tests are requested from stream samples. If resources are limited, the frequency of filtered samples can be reduced from semimonthly to monthly. BOD5, CBOD5, TOC, and DOC should be measured in as near to the same water as possible.

4 SPECIAL MONITORING AND FIELD STUDIES

In February 2003, scientists, engineers, and managers from agencies interested in developing a model of the lower Minnesota River met to discuss the modeling approach and monitoring needs. Agencies included the USACE, USGS, MPCA, and MCES. At the meeting, the CE-QUAL-W2 model was selected for the project, and the three-year monitoring program was outlined. In addition, several special monitoring tasks and field studies were suggested to meet specific model data requirements (e.g., meteorological data), set bounds on anticipated key coefficients (e.g., reaeration), and investigate the importance of other model inputs (e.g., sediment phosphorus release).

The meeting spurred other discussions and evolved into the special projects presented in this section. The projects are grouped by their current status:

- First year priorities that have been fully implemented (Section 4.1)
- Planned and contracted studies in progress or pending low flow conditions (Section 4.2)
- Projects that were proposed but not implemented (Section 4.3)
- Research that has been suggested but not yet pursued (Section 4.4)

MCES and partners will continue to review the need for additional special monitoring and field studies.

4.1 FIRST YEAR PRIORITIES

The following monitoring tasks and field studies were considered priorities to be initiated or completed before the three-year monitoring program began in October 2003:

1. Meteorological station near the river surface in the low oxygen zone (Section 4.1.1)
2. Continuous monitoring station for the Minnesota River near Jordan (Section 4.1.2)
3. Stream-flow gaging station for the Minnesota River at Fort Snelling (Section 4.1.3)
4. Study of mixing characteristics at five long-term river monitoring stations (Section 4.1.4)
5. Rapid assessment of sediment bed in the lower Minnesota River (Section 4.1.5)
6. Determination of ground-water inflows to the lower Minnesota River (Section 4.1.6)

Items 1-3 were needed to meet basic model data requirements; items 4-6 were needed early in the project to better define the modeling approach and monitoring program. They are described in the following sections.

4.1.1 Meteorological Station Near the River Surface in the Low Oxygen Zone

Meteorological data are needed to properly simulate the hydrodynamics of the river. Meteorological inputs to the CE-QUAL-W2 model are air temperature, dew-point temperature, wind speed, wind direction, cloud cover, and short-wave solar radiation (Cole and Wells, 2002). The inputs may be varied over time at any frequency. However, a single set of meteorological inputs is used to describe the entire modeled reach; that is, meteorological data are not spatially varied.

The National Weather Service maintains a meteorological station at the international airport, near the mouth of the Minnesota River. However, the station is located on the bluff above the river valley and may not represent conditions near the river. For this reason, MCES will deploy a meteorological station close to the water surface within the most critical reach for dissolved oxygen. In the lower Minnesota River watershed, meteorological data are also collected at the Flying Cloud Airport (above the river valley) and Black Dog Generating Plant (in the river valley but on towers). The nearest long-term monitoring station for solar radiation is the St. Paul campus of the University of Minnesota.

According to the wasteload allocation study (MPCA, 1985), DO concentrations are expected to be lowest in the reach containing the navigation channel (mouth to mile 14.7). Specifically, the study predicted two DO sag points: just upstream of the Seneca WWTP (MI 6.7) and at the mouth of the Minnesota River (MI 0.0). A zone of elevated DO concentrations may occur for some distance downstream of the Seneca WWTP when the effluent is aerated. Effluent aeration is required at Seneca during the summer when river flows are less than 1,200 cfs for seven consecutive days. Describing meteorological conditions in the zone of lowest DO is most important.

The MCES trailer at Black Dog (MI 8.5) was suggested as a possible location for the meteorological station, but the cooling towers at the generating plant may interfere with measurements. Instead, monitoring equipment was deployed at the MCES station at Fort Snelling (MI 3.5). Deployment was delayed until March 2005. The effects of airport traffic and a tower at Fort Snelling will be considered.

Differences in meteorological conditions certainly occur along the lower 40 miles of the Minnesota River at any point in time. For example, the USGS suggested multiple anemometers along the lower Minnesota River because field crews noticed variations in wind along the channel. With spatially invariant inputs, it will be most important to describe conditions near the DO sag points. MCES considered deploying additional meters at select locations to evaluate spatial differences, but the model developer did not think it was necessary.

4.1.2 Continuous Monitoring Station for the Minnesota River near Jordan

To describe boundary conditions, the CE-QUAL-W2 user manual (Cole and Wells, 2002) recommends daily or continuous measurements of temperature and flow as minimum parameters and DO, pH, and conductivity as additional parameters. Flow and temperature are needed for the hydrodynamic model, and the additional parameters are needed for the water-quality model. The two major boundaries of the model are the upstream boundary near Jordan (MI 39.4) and the downstream boundary at the mouth. For many years, MCES has operated a continuous monitor near the mouth of the Minnesota River at Fort Snelling (MI 3.5) to measure all of these parameters except flow; however, only grab and event samples have been collected at MCES' long-term monitoring station near Jordan.

Equipment to continuously monitor temperature, DO, pH, and conductivity at the Jordan station was installed in the spring of 2004, and MCES began collecting data on May 28, 2004. During the first year, only 64 days of data were recorded due to a problem in how the station was reconfigured after bridge construction. A problem with the sample intake opening was fixed in December 2004, and a new pump and line were reinstalled shortly after snowmelt. The monitor began operating again on April 4, 2005.

The station is located on a bridge, and river water is pumped up to the station where the water quality is monitored. The pump must be shutdown in winter, roughly November through April, due to ice. To measure temperatures in winter, an additional pair of temperature and conductivity probes was installed in the river below the ice line in the summer of 2005 for operation during the final winter of the program (2005-06).

4.1.3 Stream-Flow Gaging Station for the Minnesota River at Fort Snelling

MCES maintains a long-term monitoring station at Fort Snelling (MI 3.5), where water quality was monitored but not flow. Daily or continuous flow data at the upstream and downstream boundaries are essential for calibrating the hydrodynamic model (Cole and Wells, 2002). Since 1934 the USGS has operated a stream-flow gaging station near Jordan but none farther downstream. A gaging station near the mouth is especially important for the lower Minnesota River because an unknown amount of backwashing occurs at times from the Mississippi River. A downstream station will help define boundary conditions in the model, shed light on the frequency and magnitude of backwashing from the Mississippi River, and more accurately estimate loads at the mouth of the Minnesota River.

In January 2004 the USGS completed installation of a continuously operated stage-velocity gaging station at Fort Snelling State Park near mile 3.5 (USGS, 2003a). The primary piece of equipment at the station is a side-scanning acoustic Doppler velocity meter, which will record information about river velocity, direction of flow, and stage. Real-time data will be posted at the following Web site under site number 05330920:

http://waterdata.usgs.gov/mn/nwis/current/?type=flow

Index-velocity relationships are being developed to estimate discharge from velocity and stage. Pooling effects and backwashing may make it difficult to accurately estimate discharge at low flows. Water temperature and precipitation are also continuously monitored at this station.

4.1.4 Study of Mixing Characteristics at Five Long-Term River Monitoring Stations

At the beginning of the project, it was not known how well the river was mixed at different flows and locations. This information is critical for determining appropriate sampling protocols for the monitoring program. It is also needed to properly design the model grid elements, such as the number of dimensions (1-D, 2-D, or 3-D) and depths of the vertical layers. In 2003 and 2004, the USGS conducted a study of the mixing characteristics at five locations in the lower Minnesota River on six dates representing a variety of river flows (USGS, 2003b).

Dissolved oxygen, specific conductance, temperature, pH, and turbidity were measured at the five MCES long-term monitoring stations (miles 3.5, 8.5, 14.3, 25.1, and 39.4). At each station, the parameters were measured from a boat at five points across the channel: near the left edge of water, at the left quarter point, at mid-channel, at the right quarter point, and near right edge of water. Measurements were taken within a meter of the river surface and river bottom at each location. When differences of a certain magnitude were noted between the top and bottom measurements at any location, the parameters were measured at 3-ft increments along a vertical profile at that location.

4.1.5 Rapid Assessment of Sediment Bed in the Lower Minnesota River

The Minnesota River has been generally characterized as having a sand bed, but fine materials, such as silts, clays, and organic matter, are deposited at reduced flows at various locations. The presence of fine materials would indicate the potential for oxygen demand and nutrient fluxes from the sediment bed. To quickly and inexpensively determine the location and thickness of deposits of coarse and fine materials in the surficial layer of the sediment bed, the partners rec ommended a sediment-bed survey using a rapid assessment technique. A map of the survey results would help determine sampling locations for measuring sediment oxygen demand and nutrient fluxes. The results could also guide modeling approaches for simulating these factors.

The USGS conducted a sediment-bed survey using continuous seismic-profiling equipment during the week of September 22, 2003 when river flows near Jordan were between 500 and 600 cfs (USGS, 2003c). From past modeling efforts, it appeared that fine materials would settle at flows less than 1,500 cfs. Conditions in September 2003 were ideal for describing sediment deposition under low flows; however, they limited the survey to the lower 26 miles because the upper reach was not navigable by motorboat. The lower 22 miles are most important to the project because this reach is listed as impaired due to low oxygen on the State's list of impaired waters.

Profiles were taken along the right and left edges of the river and on ~720 transects every ~200 feet along the river channel. Identification of the bed material was field verified by collecting sediment cores and visually comparing the material to samples of known grain size (e.g., clay, silt, sand, and gravel). The sediment cores were not analyzed in the laboratory. Profiling data for the top two sediment layers were later processed by the USGS and mapped by MCES. The observed grain size, location, and thickness of deposits are recorded in the data.

4.1.6 Determination of Ground-Water Inflows to the Lower Minnesota River

Ground-water inflows and outflows are important to the water balance and quality in many rivers. It was assumed that ground water was the major source of flow to the lower Minnesota River under drought conditions because runoff is minimal at these times; however, much of the ground water enters indirectly through the headwaters, tributaries, and discharges. Monitoring programs were in place for these indirect sources but not for direct ground-water inflows, such as springs and seeps. The loss of river flow to ground water is also possible. A "seepage" study under steady, low river flows was recommended to determine whether ungaged ground-water inflows to and outflows from the lower Minnesota River were important enough to warrant further studies to quantify the flows and loads.

On September 8 and 9, 2003, the USGS conducted a study of ground-water inflows when flows in the Minnesota River near Jordan were around 500 cfs (USGS, 2003d). As in the sediment-bed survey, conditions were ideal for studying the river at low flow; however, the pooling effect of the navigation system made flow measurements in the lower 20 miles difficult and unreliable. Unfortunately, it is this lower reach that is most important to the modeling project. From the seepage study, the USGS was able to deliver flow estimates for the upper 20 miles of the Minnesota River and flow estimates for all significant tributaries to the entire 40-mile reach.

An acoustic Doppler current profiler was used to measure, or attempt to measure, flow at 12 locations in the lower 40 miles of the Minnesota River. A total of 16 tributaries to this reach were surveyed, and where streams were running, a Price current meter was used to estimate flow. Flow data for large permitted discharges were measured or obtained. By subtracting upstream river flow plus the sum of tributary and point-source flows from the downstream river flow for each reach, the amount of direct ground-water inflow or outflow was estimated, and the reach could be described as gaining or losing in regards to ground water. The profiler also provided valuable information on the complex hydrodynamics of the lower 20 miles at reduced flows.

4.2 PLANNED STUDIES

In the summer when river flows are low, two special field studies are planned in addition to low-flow monitoring by MCES:

- Assessment of oxygen dynamics, including major sources and sinks
- Synoptic survey of diurnal fluctuations in DO and other parameters

The oxygen-dynamics assessment and synoptic survey are described in Sections 4.2.1 and 4.2.2.

In March 2005, the Council entered an agreement with the USACE to conduct four research projects on nutrients and sediments in the lower Minnesota River under a variety of flows:

- Nutrient bioavailability
- Phosphorus sorption
- Sediment characteristics and nutrient fluxes
- Annual budgets of sediment and nutrients

With MCES assistance, the Eau Galle Aquatic Ecology Laboratory will conduct fieldwork for the first three USACE projects in 2005 and 2006. Annual budgets will be compiled for three water years: 2004, 2005, and 2006. The four USACE projects are described in Sections 4.2.3 to 4.2.6.

4.2.1 Oxygen Dynamics Assessment

The objective of this study is to conduct a comprehensive assessment of oxygen dynamics in the lower 40 miles of the Minnesota River during the summer when river flows at Jordan are less than 2,000 cfs. Understanding oxygen dynamics is the top priority for the Lower Minnesota River Model project. HydrO_2, Inc., a consulting firm, has been contracted by the Council to conduct the assessment, which will include measurements or estimates of the following processes (HydrO_2, 2004):

- **Reaeration,** or the transfer of oxygen from the atmosphere to the river, using a non-radioactive krypton gas technique
- **Travel time** between sampling locations, using a tracer dye study
- **Atmospheric diffusion,** or the movement of oxygen molecules from high concentrations to low concentrations between the atmosphere and river, using a floating-dome diffusion method
- **Community oxygen metabolism,** or around-the-clock measurement of oxygen gains and losses in the river from all sources and sinks in the air, water, and sediment, using a diel curve method
- **Water-column production and respiration,** or around-the-clock measurement of oxygen gains and losses in the water column due mainly to the activities of phytoplankton, using a light and dark bottle method
- **Community substrate oxygen demand** (CSOD), or the loss of oxygen due to biochemical processes across all substrates, including sediment, rocks, logs, and aquatic plants, using a computational method
- **Sediment oxygen demand** (SOD), or the loss of oxygen due to chemical oxidation and the decomposition of organic matter in the sediment bed (a component of CSOD), using an *in situ* chamber method

The most recent wasteload allocation study (MPCA, 1985) ranked reaeration and sediment oxygen demand rates among the most important inputs to a dissolved oxygen model of the lower Minnesota River. By measuring these and the other processes at the same time, a complete picture of the various credits and debits to the oxygen budget will be developed.

The oxygen dynamics assessment will be conducted under specific environmental conditions:

- Summer (June 1 through September 15)
- Low river flow (less than 2,000 cfs at Jordan, Minnesota)
- Warm water temperatures (mean daily temperature greater than 20°C)
- Steady-state conditions (dry, warm weather forecasted for the next 6-10 days)

An optional second assessment may be conducted under a different flow regime (e.g., nearer the 7Q10 flow of approximately 300 cfs).

Reaeration will be estimated for as much of the 40-mile reach as possible, using the krypton gas technique, floating dome method, or a combination. Oxygen metabolism, production, respiration, and demand will be measured at six discrete locations. The locations initially selected are river miles 1.2, 6.8, 10.8, 14.6, 25, and 37, which are generally upstream and downstream of major point sources.

4.2.2 Synoptic Field Survey

The summer low-flow monitoring program described in Section 3 will provide information on week-to-week changes in water quality during a summer drought. Also of interest are diurnal fluctuations due to algal activity. The continuous monitors at Jordan and Fort Snelling will provide 24-hour information at these two locations, but a synoptic survey of water quality at multiple stations in the lower reach was recommended.

The MPCA plans to conduct one or two synoptic surveys of the lower 21 miles of the Minnesota River in the summer when river flows at Jordan are less than 1,500 cfs (MPCA, 2005). The synoptic survey will not be conducted at the same time as the oxygen dynamics assessment because MPCA staff and equipment are needed for the assessment. During the weeklong synoptic survey, DO, temperature, pH, and conductivity will be monitored continuously using sonde-equipped buoys at four locations (approximate): river miles 20.75, 15.1, 11.2, and 7.0. In addition, daily grab samples will be collected at miles 15.1 and 3.5 for laboratory analysis. Only the Minnesota River will be monitored by the MPCA; tributary and effluent data will be obtained from other monitoring programs.

In conjunction with grab sampling at miles 15.1 and 3.5, field measurements will be taken at four points in the cross-section in a diamond-shaped pattern (mid-depth at the quarter points and one-third and two-thirds depths at mid-channel). Secchi depth will be measured at the quarter points across the channel. Water-quality samples will be collected at one-half the Secchi depth and two-thirds the water-column depth and analyzed for nutrients, solids, chlorophyll, and organic carbon. At mid-channel, DO, temperature, pH, and conductivity will also be measured at one-half the Secchi depth.

The synoptic river survey must be coordinated with MCES and local partners to ensure that samples are collected on all monitored streams at least once during the survey. Grab samples or composite samples collected over equal time intervals could be collected. The monitored streams that enter the Minnesota River downstream of mile 21 are Purgatory Creek, Eagle Creek, Credit River, Nine Mile Creek, and Willow Creek.

4.2.3 Nutrient Bioavailability

The lower Minnesota River contains excess levels of nutrients, specifically nitrogen and phosphorus, which may promote algal growth. However, nutrients exist in various forms, with some forms (e.g., soluble reactive phosphorus and ammonia nitrogen) more readily available for algal uptake than others (e.g., calcium-bound phosphorus and organic nitrogen).

The U.S. Army Engineer Research and Development Center (ERDC) will conduct research to determine the fractions of biologically-available and -unavailable nutrients, especially phosphorus, in river loads (ERDC, 2004). The Eau Galle Aquatic Ecology Laboratory in Spring Valley, Wisconsin, will conduct the research with MCES field assistance. In 2005 and 2006, water samples will be collected at Jordan (MI 39.4) and Fort Snelling (MI 3.5) during different flow regimes and seasons in order to assess input-output dynamics for the lower Minnesota River. In addition to the phosphorus analyses in the base monitoring program (Table A.2), the following fractions will be measured: loosely bound, iron-bound, labile organic, aluminum-bound, calcium-bound, and refractory organic phosphorus.

4.2.4 Phosphorus Sorption

In conjunction with researching nutrient bioavailability, the Eau Galle Aquatic Ecology Laboratory will study the kinetic and equilibrium processes of phosphorus as it moves between aqueous and particulate phases (ERDC, 2004). These processes control the degree to which soluble phosphorus becomes attached (sorbed) to suspended particles and, therefore, less available for algal growth. Combined, the sorption and bioavailability studies will provide insights on the amount of phosphorus available for algal growth under different flows and seasons.

Suspended solids in river samples will be concentrated via settling and centrifugation. The water medium for the experiments will closely reflect ionic characteristics of the lower Minnesota River. For kinetic studies, the suspended solids will be subjected to a moderately high concentration of phosphorus. Samples for soluble reactive phosphorus will be collected at varying time intervals to determine kinetic characteristics. For equilibrium studies, the suspended solids will be exposed to a range of phosphorus concentrations for up to 24 hours. For both studies, temperature will reflect ambient river temperatures and be controlled using a darkened environmental chamber.

4.2.5 Sediment Characteristics and Nutrient Fluxes

The sediment bed of the lower Minnesota River has not been monitored for nutrient fluxes but is a potential source. In previous studies (MPCA, 1985), high levels of sediment oxygen demand were measured in the lower 20 miles, which may indicate the presence of materials and conditions for nutrient releases. The deeper and slower waters of the navigation channel may promote the deposition of organic matter and lower DO concentrations at the sediment-water interface, which may, in turn, promote nutrient releases.

The Eau Galle Aquatic Ecology Laboratory will study sediment characteristics and measure sediment nutrient fluxes in the lower Minnesota River (ERDC, 2004). Sediment characteristics will be examined for comparison with nutrient fluxes. Sediment cores or ponar samples will be collected at 10-15 randomly selected sites during the summers of 2005 and 2006, ideally when river flows are less than 1,500 cfs. The sediment-bed map compiled by the USGS and MCES will be used to select sites, along with other information. The upper 5-10 centimeters of surficial sediment will be analyzed for a suite of physical and chemical variables, including organic content and nutrient fractions.

Intact sediment cores will be collected for determination of diffusive nitrogen (ammonium) and phosphorus (soluble reactive) fluxes. Up to 48 intact sediment cores will be analyzed for nutrient fluxes at incubation temperatures ranging from < 10 C to 25-30 C to represent seasonal differences. Replicate sediment cores will be incubated at the collection temperature under oxic and anoxic conditions.

4.2.6 Annual Budgets of Sediment and Nutrients

The Eau Galle Aquatic Ecology Laboratory will also compile annual budgets of sediment and nutrients in the lower Minnesota River and analyze the relative contributions of loading sources (ERDC, 2004). Information on inputs to the Minnesota River (i.e., headwaters at Jordan, tributaries, and point sources) and the output to the Mississippi River near Fort Snelling will be evaluated via mass balance to examine sediment, nitrogen, and phosphorus dynamics and source-sink relationships. Tributary and point-source loads will be estimated via the software program FLUX or other tools. Evaluations will be made on annual and seasonal time scales over a three-year period (water years 2004 through 2006). The budgetary analyses will help identify which pollutant sources are most important under different flows and seasons and whether there are unexpected sources or sinks in this reach of the river. It will also help quantify the cumulative loads of sediment and nutrients from sources between Jordan and Fort Snelling.

4.3 PROPOSED STUDIES

The University of Minnesota proposed a special field study to locate and monitor springs along the lower Minnesota River. Based on the results of the USGS seepage study, MCES decided not to pursue additional ground-water studies, including the University's spring inventory. The proposal is described in the following section.

At this time, no additional special studies have been proposed, but proposals will be solicited if important research gaps are identified.

4.3.1 Spring Location and Monitoring

The contribution of springs and seeps to the base flow and pollutant load of the Lower Minnesota River has not been quantified. The University of Minnesota proposed to systematically inventory the locations of springs and seeps in the lower Minnesota River valley and measure their flow and water quality (Alexander and Nagle, 2003). This study would provide a quantitative estimate of the contribution of ground-water inflows to the base flow and pollutant loads of the river.

The inventory would use the Global Positioning Satellite (GPS) system to map the locations of the springs, groundwater seeps, and other groundwater discharges (calcareous fens, flowing wells, dewatering discharges, etc.) in the lower Minnesota River valley. Water-quality samples would be collected from these sources and other open bodies of water. All samples would be analysed for cations and anions, and selected samples would be analysed for tritium. This basic chemistry would permit the ground-water flows from various surficial and bedrock aquifers to be differentiated into categories with characteristic pollutant loadings. Several of the ions to be analysed are affected by redox reactions and would provide additional constraints on nutrient cycling in the lower Minnesota River. Flow rates from the springs and seeps would be measured. The data would provide quantitative constraints on the modelling of river flows.

The USGS seepage study (Section 4.1.6) found that direct ground-water inflows were not an important contributor to the base flow of the Minnesota River. Ground-water inflows may be an important indirect source of flow and loads to the Minnesota River through the headwaters, tributaries, and point sources, but these inflows are being monitored through other programs. For this reason, the Metropolitan Council decided not to pursue additional ground-water studies to quantify flows and loads.

4.4 SUGGESTED STUDIES

Other studies have been suggested by project partners, stakeholders, and other interested parties, including the following:

- Resuspension and deposition studies. The model developer recommended a “shaker” study to measure resuspension rates in the lower Minnesota River and support application of the resuspension algorithm. A shaker study was conducted at selected sites in the Mississippi River for the advanced eutrophication model (HydroQual, 2002, Section 3.2.1).

- The USGS suggested a synoptic survey (2-3 days) of water quality at 17 river locations from mile 39.7 to 0.5 during summer low flow conditions. At each river site, the USGS would collect depth-integrated samples from at least 10 locations across the river and form a composite sample for laboratory analysis. MCES would monitor discharges and tributaries at the same time. The USGS survey would provide more water chemistry, cover more locations, and provide more accurate data at each location than the MPCA synoptic survey, which focuses on diurnal field measurements. The summer low-flow monitoring program (Section 3) will provide weekly data on water chemistry at 10 river locations, but most samples will be discrete grab samples at mid-channel.

- Synoptic survey of water quality in winter. Winter is suspected as a critical period for DO concentrations in the Minnesota River because ice cover can be widespread during prolonged cold weather. An ice cap seals off the river from atmospheric inputs of oxygen. However, monitoring the river in the winter is problematic due to freezing and malfunctioning equipment and unsafe ice and cold conditions for field staff.

- Ice-cover survey. The CE-QUAL-W2 model has the ability to simulate the formation and breakup of ice. Field data would be valuable for testing this ability. Snow and ice conditions are noted in the immediate vicinity of MCES’ five long-term monitoring stations; however, access is limited or difficult along the rest of the lower Minnesota River. Use of satellite imagery has been suggested as an alternative.

To date, MCES has not solicited proposals for any of the suggested studies. The project team remains open to additional studies, but the monitoring program is slated to end in September 2006.

REFERENCES

Alexander, Jr., E.C. and A. Nagle, 2003. Spring Location and Monitoring for the Lower Minnesota River Model. Proposal by the University of Minnesota, Department of Geology and Geophysics, Minneapolis, MN.

Barr, 2001. Engineer's Annual Report—Riley-Purgatory-Bluff Creek Watershed District. Prepared for years 1974-1999 by Barr Engineering Company, Minneapolis, MN.

Bonestroo, Rosene, Anderlik and Associates, Inc., 2001. Strategic Action Plan for the Citizens of the Lower Minnesota River Watershed. St. Paul, MN.

Carver County, 2004. Memorandum of Agreement Between Carver County Department of Environmental Services, the Lower Minnesota River Watershed District, and the City of Chaska Regarding Surface Water Monitoring in East Chaska and Chaska Creeks. Carver County Environmental Services, Chaska, MN.

Cole, T.M. and S.A. Wells, 2002. CE-QUAL-W2—A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.1. Draft Instruction Report EL-02-1 prepared for U.S. Army Corps of Engineers, Washington, D.C.

ERDC, 2004. Nutrient and Sediment Research on the Lower Minnesota River. U.S. Army Engineer Research and Development Center, Eau Galle Aquatic Ecology Laboratory, Spring Valley, WI.

HydrO_2, Inc., 2004. Plan of Study, Oxygen Dynamics Assessment, Lower Minnesota River. Prepared by HydrO_2, Inc., Athens, GA, for Metropolitan Council Environmental Services, St. Paul, MN.

HydroQual, Inc., 2002. Advanced Eutrophication Model of the Upper Mississippi River, Lock and Dam 1 Through Lake Pepin, Project Report. Prepared for Metropolitan Council Environmental Services, St. Paul, MN.

LMRWD, 1999. Water Management Plan. Prepared by the Board of Managers, Lower Minnesota River Watershed District, Shakopee, MN.

Metropolitan Council, 2004. 2003 Stream Monitoring and Assessment for 11 Metropolitan Area Streams. Publication No. 32-04-064, Metropolitan Council, St. Paul, MN.

MCES, 2003. Quality Assurance Program Plan: Stream Monitoring. Metropolitan Council Environmental Services, St. Paul, MN.

MCES, 2004a. Lower Minnesota River Model, Project Proposal: Proposal to develop an advanced water-quality model of the Minnesota River, Jordan to the mouth, and conduct river monitoring and studies to support the model. Metropolitan Council Environmental Services, St. Paul, MN.

MCES, 2004b. 2002 Stream Monitoring Report. Metropolitan Council Environmental Services, St. Paul, MN.

MCES, 2004c. Regional Progress in Water Quality: Analysis of Water Quality Data from 1976 to 2002 for the Major Rivers in the Twin Cities. Metropolitan Council Environmental Services, St. Paul, MN.

MCES, in progress. Seneca Effluent Aeration Study. Metropolitan Council Environmental Services, St. Paul, MN.

MDNR, 2003. A Canoe and Boating Guide to the Minnesota River (Le Sueur to Fort Snelling). Minnesota Department of Natural Resources, St. Paul, MN.

MPCA, 1985. Lower Minnesota River Waste Load Allocation Study. Minnesota Pollution Control Agency, St. Paul, MN.

MPCA, 2005. Minnesota River, Metropolitan Reach, Load Allocation Study Summer Field Survey Using Sonde-Equipped Buoys. Minnesota Pollution Control Agency, St. Paul, MN.

USGS, 2003a. Installation and operation of a continuous-record stream-flow gaging station at Minnesota River mile 3.5. U.S. Geological Survey, Minnesota District, Mounds View, MN.

USGS, 2003b. Study of mixing characteristics of the Lower Minnesota River. U.S. Geological Survey, Minnesota District, Mounds View, MN.

USGS, 2003c. A rapid assessment of the bed sediment in the Lower Minnesota River. U.S. Geological Survey, Minnesota District, Mounds View, MN.

USGS, 2003d. Determination of ground-water inflow into the Minnesota River between Jordan, Minnesota, and the mouth of the river. U.S. Geological Survey, Minnesota District, Mounds View, MN.

APPENDIX

Figure A.1. Map of the portion of the Minnesota River Basin lying with the Twin Cities Metropolitan Area (Matthew McGuire, MCES)

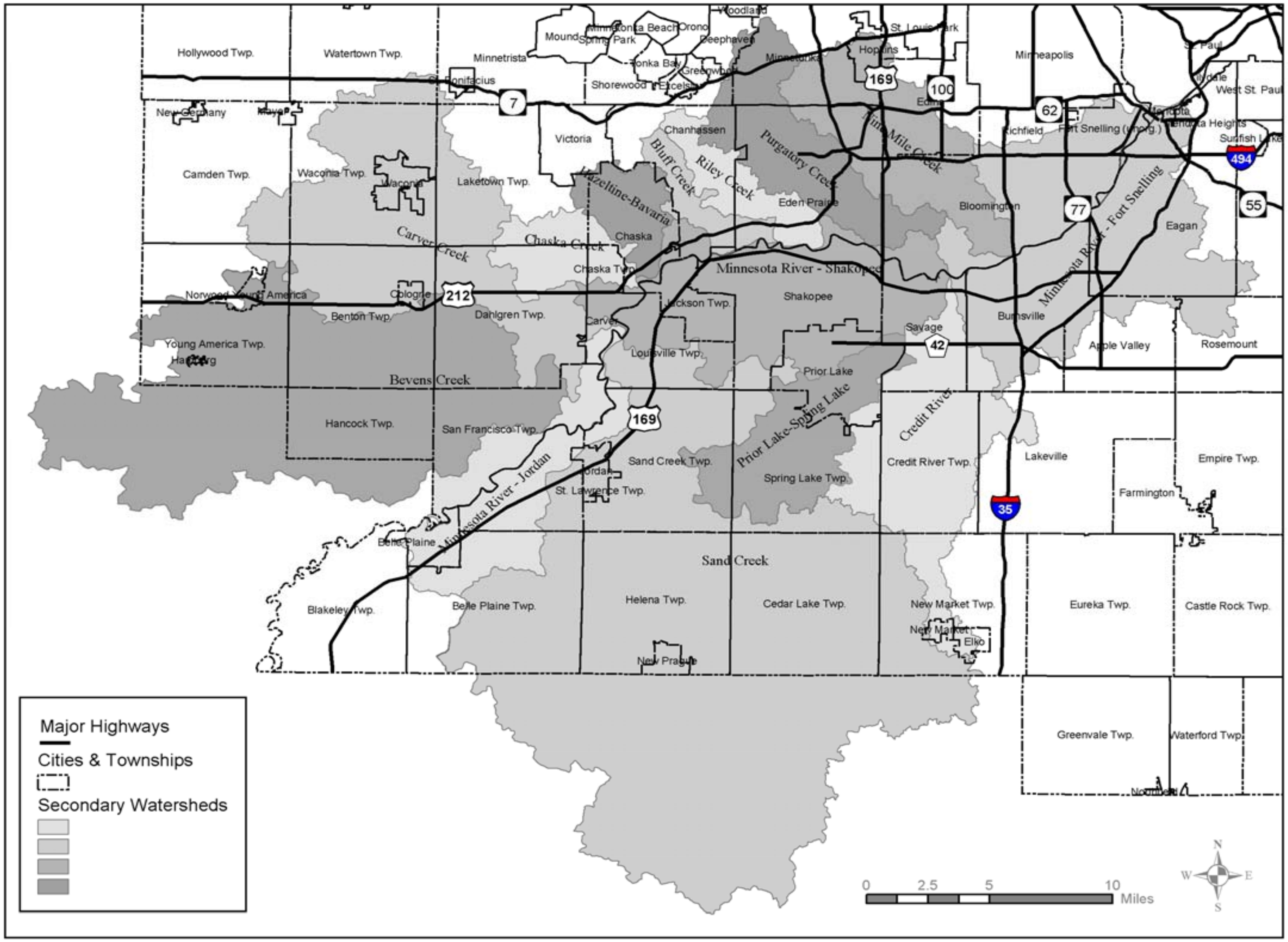

Figure A.2. Map of minor watersheds, major point sources, and MCES monitoring stations in the study area (Matthew McGuire, MCES)

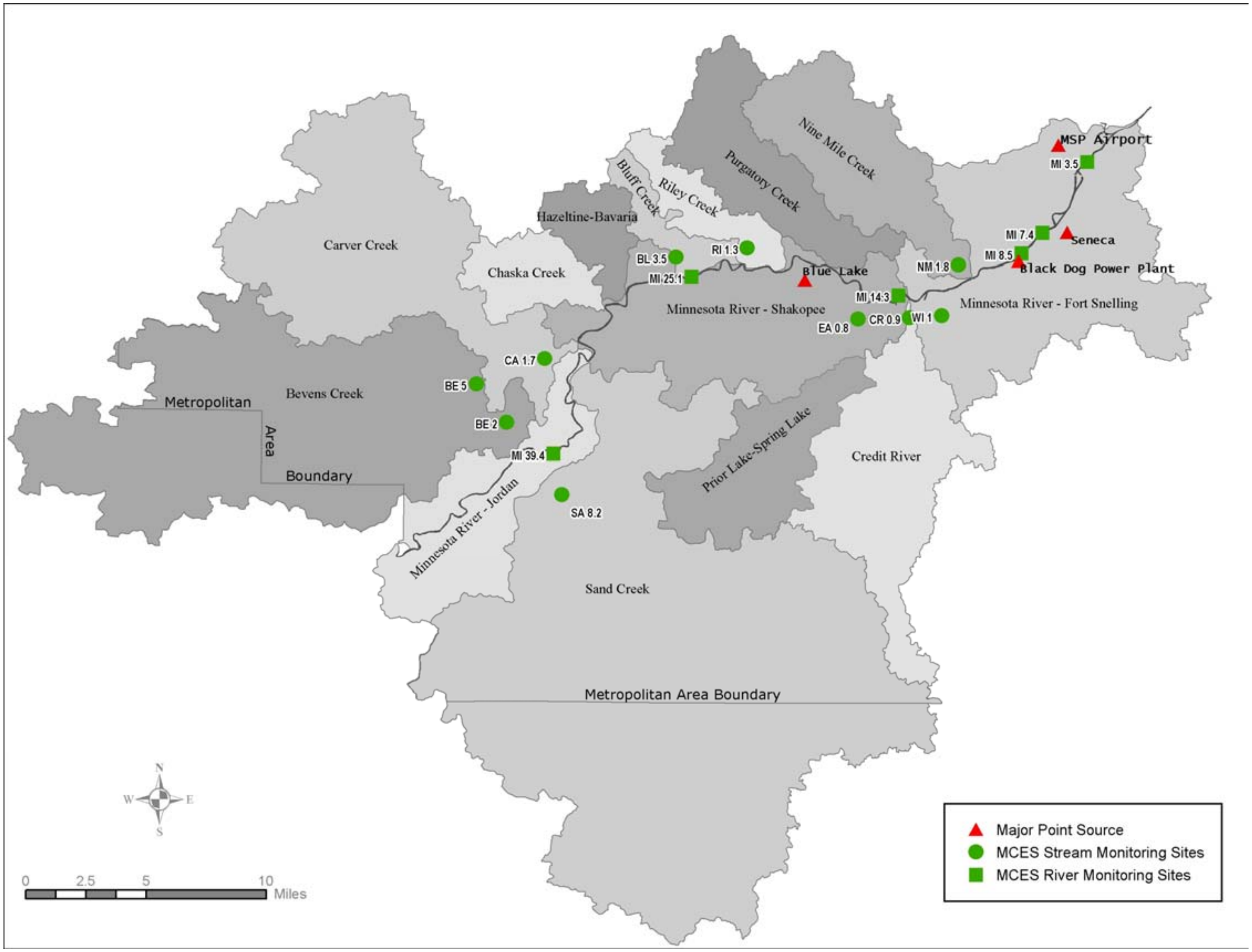

Table A.1. Base monitoring program for boundaries (Jordan, Fort Snelling, tributaries, and discharges)

Model Recommendations			River, Tributary, and Discharge Monitoring by Various Agencies						
			River (2 locations)		Tributaries (12)	Discharges (7 outfalls + 1 intake)			
Parameter	**Level**	**Freq**	**MCES MI 39.4**	**MCES MI 3.5**	**Full Set at 4; Subset at 9**	**MCES Blue Lake**	**MCES Seneca**	**Xcel: Black Dog (2 + 1)**	**MAC Airport (3)**
Flow	1	D or C	C	C	C	C	C	C	C
Temperature	1	D or C	C	C	C	D	D	C	W
Conductivity	2	D or C	C	C	C	2/M	2/M		
Dissolved oxygen	2	D or C	C	C	2/M or more	D	C	See text	1/year
PH	2	D or C	C	C	2/M+S	D	D	See text	D
Total dissolved solids	2	D or C	2/M+S	2/M	2/M +S	2/M	2/M		
Total organic C	1	W + S	W + S	W	2/M +S	2/M	2/M		
Dissolved organic C	2	W + S	W + S	W	2/M +S	2/M	2/M		
BOD and CBOD, 5-day	2	W + S	W ± S	W	2/M ± S	2/M*	2/M*		D
BOD and CBOD, 70-day			4/yr	4/yr	4/yr at 4 streams	4/yr	4/yr		4/yr at 020
Soluble reactive P	1	W + S	W ± S	W	2/M ± S	2/M	2/M		
Total P	1	W + S	W + S	W	2/M + S	2/M*	2/M*		1/year
Total dissolved P	2	W + S	2/M + S	2/M	2/M + S	2/M	2/M		
Total particulate P			2/M	2/M					
Total reactive P	2	W + S	2/M+S	2/M	2/M +S	2/M	2/M		
Nitrite-nitrate N	1	W + S	W + S	W	2/M +S	2/M*	2/M*		
Ammonium N	1	W + S	W + S	W	2/M + S	2/M*	2/M*		W
Total Kjeldahl N	2	W + S	2/M + S	2/M	2/M + S	2/M*	2/M*		1/year
Dissolved Kjeldahl N	2	W + S	2/M+S	2/M	2/M +S	2/M	2/M		
Total suspended solids	1	W + S	W + S	W	2/M + S	2/M*	2/M*		W or 1/M
Volatile suspended solids	1	W + S	W + S	W	2/M + S	2/M	2/M		
Dissolved silica	2	W + S	2/M±S	2/M	2/M+S	2/M	2/M		
Chlorophyll *a*	2	W + S	2/M±S	2/M	Collect some to see if #s are low enough to ignore	Collect some to see if #s are low enough to ignore			
Phytoplankton biomass	2	M	1-2/M	1-2/M					
Light readings	2	M	Boat runs	Boat runs					

Level:	1 Minimum parameter, 2 Additional parameter (Level as listed in CE-QUAL-W2 manual)
Frequency:	D daily, C continuous, W weekly, +S and storm sampling, ±S and some storm sampling, 2/M twice a month, M monthly

* Blue Lake and Seneca WWTPs: Monitored more frequently (3-5/wk) by Operations for process control or permit. See text.

Table A.2. Base monitoring program at intermediate river stations

Model Recommendations			River Monitoring by Three Agencies					
			MCES			Xcel	MAC*	MAC*
Parameter	**Level**	**Freq**	**MI 25.1**	**MI 14.3**	**MI 8.5**	**MI 11.5**	**MI 4.2**	**MI ~0.3**
Temperature	1	2/M	W	W	W	C	W	W
Conductivity	1	2/M	2/M	2/M	2/M			
Dissolved oxygen	1	2/M	W	W	W	See text	W	W
PH	1	2/M	W	W	W	See text	W	W
Total dissolved solids	2	M	2/M	2/M	2/M			
Total organic C	1	M	2/M	2/M	2/M			
Dissolved organic C	2	M	2/M	2/M	2/M			
BOD and CBOD, 5-day	2	M	2/M	2/M	2/M		W	W
BOD and CBOD, 70-day			4/yr	4/yr	4/yr			
Soluble reactive P	1	M	2/M	2/M	2/M			
Total P	1	M	2/M	2/M	2/M			
Total dissolved P	2	M	2/M	2/M	2/M			
Total particulate P					2/M			
Total reactive P	2	M	2/M	2/M	2/M			
Nitrite-nitrate N	1	M	2/M	2/M	2/M			
Ammonium N	1	M	W	W	W		W	W
Total Kjeldahl N	2	M	2/M	2/M	2/M			
Dissolved Kjeldahl N	2	M	2/M	2/M	2/M			
Total suspended solids	1	M	2/M	2/M	2/M			
Volatile suspended solids	1	M	2/M	2/M	2/M			
Dissolved silica	2	M	2/M	2/M	2/M			
Chlorophyll *a*	1	M	2/M	2/M	2/M		* Required only during June-September when river flows near Jordan are less than 1,000 cfs.	
Phytoplankton biomass	2	M						
Light readings	2	M	Boat runs	Boat runs	Boat runs			

Level: 1 Minimum parameter, 2 Additional parameter (Level as listed in CE-QUAL-W2 manual)
Frequency: D daily, C continuous, W weekly, +S and storm sampling, ±S and some storm sampling, 2/M twice a month, M monthly