2005 Project Abstract
For the Period Ending June 30, 2008

PROJECT TITLE: Accelerating and Enhancing Surface Water Monitoring
PROJECT MANAGER: Daniel Helwig
AFFILIATION: Minnesota Pollution Control Agency (MPCA)
MAILING ADDRESS: 520 Lafayette Road
CITY/STATE/ZIP: St. Paul, MN 55155
PHONE: 651-296-7215
FAX: 651-297-8324
E-MAIL: daniel.helwig@pca.state.mn.us
WEBSITE: www.pca.state.mn.us
FUNDING SOURCE: The Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2005, First Special Session, Chp. 1, Art 2, Sec.11, Subd.7b
Appropriation Language: 7b W8 Accelerating and Enhancing Surface Water Monitoring for Lakes and Streams $600,000 $300,000 the first year and $300,000 the second year are from the trust fund to the commissioner of the pollution control agency for acceleration of agency programs and cooperative agreements with the Minnesota Lakes Association, Rivers Council of Minnesota, and the University of Minnesota to accelerate monitoring efforts through assessments, citizen training, and implementation grants. This appropriation is available until June 30, 2008, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

APPROPRIATION AMOUNT: $600,000.00

Overall Project Outcome and Results

Building upon and continuing work begun from a 2003 appropriation, this second appropriation for the Accelerating and Enhancing Surface Water Monitoring Project was designed to pilot new monitoring approaches for streams (biological and remotely sensed), and to educate and increase citizen participation in water monitoring efforts in Minnesota.

The Minnesota Pollution Control Agency's (MPCA) goal was to develop and pilot a systematic, intensive, watershed assessment monitoring system to identify waters exhibiting impairments. MPCA staff using LCMR funds sampled 57 sites in the Snake River Watershed using the intensive watershed assessment monitoring system. In addition, staff sampled 105 sites in the Rainy and Red River Basins to complete sampling needed to develop a state-wide index of biological integrity. The University of Minnesota Remote Sensing Laboratory's (RSL) objective was to develop and evaluate the potential of remote sensing for monitoring water quality of rivers. The RSL continued work started with 2003 LCMR funds to collect hyperspectral remote sensing data and water quality data in 2004, 2005, and 2007 for 7 major river systems in Minnesota. Strong relationships were found between the remote sensed data and water quality data; this indicates an excellent potential for use of this technology in large river systems. The University of Minnesota Water Resources Center's (WRC) goal was to expand and support a network of volunteers monitoring macroinvertebrates and *E. coli* bacteria on lakes and streams in Minnesota. The WRC trained 66 volunteers in 9 workshops, resulting in 48 sites being monitored on 28 different lakes and streams in 18 Minnesota counties. In total, 369 bacteria samples were collected, with 22 samples exceeding state standards. Minnesota Waters' objective was to continue enhancement of the ability of volunteer citizen groups to collect water quality data that will be useful for local water management and/or state water quality assessment.[1]

Project Results Use and Dissemination

[1] A separate abstract and final work program report were assembled to cover the Minnesota Waters portion of the LCMR funding. Please refer to those documents for further information.

The MPCA is currently using this intensive watershed monitoring framework to plan future MPCA stream sampling efforts funded under the Clean Water Legacy Act. Approximately 3,600 sites have been picked to sample state-wide over the next 10 years (2008 to 2017). The Snake River Watershed Assessment Report will be available online at: http://www.pca.state.mn.us/water/biomonitoring/bio-streams-fish.html#reports.

The RSL has received coverage from the Star Tribune and Kare 11 on the river remote sensing project. The information is also available online at: http://water.umn.edu/rivers/index.html. Leif Olmanson presented and had a poster on, "Use of Airborne Remote Sensing Imagery for Water Quality Assessment of Minnesota's Rivers," with the initial results at the North American Lake Management Society annual conference at Madison, Wisconsin on November 9-11, 2005 and included a summary of current results in a presentation entitled, "Using Remote Sensing Applications for Local Water Planning & Management," at the Minnesota Waters: Lakes and Rivers Conference at Duluth on September 7, 2006.

The WRC presented the project at the 2006 Minnesota Lakes and Rivers Conference in Duluth, MN and at the MPCA Lakes and Stream Team Meeting in January, 2007. Information and the training manual are available online at: http://wrc.umn.edu/outreach/ecolimonitoring/index.html. Two peer reviewed journal articles are in preparation on the project and articles were included in the WRC Minnegram and the Minnesota Sea Grant Seiche newsletters. In addition, data from Minnesota has been included in presentations at 8 different regional/national meetings in 2006 and 2007. Finally, based on the results of a year end survey of volunteers in 2006, over 60% said they shared results of monitoring efforts with neighbors/friends, 30% with lake association leaders, 30% with elected or appointed officials, and 25% with local resource managers.

LCMR Final Work Program Report

Date of Report: June 30, 2008
Date of Work Program Approval: June 14, 2005
[1]**Project Completion Date:** June 30, 2008

I. Project Title: Accelerating and Enhancing Surface Water Monitoring

Project Manager: Daniel Helwig
Affiliation: Minnesota Pollution Control Agency (MPCA)
Mailing Address: 520 Lafayette Road, St. Paul, MN 55155
Telephone Number: 651-296-7215 **E-Mail:** daniel.helwig@pca.state.mn.us
Fax: 651-297-8324 **Web Address:** www.pca.state.mn.us

Location: Minnesota surface water resources and watersheds, statewide. Initial plans for Result 1 indicate that work will be completed in the St. Croix River Basin. For Result 2, tentative plans involve work on river confluences in the following watersheds: St. Croix, Mississippi, Minnesota, Blue Earth, Crow (North and South), and Rum. Result 3A has indicated volunteer interest in the Red River Basin, the St. Louis River Watershed, the Sauk River Watershed, and the Minnesota River Watershed at Mankato. All result locations are subject to change depending on volunteer interest, availability of field staff, and/or cost of work.

[2]**Total Biennial Project Budget:**

	Results 1, 2, 3a	Result 3b	Total
LCMR Appropriation:	**$ 350,000.00**	**$ 250,000.00**	**$ 600,000.00**
Minus Amount Spent:	**$ 350,000.00**	**$ 248,704.31**	**$ 598,704.31**
Balance:	**$ 0.00**	**$ 1,295.69**	**$ 1,295.69**

Legal Citation: ML 2005, First Special Session, Chp. 1, Art 2, Sec.11, Subd.7b.

Appropriation Language: 7b W8 Accelerating and Enhancing Surface Water Monitoring for Lakes and Streams $600,000 $300,000 the first year and $300,000 the second year are from the trust fund to the commissioner of the pollution control agency for acceleration of agency programs and cooperative agreements with the Minnesota Lakes Association, Rivers Council of Minnesota, and the University of Minnesota to accelerate monitoring efforts through assessments, citizen training, and implementation grants. This appropriation is available until June 30, 2008, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

[1] Project end dates and Results 1 and 2 milestones amended to better match project. Amended 9/29/06.
[2] Total Biennial Project Budget format changed per request by LCMR via Susan Von Mosch email 12/7/05.

II. and III. FINAL PROJECT SUMMARY

The Accelerating and Enhancing Surface Water Monitoring Project was designed to pilot new monitoring approaches for streams (biological and remotely sensed), and to educate and increase citizen participation in water monitoring efforts in Minnesota. The Minnesota Pollution Control Agency's (MPCA) goal was to develop and pilot a systematic, intensive, watershed assessment monitoring system to identify waters exhibiting impairments. MPCA staff using LCMR funds sampled 57 sites in the Snake River Watershed using the intensive watershed assessment monitoring system. In addition, staff sampled 105 sites in the Rainy and Red River Basins to complete sampling needed to develop a state-wide index of biological integrity. The University of Minnesota Remote Sensing Laboratory's (RSL) objective was to develop and evaluate the potential of remote sensing for monitoring water quality of rivers. The RSL continued work started with 2003 LCMR funds to collect hyperspectral remote sensing data and water quality data in 2004, 2005, and 2007 for 7 major river systems in Minnesota. Strong relationships were found between the remote sensed data and water quality data; this indicates an excellent potential for use of this technology in large river systems. The University of Minnesota Water Resources Center's (WRC) goal was to expand and support a network of volunteers monitoring macroinvertebrates and *E. coli* bacteria on lakes and streams in Minnesota. The WRC trained 66 volunteers in 9 workshops, resulting in 48 sites being monitored on 28 different lakes and streams in 18 Minnesota counties. In total, 369 bacteria samples were collected, with 22 samples exceeding state standards. Minnesota Waters' objective was to continue enhancement of the ability of volunteer citizen groups to collect water quality data that will be useful for local water management and/or state water quality assessment.[3]

IV. OUTLINE OF PROJECT RESULTS:

Result 1: *Develop and Initiate Progressive Biological Monitoring*

Description: A systematic site selection approach is needed to identify problem areas within major watersheds. Progressive site selection involves sampling in a watershed starting from larger streams and moving upstream to smaller streams, using integrated biological, physical, and chemical monitoring. This provides an unbiased systematic coverage within a watershed by ensuring streams with similar drainage areas are sampled with the same frequency. This initiative would allow two crews to sample a total of 100 sites over one field season.

Summary Budget Information for Result 1:	**LCMR Budget**	**$235,000.00**
	Minus amount spent	**$235,000.00**
	Balance	**$ 0.00**

[4]Project Milestones

June – September 2005: Partially sample the Red and Rainy river Basins

[3] A separate abstract and final work program report were assembled to cover the Minnesota Waters portion of the LCMR funding. Please refer to those documents for further information.

[4] Project milestones updated to better reflect project end dates. Amended 9/29/06.

October – May 2006: Enter all data into MPCA's Environmental Data Access database (EDA), develop IBI indices, pick sites, and develop site files for the 2006 sampling season.

June – September 2006: Sample the St. Croix River Basin for time trends, sample one watershed using the new progressive design. The watershed will be determined by the MPCA TMDL (Total Maximum Daily Load) program.

October – December 2006: Enter all data into EDA, and determine which watersheds are impaired in the Snake River pilot watershed.

January – March 2007: Determine what sites and parameters to sample in the impaired watersheds in the Snake River.

March – September 2007: Complete follow-up sampling in one or two impaired watersheds depending on needs.

September – December 2007: Computerize and assess data from the impaired watershed sampling.

January – June 2008: Write final condition report on the Snake River and assess the usefulness of the new design for Agency-wide use.

Completion Date: June 2008

Final Report Summary:

LCMR funds were used by the MPCA to develop and pilot a systematic and intensive watershed assessment system. In 2006, 57 sites in the Snake River watershed were sampled for biological, chemical, and physical indicators of impairment using a nested watershed framework. Sites were hydrologically selected ranging from large watersheds (~1000 square miles) to small watersheds (10-20 square miles) near each of the tributary mouths, providing an unbiased assessment of the watershed. Fish and invertebrate communities, water quality, bacteria, fish contaminants, flow, and habitat were sampled at each site. The information was used to develop a list of impaired sites approved by EPA in 2008. Follow-up investigations in the Ann and Mission sub-watersheds have been started to determine sources of impairments to develop total maximum daily load restoration goals and plans.

This new sampling design is serving as a framework for future MPCA stream sampling efforts funded through the Clean Water Legacy Act. Using this framework, approximately 3,600 sampling sites have been picked to sample state-wide. A 10-year schedule of watershed sampling has been developed to help guide state and local sampling efforts.

In addition to the Snake River watershed work, biologists hired with LCMR funds sampled 105 sites in the Red and Rainy Basins to complete sampling needed to develop a state-wide index of biological integrity.

Result 2: *Provide the capability to use remote sensing tools to assess rivers and streams.*

Description: Development of aircraft-based and satellite-based remote sensing of river water quality was started with LCMR funding in FY04-05. These additional funds will continue development and application of this technology to provide a cost effective measurement of river water quality. The focus of this effort will be to develop procedures that minimize the need for collection of ground-based data to calibrate remotely sensed measurements. One reconnaissance in late summer of 2005 would be completed for this biennium. This flight will be of similar duration and number of river reaches to the 2004 pilot study. The project will research and develop methods for acquiring and analyzing remotely sensed spectral reflectance data to estimate and map biophysical properties of rivers and streams. Key properties include: total suspended solids, turbidity, and chlorophyll. This would be a joint effort of the University of Minnesota Remote Sensing Lab (U of M RSL), MPCA, and DNR.

Summary Budget Information for Result 2:	**LCMR Budget**	**$65,000.00**
	Minus Amount Spent	**$65,000.00**
	Balance	**$ 0.00**

[5]Project Milestones

May – June 2005: Select and identify river and stream segments for data acquisition.
June – July 2005: Specify sensor system and contract for collection of acquisition of remote sensing imagery. Develop river sampling and field data collection plan in cooperation with MPCA, DNR, and other agencies.
August 2005: Collect remote sensing imagery and in-situ water properties data for calibration of remote sensing data.
September 05 – March 06: Process and analyze remote sensing data and develop initial models relating spectral reflectance trophic status and water quality conditions in river segments.
January 06 – June 07: Develop and document data acquisition, processing, analysis, and estimation protocols. Evaluate feasibility and make initial recommendations for continued data acquisition and analysis, including an additional 2007 mission based on evaluation of methods and results from 2005 mission.
July 07 – August 07: Collect remote sensing imagery and in-situ water properties data for calibrations of remote sensing data.
September 07 – March 08: Process and analyze 2007 remote sensing data and develop models relating spectral reflectance to trophic status and water quality conditions in river segments.
April 08 – June 08: Complete documentation of methods and results for all missions and finalize recommendations for future data acquisition and analysis.

Completion Date: June 30, 2008

[5] Project milestones amended to better reflect project end date. Amended 9/28/06.

Final Report Summary:

Data acquisition for monitoring river water quality using high resolution hyperspectral imagery

Recent activities directed at completing this project focused on processing and classifying airborne hyperspectral imagery acquired in 2007 and comparing the results with previously acquired 2004 and 2005 imagery. The imagery was collected by the Center for Advanced Land Management Information Technologies (CALMIT) at the University of Nebraska-Lincoln using hyperspectral imaging systems installed in a Piper Saratoga aircraft. The imaging systems used for the project changed over the three years of image acquisition as technological improvements of equipment, software and techniques became available. The imagery was processed in the University of Minnesota Remote Sensing and Geospatial Analysis Laboratory using ERDAS Imagine and ArcGIS software. Flight lines for each mission are shown in Figure 1.

In 2004, 40 miles of imagery were collected in six segments along the confluences of several key rivers in Minnesota using an Imaging Spectrometer (AISA-Classic) system. The river segments (Table 1) include the Minnesota-Mississippi, Mississippi-St. Croix, Mississippi-Crow and Rum, and Crow North-South Forks, which were acquired on August 19, 2004, and the Blue Earth-Watonwan and Blue Earth-Minnesota, which were acquired on August 20, 2004. Although this imagery is not technically hyperspectral (that term usually is used for spectra collected in more than 100 wavelength bands), the flexibility of the AISA-Classic Imaging Spectrometer system allowed key spectral bands related to water features to be selected. It included 26 spectral bands at 3-meter (m) spatial resolution, 24 bands at 2-m resolution, and 16 bands at 1 m. Weather conditions during the flights were clear except for the Blue Earth River segments, which were affected by some cumulus "popcorn" clouds. The imagery was corrected to "at sensor" reflectance.

Supporting field data were collected on August 19, 2004 near the same time as the remote sensing data acquisition for most of the sites and one day before the Blue Earth images were acquired. Sampling crews from the Minnesota Pollution Control Agency (MPCA), Metropolitan Council Environmental Services (MCES), Minnesota Department of Natural Resources and the Minnesota Department of Agriculture collaborated to collect field data at 37 locations. *In-situ* water quality data include transparency tube (T-tube), turbidity, total and volatile suspended solids (VSS), color, total chlorophyll *a* (Chl *a*), chlorophylls *b*, and *c*, and pheophytin *a*. Water color was analyzed by the Minnesota Department Health; the other analyses were completed at the MCES Laboratory.

Figure 1. Flight lines for hyperspectral image acquisition on Minnesota Rivers.

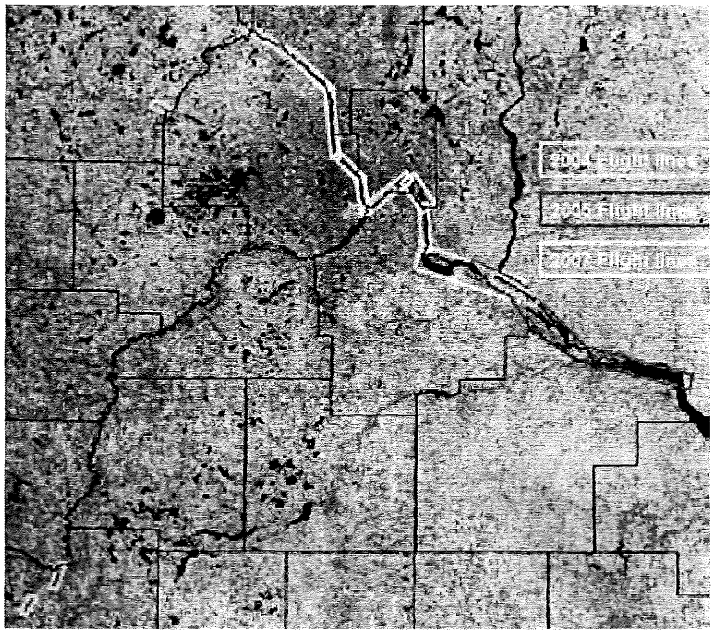


Table 1. Summary of data acquisition attributes, 2004.

Segment	Description	Date	Length (mi)	Resolution (m)	Spectral Bands
Crow N-S Forks	Confluence of North and South Forks of Crow River	Aug 19,2004	3	1	16
MS Crow-Rum	Mississippi R. above Crow R. to below Rum R.	Aug 19,2004	12	2	24
MN-MS	Confluence of Mississippi and Minnesota Rivers	Aug 19,2004	6	2	24
MS-STC	Mississippi R. Cofluence with St. Croix R.	Aug 19,2004	10	3	26
Blue-MN	Blue Earth R. Confluence with Minnesota R.	Aug 20,2004	5	2	24
Blue-WA	Blue Earth R. Confluence with Watonwan R.	Aug 20,2004	4	2	24

The 2005 imagery was acquired on August 15, 2005 along 36 miles of the Mississippi River from Spring Lake to Lake Pepin, including a 15-mile stretch along the lower portion of the Vermillion River from near Lake Isabelle to Lock and Dam No. 3. Additional imagery planned for the Blue Earth River could not be collected because of cloud cover. The images were collected using an AISA-Eagle hyperspectral imaging system, which had the capability of collecting data in more bands and a swath width three times wider than the system used in 2004. Imagery with a spatial resolution of 2 m was acquired in 86 contiguous spectral bands, ~2.5 nanometers (nm) wide, from 435 to 724 nm, ~20 nm wide from 742 to 896 nm and ~30 nm from 930 to 960 nm. Weather during the flights was clear, and excellent imagery was obtained. This imagery also was corrected to “at sensor” reflectance. At the time the images were being collected, crews from the MPCA and the MCES collected water samples at 22 sites along the river. Seven additional samples collected from the Blue Earth River were not utilized since the imagery was not collected. *In-situ* water quality data include T-tube water clarity, turbidity, total and volatile suspended solids, total chlorophyll *a*, *b*, and *c*, pheophytin *a*, and total phosphorus. The water quality variables were analyzed by the MCES Laboratory.

In 2007, an AISA-Eagle Hyperspectral Imager was used to collect imagery along a 60-mile stretch of the Mississippi River through the Twin Cities Metropolitan Area from the Rum River near Anoka to the St. Croix River near Prescott, Wisconsin. Imagery with spatial resolution of 2 m was acquired in 97 contiguous spectral bands, ~2.5 nm wide from 435 to 734 nm and ~10 nm from 744 to 950 nm. Weather conditions during the flights were clear and excellent imagery was obtained. The 2007 data were corrected to "at ground" reflectance using the ENVI FLASH Module, which uses the MODTRAN atmospheric correction model. This "atmospherically corrected" product yields reflectance spectra that resemble *in situ* reflectance spectra more closely than the "at-sensor" reflectance images collected in 2004 and 2005.

At the time the images were being collected, crews from the MPCA and the MCES collected water samples at 19 sites along the river. The *in-situ* water quality data include T-tube water clarity, turbidity, total and volatile suspended solids, total chlorophylls *a*, *b*, and *c*, and pheophytin *a*. The water sample analyses were completed at the MCES Laboratory.

Water Quality and River Flow

Water quality conditions associated with sediment and chlorophyll in the rivers of this study are spatially and temporally complex, and conditions within specific reaches of the rivers exhibit high variability depending on river flow and season. Pollutant loads also depend strongly on flow, which varied significantly between the three sets of image acquisition dates. The average volume contributions from major rivers in the Twin Cities Metropolitan Area (TCMA) to the flow of the Mississippi River below the confluence with the St. Croix River (i.e., below the TCMA) are 40–45% from the Mississippi River and 25–30% from the Minnesota and St. Croix Rivers (2004 Met Council Report). To determine river flows on the day of each flight, data were acquired from waterdata.usgs.gov. Data were available for the Minnesota River at Jordan and for the Mississippi near Anoka. A flow estimate was calculated for Stillwater using flow data at St. Croix Falls, Wisconsin multiplied by 1.1 to simulate Stillwater flow, as described in a 2004 Met Council Report. Daily flow data for the three sets of image acquisitions are shown in Table 2.

The contributions of the major rivers in the TCMA varied considerably for each mission (Table 2). In 2004; the contributions were similar for each river, with the Minnesota and the St. Croix River contributing 35% and the Mississippi contributing 30%. In 2005, the majority of flow came from the Mississippi River (56%), and the Minnesota River contributed 25% and the St. Croix 19%. In contrast, the majority of the flow in 2007 was from the Minnesota River (52%), and the St. Croix and Mississippi Rivers contributed 24% each.

Table 2. Flow contributions of major rivers in TCMA.

			August 19, 2004	August 15, 2005	August 30, 2007
River	Site	Discharge mean (cfs)	Discharge (cfs) - Contribution	Discharge (cfs) - Contribution	Discharge (cfs) - Contribution
Minnesota	Jordan	8810 - 33%	3190 - 35%	1840 - 25%	4160 - 52%
Mississippi	Anoka	11700 - 44%	2770 - 30%	4100 - 56%	1930 - 24%
St. Croix	Stillwater	6094 - 23%	3170 - 35%	1430 - 19%	1980 - 24%

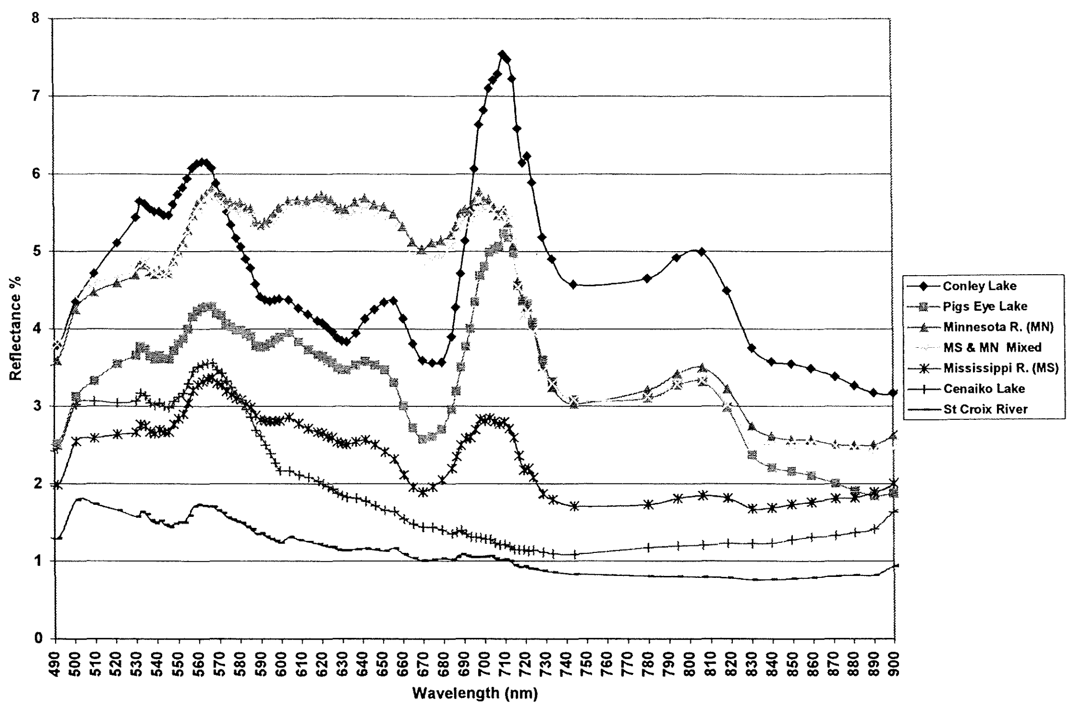
Spectral Characteristics of River Water Reflectance

Examination of the reflectance spectra of the atmospherically corrected 2007 imagery showed four distinct patterns that can be identified as characteristic of waters with different optically related water quality characteristics (Figure 2). The reflectance from waters dominated by inorganic suspended sediments is low at shorter wavelengths and increases with increasing wavelength through the visible and near infrared spectrum than decreases sharply. Examples include the Minnesota River and the Mississippi River downstream of the confluence with the Minnesota (mixed MS & MN), which can be characterized as having high inorganic sediment and moderate phytoplankton concentrations. The mixed MS & MN has a little less inorganic sediment and a little more phytoplankton than the Minnesota River.

In water dominated by phytoplankton the reflectance is generally similar to waters dominated by inorganic suspended sediments but includes some unique chlorophyll signals, including a chlorophyll absorption peak (reflectance minimum) around 675-680nm and a reflectance peak at 700-705 nm. Gittelson et al. (1994) found the red-edge (700-705 nm) to be a good predictor of chlorophyll, and more recent studies have found that the difference or ratio between the 700-705 nm peak and the trough caused by chlorophyll absorption around 675-680 nm is a good predictor of chlorophyll. This relationship was found to hold in laboratory experiments in which high levels of inorganic sediment were added to water samples with high concentrations of phytoplankton (Schalles et al., 1997). Examples in the river images include Conley Lake and Pigs Eye Lake, which are backwaters of the Mississippi River with very high phytoplankton concentrations and moderate suspended inorganic sediment. Another example is the Mississippi River upstream of the confluence with the Minnesota River, which is characterized by low levels of suspended inorganic sediment and moderate to high phytoplankton concentrations.

The remaining spectra have low phytoplankton and sediment. Lake Cenaiko is characteristic of very clear water and has a reflectance pattern similar to that of oligotrophic, clear-water Square Lake (Washington County) (Menken et al. 2006), which has a reflectance high around 560 nm and lower absorption in the blue and green portions of the spectrum. The St. Croix River has moderate levels of staining by humic matter, and its reflectance spectra is characterized by increased light absorption by CDOM in the blue and green portions of the spectrum.

Figure 2. Characteristic reflectance spectra from seven water bodies.



Water Quality Model Development

The primary objective of this project was to evaluate the feasibility of using aircraft-mounted reflectance spectral imagers to map water quality conditions in the optically complex waters of Minnesota's major river systems. A critically important component of the analysis involved evaluating the accuracy and reliability of the derived information on specific water quality variables, especially chl *a* and measures of suspended solids (turbidity, T-tube water clarity, Secchi depth, suspended solids concentrations). Many studies have investigated the use of remotely sensed data to predict these water quality variables, but the waters used in those investigations usually were dominated by either inorganic suspended sediment or phytoplankton. In this project we had a very optically complex water system: high inorganic sediment in the Minnesota River, moderate chlorophyll levels and lower sediment in the Mississippi river upstream of the Minnesota River, high chlorophyll levels and low inorganic suspended sediment in river backwaters and Lake Isabella, clear water in Lake Cenaiko, humic-stained water with low chlorophyll and sediment of the St. Croix River, and a variety of mixtures of these waters.

With representative samples from the hyperspectral imagery and the field calibration data we were able to develop models that predict several important water quality variables from reflectance data provided by the imagery. Model development was conducted using stepwise regression of single bands and band combinations to determine the best correlations separately for each year of data collection. Band combinations included both the difference and band ratios of all combinations. Because of the large number of bands and because a different sensor was used for the earlier mission, two sets of bands were used for model development. The first set used 13 bands related to water characteristics that are common among all three missions, and the second set was used to take advantage of the larger number of bands in the 2005 and 2007 missions. The 13 selected bands are associated with reflectance peaks and absorption troughs identified from the spectral signatures of representative water samples in reflectance plots (Figure 2).

The best simple and multiple regression relationships were explored using stepwise multiple regression analysis. Strong relationships were found between many bands and band combinations and the water quality variables for each data set, and strong relationships also were found for several water quality variables using some band combinations that were consistent among all three data sets. The relationships that were consistent for each data set are discussed further below. As expected, the second band set with 2005 and 2007 data had slightly stronger correlations for most variables.

Table 3 shows the band combinations that had the best consistent fit with the water quality variables. The strongest coefficient of determination observed for all data sets were for VSS and Chl *a*. VSS essentially is a measure of total particulate organic matter, and in these waters VSS probably is strongly correlated with phytoplankton. Chl *a* is a measure of phytoplankton biomass; thus these variables are most likely strongly related. The strongest coefficient of determination with VSS was the difference between band 703 and band 670 (Rf_{703} - Rf_{670}) with r^2 = 0.97, 0.98 (2005, 2007). The strongest coefficient of determination for chl *a* was the difference between band 700 and band 670 (Rf_{700} - Rf_{670}) with r^2 = 0.97, 0.95, 0.96 (2004, 2005, 2007). These are essentially the same band combinations found to correlate well with chl *a* in previously published studies (e.g., Shafique et al., 2003; Kallio et al., 2001; Zimba & Gitelson, 2006).

Table 3. Best fit (r^2) band combinations for selected water quality variables.

Variables	Band Combination	2004	2005	2007
VSS	b703 - b670		0.97	0.98
Chl *a*	b700 - b670	0.97	0.95	0.96
T-Tube	b710/b449, b703/b532		0.91	0.93
Turbidity	b710 - b449, b546/b492		0.91	0.94
TSS	b670 - b492, b710 - b546		0.93	0.92

Total suspended sediment (TSS) is a direct measurement of the mass concentration of organic and inorganic particles in the water, and turbidity (turb) is a measurement of how well light can penetrate water containing suspended particles. Turbidity is an indirect measurement of the organic and inorganic particles in the water, but other factors (e.g., particle size, shape and composition) affect turbidity in addition to the mass concentration of suspended solids. Transparency tubes (T-tube) provide a measurement of water clarity in rivers (instead of Secchi disks, which are used in lakes), and T-tube data thus are another indirect measurement of the amount of organic and inorganic particles in the water. TSS, turbidity and T-tube data are related, and as shown in Table 4, results from the Minnesota rivers are highly correlated.

Table 4. Correlation (r) between TSS, Turbidity and Transparency-tube.

	ln(T-Tube)	ln(TSS)	ln(Turb)
ln(T-Tube)	1.00		
ln(TSS)	**0.95**	1.00	
lnN(Turb)	**0.90**	**0.96**	1.00

For these variables the strongest relationships to the spectral bands were for the most part in the blue-green range and near the red-edge (700-705 nm). The best relation for TSS was the difference (Rf_{670} - Rf_{492}) and (Rf_{710} - Rf_{546}) with r^2 = 0.93, 0.92 (2005, 2007). For turbidity the difference (Rf_{710} - Rf_{449}) combined with the ratio (Rf_{546}/Rf_{492}) gave the best results with r^2 = 0.91, 0.94 (2005, 2007). The strongest relation of reflectance data with T-tube data was for the ratio (Rf_{710}/Rf_{449}) added to the ratio (Rf_{703}/Rf_{532}): r^2 = 0.91, 0.93 (2005, 2007).

Water Quality Map Creation

Having determined the best band combinations for each variable, we next developed models for each set of imagery to create water quality maps. Using the water quality variable data as the dependent variable and the band combination or combinations as independent variables, we performed least-squares simple or multiple regression using the general form:

Water Quality Variable = a(Band Combination) + b

or

Water Quality Variable = a(Band Combination 1) + b(Band Combination 2) + c

where a, b and c are coefficients fit to the calibration data by the regression analysis. The models were then applied to the imagery using Model Maker in ERDAS Imagine. Water quality maps of each variable were created from the imagery for all three years of over-flights and will be available as Google Maps in a RiverBrowser at water.umn.edu.

Representative examples of water quality maps (Figures 3, 4 and 5) show the complex patterns and interactions of sediment and chlorophyll in these river segments. These patterns illustrate the utility of aircraft-based river monitoring and indicate that current land-based water quality monitoring efforts are not able to characterize spatial variability of conditions in the river system. Figure 3 shows the classification of the 2005 imagery when the majority of the flow (56%) was from the Mississippi River. The relatively low inorganic sediment concentration is evident, and the deposition of sediment and clearing of the water can be seen in Lake Pepin. The resulting increased light availability and longer hydraulic residence time of water in Lake Pepin led to an increase in phytoplankton, and a blue-green (*Aphanizomenon*) bloom is clearly seen in the map. Phytoplankton concentrations also were elevated in the back water areas along the rivers.

Figure 3. Example water quality maps (turbidity and chlorophyll *a*). Mississippi and lower Vermillion Rivers – Spring Lake to Lake Pepin, August 15, 2005.

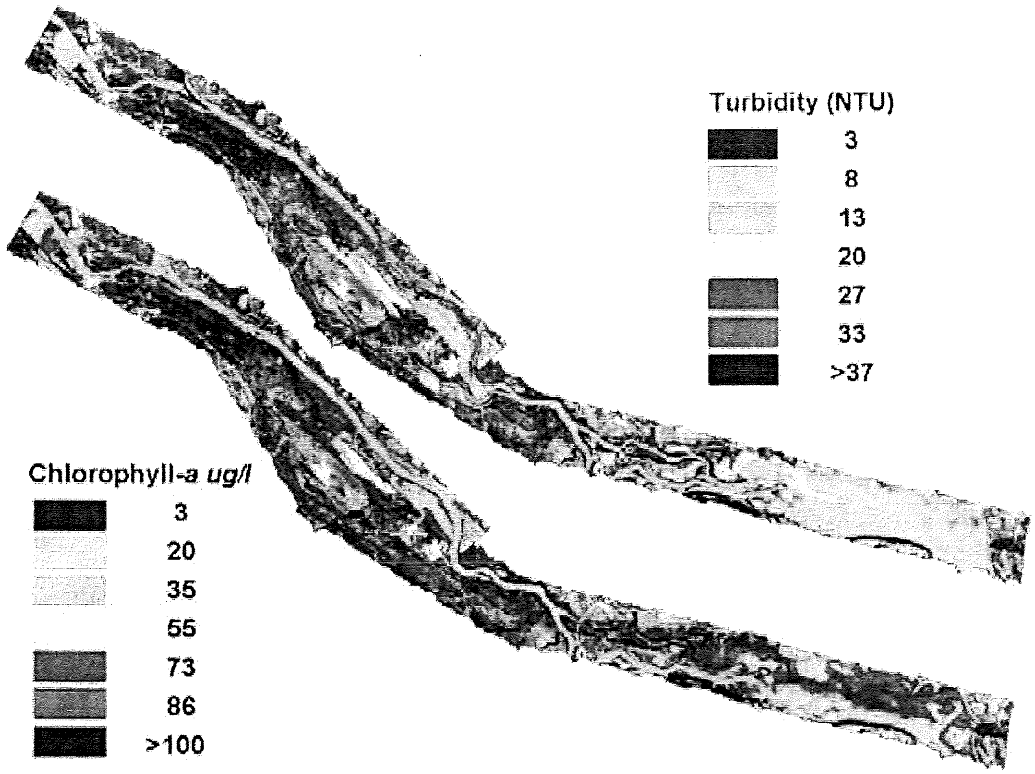


Figure 4 shows the classification of the August 30, 2007 imagery when the majority of the flow (52%) was from the Minnesota River, and Figure 5 is a blow up of the confluence of the Minnesota River with the Mississippi River. These results were obtained during the recovery efforts of the 35W bridge collapse when water levels were lowered in the Mississippi River. High sediment concentrations in the Minnesota River dominated conditions in the Mississippi River downstream of its confluence with the Minnesota River. Phytoplankton concentrations were low in the Minnesota River, likely because of a lack of light for phytoplankton growth. Phytoplankton concentrations were relatively high in the Mississippi River before the confluence with the Minnesota River, but decreased after the confluence because of dilution by the flow from the Minnesota River.

Figure 4. Example water quality maps (turbidity and chlorophyll-a). Mississippi River from the confluence of the Rum River to the confluence with the St. Croix River, August 30, 2007.

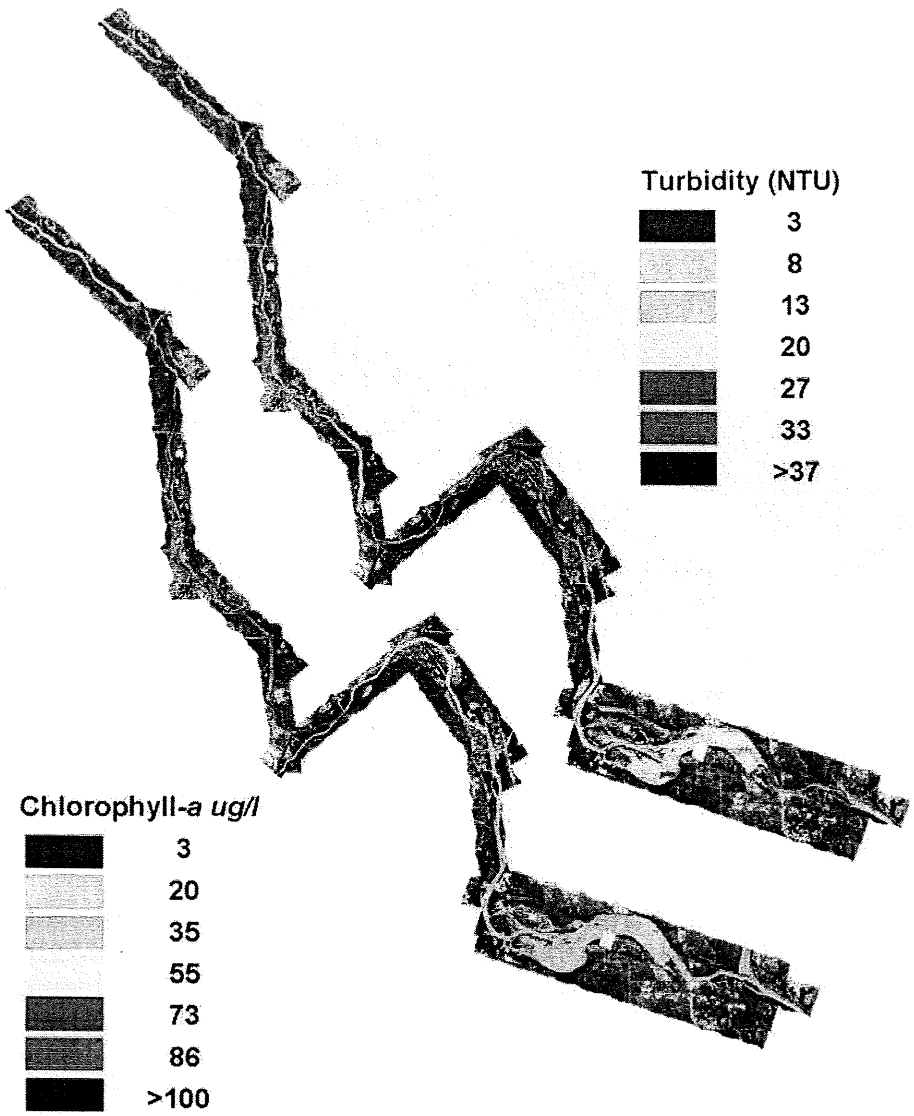
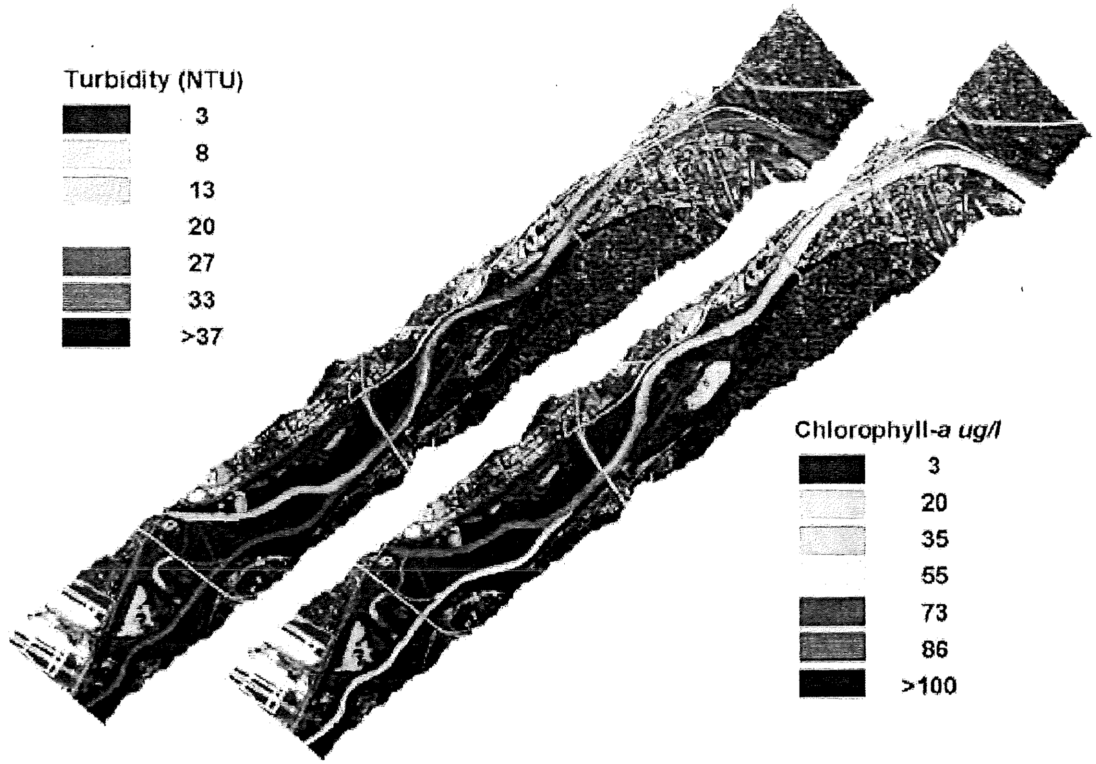


Figure 5. Example water quality maps (turbidity and chlorophyll-a). Confluence of the Minnesota River with the Mississippi River August 30, 2007.



Summary and Conclusions

The results of this study indicate that accurate mapping of key water quality characteristics in complex river systems is feasible using aircraft-mounted spectral imagers. This project has developed and extended the capability for using remote sensing to monitor conditions in streams and rivers in Minnesota. The three sets of hyperspectral imagery provide water quality information for a range of late-summer flow conditions for several major streams and rivers, including the Mississippi, Minnesota, St. Croix, Blue Earth, Rum, Crow and Vermillion Rivers. Strong relationships were found between sensor-derived reflectance data and key indicators of water quality, including chlorophyll, suspended sediments, and transparency. Models relating spectral reflectance to the biophysical variables were used to map spatial patterns and variation for the streams, providing information that is not available from conventional sampling. The results from this project indicate excellent potential for monitoring and mapping key river properties.

Result 3A: *Continued enhancement of the ability of volunteer citizen groups to collect water quality data that will be useful for local water management and/or state water quality assessment.*

Description:

The University of Minnesota Water Resources Center (WRC) will provide training and ongoing technical support for volunteers monitoring E. coli bacteria and aquatic macroinvertebrates across Minnesota. Selection of up to 19 watershed groups and the training workshops will be conducted in collaboration with the RCM and MLA volunteer training program (See Result 3B). Volunteers will receive training and equipment, as well as quality assurance for macroinvertebrate data and management of E. coli data. The WRC will also work with the Remote Sensing Lab to help coordinate sampling efforts in conjunction with satellite overpasses and to inform citizens about the results and implications of remote sensing of Minnesota's water resources.

Summary Budget Information for Result 3A:	**LCMR Budget:**	**$50,000.00**
	Minus Amount Spent:	**$50.000.00**[6]
	Balance:	**$ 0.00**[7]

Project Milestones

July – September 2005: Train 5 stream teams to monitor bacteria.
October – December 2005: Identify at least 2 groups desiring macroinvertebrate training.
January – June 2006: Conduct bacteria monitoring training to 5 stream and 5 lake groups. Train two macroinvertebrate groups.
July – September 2006: Conduct QA on spring macroinvertebrate samples, report to volunteers. Collect bacteria data and compile into interim report.
October – December 2006: Write newsletter article summarizing initial results of bacteria monitoring. Conduct QA on fall sampling. Plan a workshop for citizens on the use of Remote Sensing and Monitoring in Minnesota.
January – March 2007: Plan spring training dates and workshops for macroinvertebrates. Conduct workshop on Remote Sensing.
April – June 2007: Monitoring continues for at least 5 volunteer teams trained to monitor bacteria. Train 2 watershed groups to monitor macroinvertebrates. Two original watershed groups will again monitor macroinvertebrates.
July – September 2007: Conduct QA on spring macroinvertebrate samples and report to groups. Bacteria monitoring will be ongoing. Collect and summarize bacteria monitoring into report and newsletter article.

---

[6] Due to an error in billing, no funds were charged against the LCMR project for work completed in the first quarter. The error has been corrected and fund will be charged against the LCMR project from this point forward.
[7] Billing error caught by project staff; $1,098 in funds were correctly replaced in the budget after being charged incorrectly in summer 2007.

Develop recommendation for using rapid assessment bacteria test kits for volunteer lake monitoring.

[8]Completion Date: June 30, 2008

Final Report Summary:

In 2006, 42 volunteers were trained at five workshops held across the state (North Branch, Red River, Sauk River, Circle Pines, and Rochester). They monitored 24 stream sites and 6 lakes sites in 14 counties; 226 samples were collected during the summer months.

In 2007, 22 volunteers were trained at four workshops (St. Peter, Fountain, Hackensack, and Barnum). Volunteers monitored 14 stream and 15 lake sites in 9 counties; 143 samples were collected during the summer months.

Volunteers helped research the accuracy of home test kits in comparison with certified laboratories. The study showed that Petrifilm test kits are accurate and reliable: excellent for screening, targeting additional resources, or identifying tributary loading. Most lakes and streams sampled showed very low bacteria levels; only a few sites exceeded the state standards for bacteria in surface water. Recognition that the test kits are reliable and accurate shows that simple, inexpensive methods are available for screening a greater number of Minnesota's water resources. This could allow for more targeted use of agency resources and identification of potential public health risks.

Citizens and local units of government benefited by learning more about sources and causes of bacterial contamination and the presence of bacteria in their local water resources. Additional allocation of LGU resources or Lake Association resources followed discovery of bacterial problems. Cross Lake Association, for example, began an extensive monitoring program that leaders attribute to participating in this volunteer monitoring project. Citizens in St. Peter documented excessive bacterial levels in detention pond overflow that resulted in repair and redesign of an overflow pipe. Improper discharge from the Pine City wastewater treatment plant was halted after volunteer documented elevated bacteria levels at the outfall. Data from the project will be entered into STORET so it is publicly available.

The initial proposal called for 2 macroinvertebrate workshops to be held as part of the proposal. A training was held in 2006; however, little interest was shown for a second training. Considering Minnesota Waters' abilities to offer this training and the huge interest in the bacterial monitoring, funds were shifted to offer additional supplies and equipment to allow more volunteers to complete bacterial monitoring.

When the proposal was developed, the use of remote sensing and geographic information systems (GIS) techniques were not widely used by local units of government (LGUs). By the time the proposed workshop on remote sensing was offered, it was determined that LGUs has already gained considerable experience in the value, methods, and techniques of remote

[8] Project end date changed to reflect actual anticipated end date of work. A no cost extension has been requested to accommodate data analysis and interpretation and to host a remote sensing workshop. Amended 9/27/07. Approved via Susan Thornton email 9/28/07.

sensing. As a result, workshop registration was very low and the workshop was cancelled. Registered parties received materials electronically; the remote sensing researchers are working with the Minnesota GIS Consortium to offer a workshop at one of their statewide events.

Result 3B: *Continued enhancement of the ability of volunteer citizen groups to collect water quality data that will be useful for local water management and/or state water quality assessment.*

Description: There is a need to provide volunteer monitors with a framework and training which aligns monitoring methods and data management with the intended information use. Building upon the FY04-05 LCMR project, training for additional volunteer groups will be offered on how to: design a monitoring plan, conduct water-quality monitoring data that is useable for its intended purpose (local and/or state level water quality management), and interpret and communicate this information. Refer to the Work Program submitted by the Minnesota Lakes Association (MLA) and Rivers Council of Minnesota (RCM) (and the entity they are to become, Minnesota Waters) for details on Monitoring Plan Trainings and additional skills trainings.

Summary Budget Information for Result 3B:	**LCMR Budget**	**$250,000.00**
	Amount Spent	**$248,704.31**
	Balance	**$ 1,295.69**

Completion Date: September 30, 2007

[9]V. TOTAL LCMR PROJECT BUDGET

[10]All Results: Personnel: $202,158.90 (MPCA: 3 FTE and 6 interns)

All Results: Equipment: $8,634.55 (MPCA: backpack shocker)

All Results: Other: $218.55 supply and expense; **$0** printing; **$23,100** contracts; **$365,000** to cooperators (of this $250,000 is detailed in the RCM/MLA/entity they are to become work program, the remaining $115,000 is detailed in this work program); **$888.00** travel expense in Minnesota

TOTAL BUDGET: $600,000

Explanation of Capital Expenditures Greater Than $3,500: Equipment provided to groups by the Water Resources Center (Result 3A) will be used through the useful life of the equipment (waders, nets, incubators, microscopes, etc.) by volunteers. Any reusable equipment no longer needed by groups will be returned to the Water Resources Center for future trainings.

IV. OTHER FUNDS & PARTNERS:

---

[9] Personnel, equipment, and other categories updated to reflect proposed amendments found in Attachment A. Please see Attachment A for details. Amended 9/27/07. Approved 9/28/07 via Susan Thornton email.

[10] Personnel and equipment expenses updated to reflect proposed MPCA budget amendment dated 4/5/07 to purchase one backpack electroshocker and one YSI multi-parameter probe. Approved per Susan Thornton email 4/5/07.

A. Project Partners: U of M Water Resources Center ($50,000), RCM/MLA/entity they are to become, Minnesota Waters ($250,000), and U of M Remote Sensing Lab ($65,000).

B. Other Funds being Spent during the Project Period: MPCA's baseline efforts for stream and lake assessments will continue as outlined below in "D." This initiative would significantly augment the MPCA's current efforts, allowing those efforts to be accelerated and improved.

C. Required Match (if applicable): N/A

D. Past Spending: The MPCA spends approximately $250,000 and 5.5 FTE each year on stream monitoring and assessment, and $35,000 and 2 FTE on detailed lake assessments and trend analysis. The LCMR provided $740,000 in FY04-05 to complete the biological index (MPCA $260,000), develop and calibrate lake remote sensing technologies (U of M RSL $115,000), begin development of stream remote sensing technologies (U of M RSL $65,000), and develop a volunteer monitoring training system ($112,625 MLA, $137,375 RCM, and $50,000 Initiative Foundation).

E. Time: Because proposed field work activities must be completed during the open water season, we request that the project span 3 years, starting July 1, 2005 and completing June 30, 2008.

VII. DISSEMINATION:

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than November 30, 2005, March and September 2006, March and September 2007 and March 2008. A final work program report and associated products will be submitted by June 30, 2008.

IX. RESEARCH PROJECTS: N/A

Appendix A.

Appendix B.

Result 2 References

Metropolitan Council, 2004. Regional Progress in Water Quality - Analysis of Water Quality Data from 1976 to 2002 for the Major Rivers in the Twin Cities. Metropolitan Council Regional Report.

Gitelson, A., Mayo, M., Yacobi, Y., Parparov, A., Berman, T., 1994. The use of high spectral radiometer data for detection of low chlorophyll concentrations in Lake Kinneret. J. Plankton Res. 16, 993-1003

Schalles, J., Schiebe, F., Starks, P. Troeger, W. 1997. Estimation of algal and suspended sediment loads (singly and combined) using hyperspectral sensors and integrated mesocosm experiments. Proceedings of the 4th International Conference on Remote Sensing for Marine and Coastal Environments, Vol. 1, pp. 247-248.

Menken,K.D., P.L. Brezonik and M.E. Bauer. 2006. Influence of chlorophyll and colored dissolved organic matter (CDOM) on lake reflectance spectra: Implications for measuring lake properties by remote sensing. Lake and Reservoir Management 22(3):179-190.

Zimba, P.V., Gitelson, A.A. 2006. Remote estimation of chlorophyll concentration in hypereutrophic aquatic systems: model tuning and accuracy optimization. Aquaculture pp. 272-286

Kallio, K., Kutser, T. Hannonen, T. Koponen, S. Pulliainen, J., Vepsäläinen, J. Pyhälahti, T. (2001). Retrieval of water quality from airborne imaging spectrometry of various lake types in different seasons. Science of the Total Environment, 268(1-3):59-77.

Shafique, N., Fulk, F., Autrey, B., Flotemersch J. 2003. Hyperspectral Remote Sensing of Water Quality Parameters for Large Rivers in the Ohio River Basin. Proc. First Interagency Conf. on Research in the Watersheds.

Attachment A: Budget Detail for 2005 Projects - Summary

Proposal Title: *Accelerating and Enhancing Surface Water Monitoring - Continuation W-08*

Project Manager Name: *Dan Helwig*

LCMR Requested Dollars: $ *600,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet
2) Remove any budget item lines not applicable

2005 LCMR Proposal Budget	Result 1 Budget:	Description	Amount Spent (06/30/08)	Balance (06/30/08)	Result 2 Budget:	Description	Amount Spent (06/30/08)	Balance (06/30/08)	Result 3A Budget:	Description	Amount Spent (6/30/08)	Balance (6/30/08)	1,2,3,4,5,6,7,8,9 Result 3B Budget:	Description	Amount Spent (6/30/08)	Balance (06/30/08)	
	Develop and Initiate Progressive Biological monitoring				*Provide the capability to use remote sensing tools to assess rivers and streams*				*Continued enhancement of the ability of individuals and organizations to collect water quality data that will be useful for intented purposes.*				*Continued enhancement of the ability of individuals and organizations to collect water quality data that will be useful for intented purposes.*				
BUDGET ITEM									Bacterial and Biological Training (WRC)				Monitoring Plan and Skills Trainings (MLA & RCM)	Refer to MLA/RCM/entity they are to become Work Program and Attachment A Budget Detail.			TOTAL FOR BUDGET ITEM
PERSONNEL: Staff Expenses, wages, salaries	$202,158.90	See Result 1 Detail	$202,158.90	$0.00	$31,902.00	See Result 2 Detail	$31,902.00	$0.00	$35,755.00	See Result 3 Detail - WRC	$35,755.00	$0.00	$126,153.39	Refer to MLA/RCM/entity they are to become Work Program and Attachment A Budget Detail.	$126,095.57	$57.82	$395,969.29
PERSONNEL: Staff benefits																	$0.00
Contracts																	
Professional/technical	$23,100.00	See Result 1 Detail	$23,100.00	$0.00	$31,698.00	See Result 2 Detail	$31,698.00	$0.00					$85,733.11	Refer to MLA/RCM/entity they are to become Work Program and Attachment A Budget Detail.	$85,733.11	$0.00	$140,531.11
Equipment / Tools	$8,634.55		$8,634.55	$0.00					$5,214.00	See Result 3 Detail - WRC	$5,214.00	$0.00	$1,116.16	Refer to MLA/RCM/entity they are to become Work Program and	$1,116.16	$0.00	$14,964.71
Other direct operating costs									$1,200.00	See Result 3 Detail - WRC	$1,200.00	$0.00	$9,691.85	Refer to MLA/RCM/entity they are to become Work Program and Attachment A Budget Detail.	$9,691.85	$0.00	$10,891.85
Other direct operating costs									$5,394.00	See Result 3 Detail - WRC	$5,394.00	$0.00					$5,394.00
Computer Lab fees and supplies					$1,000.00	See Result 2 Detail	$1,000.00	$0.00									$1,000.00
Printing	$0.00	See Result 1 Detail	$0.00	$0.00									$19,805.49	Refer to MLA/RCM/entity they are to become Work Program and Attachment A Budget Detail.	$19,070.31	$735.18	$19,805.49
Other Supplies *(list specific categories)*	$218.55	See Result 1 Detail	$218.55	$0.00					$167.00	See Result 3 Detail - WRC	$167.00	$0.00					$385.55
Travel expenses in Minnesota	$888.00	See Result 1 Detail	$888.00	$0.00	$400.00	See Result 2 Detail	$400.00	$0.00	$1,363.87	See Result 3 Detail - WRC	$1,363.87	$0.00	$7,500.00	Refer to MLA/RCM/entity they are to become Work Program and Attachment A Budget Detail.	$6,997.31	$502.69	$10,151.87
Out of state Travel									$906.13		$906.13						$906.13
COLUMN TOTAL	$235,000.00		$235,000.00	$0.00	$65,000.00		$65,000.00	$0.00	$50,000.00		$50,000.00	$0.00	$250,000.00		$248,704.31	$1,295.69	$600,000.00

1. Personnel funds shifts and categories managed on a broader scale. Approved per Susan Von Mosch email 10-24-05. See Result 3B Appendix A for complete details.
2. Funds shifted from personnel to contracts for sub-contract due to employee status change. Approved via Susan Thornton email 3/9/06. See Result 3B Appendix A for complete details.
3. Personnel and printing will be combined into 2 separate line items, 'other contracts' will be moved to one line. Per phone call with Susan Thornton 10/11/05.
4. Combined 'other contractor' lines $12,000 + $7,500; combined 'other direct operating' lines $4,000+$3,400 for program management per phone call with Susan Thornton 10/11/05. Approved 10/24/05 in Susan Von Mosch email.
5. Shifted $48,000 from personnel to contractor for sub-contract of Sandra Holm March 2006 through June 2007, per her new contractor status under MN Waters merger. Amended 3/1/06. Approved 3/9/06 per Susan Thornton email.
6. Shifted $913.84 from capital expense to telephone expense. Amended 11/7/06. Approved 11/8/06 in John Velin email.
7. Shifted $2,500 from printing to travel expense. Amended 11/20/06. Approved 11/30/06 in John Velin email.
8. Change Project Manager name from Angie Becker Kudelka to Courtney Kowalczak effective 9/20/07. Amended 9/10/07. Approved per John Velin email 9/12/07.
9. Shifted $4,500 from salary to contractor and shifted $805.49 from other direct operating costs to printing to closeout direct operating cost line item. Amended 9/10/07. Approved per John Velin email 9/12/07.

Attachment A: Budget Detail for Result 1 - MPCA

Proposal Title: *Accelerating and Enhancing Surface Water Monitoring*

Project Manager Name: *Dan Helwig*

LCMR Requested Dollars: $ *235,000*

	[2,3,6]Result 1 Budget:	Description	Amount Spent (06/30/08)	Balance (06/30/08)	
	Develop and Initiate Progressive Biological monitoring				
BUDGET ITEM					TOTAL FOR BUDGET ITEM
[1,2,3,6]PERSONNEL: Staff Expenses, wages, salaries	$202,158.90	3 unclassified staff for 1.25 years @ $34,533 each plus $12,133 in benefits and 6 interns for 1 year at $6,200 plus $466 each for FICA (benefits)	$202,158.90	$0.00	$202,158.90
PERSONNEL: Staff Expenses, wages, salaries	$117,974.52	3 unclassified staff for 1.16 years @ $34,533 each.			
PERSONNEL: Staff benefits	$44,184.38	3 unclassified staff for 1.16 year @ $12,133 each in benefits.			
PERSONNEL: Staff Expenses, wages,	$37,200.00	6 interns for 1 year @ $6,200 each.			
PERSONNEL: Staff benefits –	$2,800.00	6 interns for 1 year @ $466 each in benefits			
Contracts					
[4]Professional/technical	$23,100.00	Macroinvertebrate identification (Rithron Associates, Montana.)	$23,100.00	$0.00	$23,100.00
[2,3,6]Equipment/Tools	$8,634.55		$8,634.55	$0.00	$8,634.55
Printing	$0.00		$0.00	$0.00	$0.00
Other Supplies (*list specific categories*)	$218.55	Bottles, nets, preservative	$218.55	$0.00	$218.55
Travel expenses in MN	$888.00		$888.00	$0.00	$888.00
COLUMN TOTAL	$235,000.00		$235,000.00	$0.00	$235,000.00

1. Personnel salaries, benefits, and expenses were combined for ease of reporting. Amended 3/30/06. Approved per Susan Thornton email 3/31/06.

2. Shifted $18594.44 from personnel to equipment/tools to cover the purchase of one backpack electroshocker ($7626) and one YSI multi-parameter probe ($10968.44). Amended 4/5/07. Approved per Susan Thornton email 4/5/07.

3. Shifted $41,387.89 to personnel from contracts ($16,900), travel ($9,112), printing ($2,500), equipment ($10,594.44), and other supplies ($2,281.45) to better reflect actual project costs. Printing was covered in house, the YSI probe, travel, and supplies were purchased using agency funds. Amended 9/27/07. Approved via Susan Thornton email 9/28/07.

4. Other agency funds were used to cover the $21,000 billed against the project in March 2007. $21,000 was returned to the LCMR funds in June 2007. Shifted $6,900 from contracts to personnel to better reflect actual project costs. Amended 9/27/07. Approved via Susan Thornton email 9/28/07.

5. Other agency funds were used to cover the fish voucher contract. The $7,165 that was billed against the project in March 2007, was returned to the LCMR funds in June 2007, as other agency funds were used. The $10,000 was shifted to personnel to better reflect project costs. Amended 9/27/07. Approved via Susan Thornton email 9/28/07.

6. Shift of $634.55 from personnel to equipment/tools to close out accounts. Amended 6/30/08.

Detailed Budget for Result 2: Remote Sensing ($65,000 total budget)
Contract with the U of M Remote Sensing Lab

2005 LCMR Proposal Budget	[2,3]Result 2 Budget:	Description	Amount Spent *(06/30/08)*	Balance *(06/30/08)*	
	Provide the capability to use remote sensing tools to assess rivers and streams				
BUDGET ITEM					TOTAL FOR BUDGET ITEM
[1]PERSONNEL AND FRINGE:	$31,902.00	Personnel and Fringe for Leif Olmanson and Marv	$31,902.00	$0.00	$31,902.00
Contracts					
Professional/technical *University of Nebraska*	$31,698.00	University of Nebraska for reconnaissance flight	$31,698.00	$0.00	$31,698.00
Computer Lab Fees and supplies	$1,000.00	Software and other supplies	$1,000.00	$0.00	$1,000.00
Travel expenses in Minnesota	$400.00	Travel for ground based data collection	$400.00	$0.00	$400.00
COLUMN TOTAL	$65,000.00		$65,000.00	$0.00	$65,000.00

1. Personnel categories combined for ease of reporting. Amended 3/30/06. Approved per Susan Thornton email 3/31/06.

2. Funds shifted from personnel, supplies, and travel to technical contracts to allow for a second reconnaissance flight in the summer of 2007. Amended 9/28/06. Approved per Susan Thornton email 10/4/06.

3. Shifted $698 from computer lab fees to the University of Nebraska contract to cover final costs for the line item. Shifted $302 from computer lab fees and $600 from travel expenses to personnel to better reflect actual project costs. Amended 9/27/07

Detailed Budget for Result 3A: Volunteer Monitoring Training ($50,000 total budget)
Contract with the U of M Water Resources Center

2005 LCMR Proposal Budget	[3,5,6]Result 3 Budget:	Description	Amount Spent *(06/30/08)*	Balance *(06/30/08)*	
	Continued enhancement of the ability of individuals and organizations to collect water quality data that will be useful for intented purposes				
BUDGET ITEM					TOTAL FOR BUDGET
[1,4]PERSONNEL: TOTAL EXPENSES, WAGES, SALARIES	$35,755.00		$35,755.00	$0.00	$35,755.00
PERSONNEL: Staff Expenses, wages, salaries –	$19,905.00	14% FTE B. Liukkonen, Project Coordinator			
PERSONNEL: Staff Expenses, wages, salaries –	$5,460.00	5% FTE T. Thomas, administrative assistant			
PERSONNEL: Staff Expenses, wages, salaries –	$4,000.00	Graduate Student to be hired			
PERSONNEL: Staff Expenses, wages, salaries –	$6,390.00	Macroinvertebrate monitoring training workshops, Julia Frost, U of M			
[5]Out of State Travel	$906.13	Out of state travel for grad student and project coordinator to attend a Great Lakes Regional Water Program E Coli Team meeting in Indianapolis	$906.13	$0.00	$906.13
Equipment / Tools	$5,214.00	Macroinvertebrate and bacteria monitoring equipment	$5,214.00	$0.00	$5,214.00
Other direct operating costs E. coli test kits for volunteers	$1,200.00	E. coli test kits (600 kits at $2.00/kit)	$1,200.00	$0.00	$1,200.00
Other direct operating costs Lab analysis of E. coli samples	$5,394.00	Lab analysis to QA E. coli test kits (150 samples @ $22/sample)	$5,394.00	$0.00	$5,394.00
[2]Workshop expenses	$167.00		$167.00	$0.00	$167.00
[5]Travel expenses in Minnesota	$1,363.87	$3200 for 4000 miles @ $0.40/mi. $800 for travel expenses (4 overnight trips)	$1,363.87	$0.00	$1,363.87
COLUMN TOTAL	$50,000.00		$50,000.00	$0.00	$50,000.00

1. Per suggestion from Susan Thornton email, personnel expenses combined for ease of reporting. Approved 3/31/06.

2. Creation of workshop expenses - inadvertantly combined with equipment/tools in the original proposal. Moved to better fit University reporting system. Amended 9/29/06. Approved per Susan Thornton email 10/4/06.

3. Funds shifted from personnel and equipment to increase funds for lab analysis and workshop expenses. This will allow for more participants in 2007. Amended 9/29/06. Approved per Susan Thornton email 10/4/06.

4. Eliminated position. MN Waters staff will cover the work the position required. Amended 9/29/06. Approved per Susan Thornton email 10/4/06.

5. 818.13 Shifted from in state to out of state travel to cover expenses incurred for regional E. coli meeting. Discussed via phone with Susan Thornton 2/27/07. Amended 3/26/07. Approved 3/28/07 per Susan Thornton email. Additional $88 dollars reallocated from travel to out-of-state to accomodate late invoices. Amended 9/27/07.

6. Shifted $155 from travel to personnel to cover staff time. Requested via phone conversation with John Velin (9/4/07) to be allowed to shift remaining funds (travel and workshop expenses, $2034 and $33, respectively) to close out line items (equipment and lab analysis) as needed. Amended 9/27/07

Snake River Watershed Monitoring Assessment Project

Minnesota Pollution Control Agency

Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

1.0 Introduction

The Minnesota Pollution Control Agency (MPCA) is charged under both federal and state law with the responsibility of protecting the water quality of Minnesota's water resources. The Federal Clean Water Act (CWA) requires states to adopt water quality standards to protect their water resources and the designated uses of those waters, such as for drinking water, fishing, or swimming. Section 305(b) requires a summary of the status of the state's surface waters, while Section 303(d) of the CWA requires the state to develop a list of water bodies that do not meet established standards. Such waters are referred to as "impaired waters" and the state must take appropriate actions to restore these waters, including the development of Total Maximum Daily Loads (TMDL's). A TMDL is a comprehensive study identifying all pollution sources causing or contributing to impairment and the reductions needed to restore a water body so that it can support its intended use.

The MPCA currently conducts a variety of surface water monitoring activities that support our overall mission of helping Minnesotans protect the environment (MPCA 2006). To be successful preventing and addressing problems, decision makers need good information about the status of the resources, potential and actual threats, options for addressing the threats, and data on how effective management actions have been. The MPCA's monitoring efforts are focused on providing that critical information. Overall, the MPCA is striving to provide information to assess - and ultimately to restore or protect - the integrity of Minnesota's waters.

The Minnesota Legislature has recently appropriated additional resources as part of the Clean Water Legacy Act to be directed towards water quality assessment and TMDL development. In response, the MPCA has developed a watershed monitoring strategy which will promote an effective and efficient integration of water monitoring programs to provide a more complete assessment of water quality and expedite the TMDL process. This strategy utilizes a nested watershed approach allowing aggregation of watersheds from course (8-digit major watershed), intermediate (11-digit watersheds), and fine scales (14-digit minor watersheds). In the summer of 2006 a pilot study of this new monitoring strategy was conducted in the Snake River Watershed. The primary objective of this study was to integrate monitoring resources to provide a more complete and systematic assessment of water quality at a geographic scale useful for the development and implementation of effective TMDL's.

2.0 Study Area

Located in east-central Minnesota, the Snake River Watershed encompasses most of Kanabec County and parts of Aitkin, Mille Lacs, Pine, and Isanti Counties. The total drainage area of the watershed is 1,008 square miles. The watershed is a relatively flat glacial till plain crossed by several east-west morainal belts. The moraines are mainly undulating areas of hills and depressions (MCD 1959). Land cover percentages in the watershed are: forest (48.3%), rangeland (24.3%), wetland (14.3%), cropland (8.1%), developed (3.6%), and open water (1.3%) (Fig. 1).

The approximately 100 mile long Snake River has its source in the wetland region of Solona State Forest and flows in a southerly direction to Mora where it turns and flows eastward to its junction with the St. Croix River below Pine City. The mean gradient is 4.9 ft./mi., one of the highest in central Minnesota, and the mean discharge is approximately 600 cfs (Waters 1977). Principal tributaries include the Groundhouse, Ann, and Knife rivers; as well as Mud, Mission, and Pokegama Creeks. The upper watershed is primarily undeveloped with extensive forest and wetland land cover. From Mora to Pine City the Snake River is considerably lower in gradient and the wooded banks give way to a wide farming valley. Downstream of Pine City the river returns to wooded bluffs and flows through a series of rapids and pools to it's confluence with the St. Croix River.

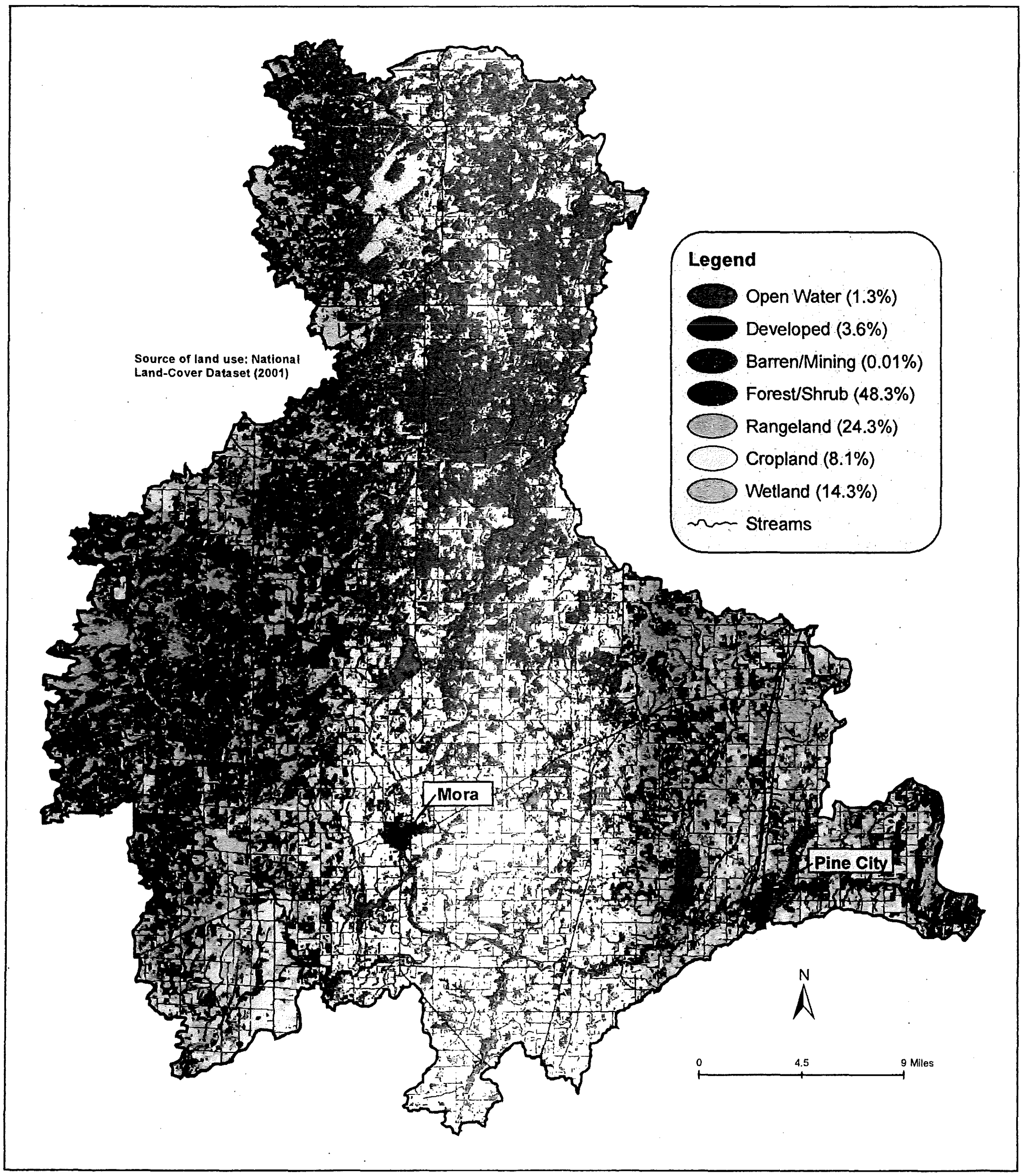


Figure 1. Land use in the Snake River Watershed.

Like much of the Upper St. Croix River Basin, the Snake River Watershed was once densely covered with stands of white pine that were extensively logged in the latter half of the 19th century. Although the second growth trees of aspen, birch and other hardwoods are still harvested for pulpwood and other wood products, agriculture is now the primary industry (MDNR 1977). As Fig. 1 illustrates, much of the agricultural activity occurs in the southern half of the watershed. Recreational opportunities such as fishing, hunting, camping, and canoeing are also numerous due to the amount of public land and river access available in the watershed.

3.0 Methods

Site selection

In the interest of restoring and protecting our water resources the legislature recently appropriated additional resources for monitoring, assessment, and TMDL development. In response, the MPCA developed a watershed monitoring strategy intended to integrate water monitoring programs to provide a more complete assessment of water quality and to facilitate the collection of data necessary for the development of TMDL's on surface waters determined to be impaired. Initially this monitoring effort will focus on streams and rivers within a watershed but could eventually include lakes and wetlands.

This new monitoring strategy utilizes a nested watershed approach allowing aggregation of watersheds from a course to fine scale (Fig. 2). The course level framework that serves as the foundation of this comprehensive monitoring strategy is the major watershed or 8-digit Hydrologic Unit Code (HUC), of which there are 81 delineated within Minnesota (Fig. 3). Intermediate (equivalent to 11-digit HUC) and minor (14-digit HUC) watersheds within the major watershed are also sampled to provide a complete assessment of water quality. Site selection is determined by systematically sampling

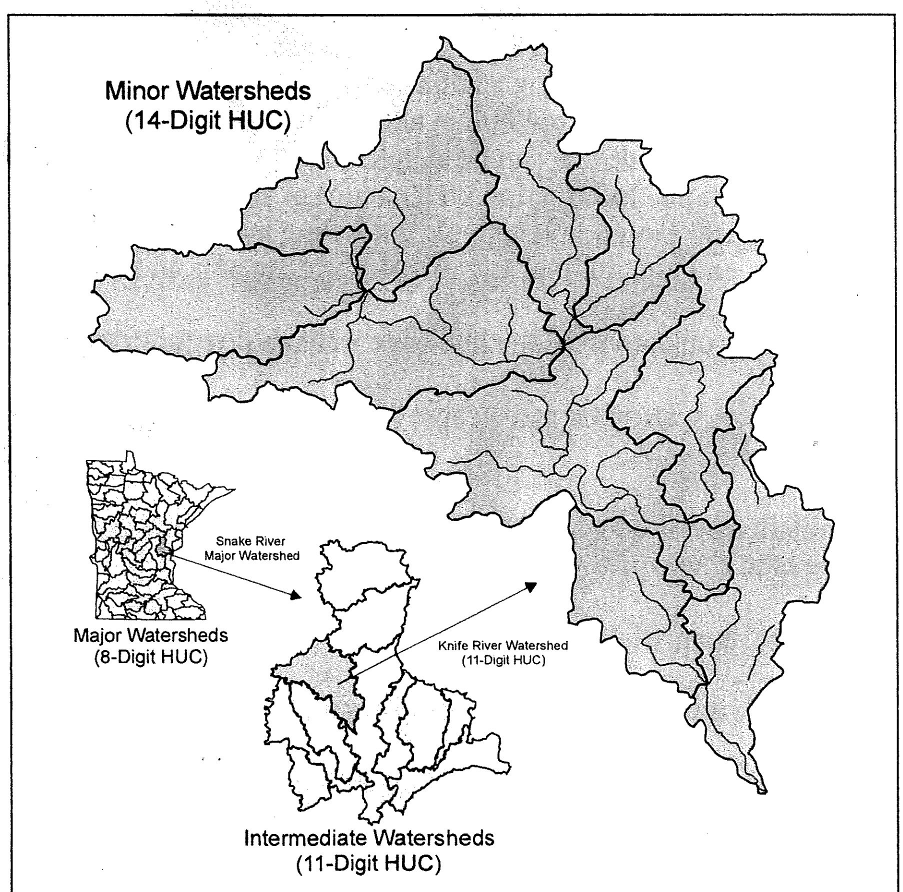


Figure 2. The nested watershed monitoring design.

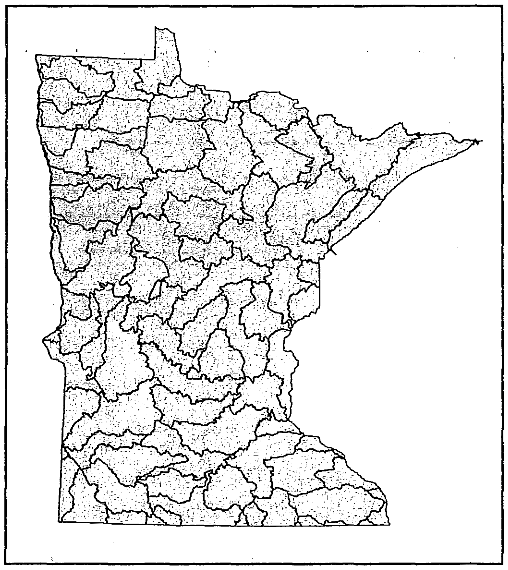


Figure 3. Major watersheds within Minnesota (8-Digit HUC).

near the mouth or "pour point" at all watershed scales. This approach provides an unbiased, systematic census of all streams within a major watershed down to the scale of minor watersheds (typically 10 -20 square mile drainage areas).

The pour point of the major watershed is sampled for biology, water chemistry, and fish contaminants to provide data for the assessment of aquatic life and aquatic consumption use support, as well as preliminary screening level data for aquatic recreation use support. Moving up the watershed, each 11-digit HUC pour point is sampled for biology and water chemistry to allow for the assessment of aquatic life use support and aquatic recreation screening. Watersheds at this scale generally consist of major tributary streams (typically 75 – 150 square miles). Lastly, most minor watersheds within each 11-digit HUC are sampled for biology to make assessments of aquatic life use support. Sampling is not conducted at some minor watersheds for reasons including; wetland or lake dominated minors that do not represent riverine conditions, flow through minors or multiple upstream minors adequately characterized by a downstream sampling location, minor watersheds representing ephemeral streams, and remote watersheds that are too difficult to access. Sampling stations are located in a systematic, unbiased manner near the pour point of each watershed outlet that allows for reasonable stream access and represents a lotic environment. This design can be supplemented with more traditional site selection protocols to provide additional information on locations of site specific interest such as; regional reference sites, historical sampling locations, bracketing point source discharges or other known locations of interest, and longitudinal surveys of larger streams and rivers.

The primary objectives of the intensive watershed monitoring design are to:

1) provide a systematic assessment of overall stream water quality within 11-digit hydrologic watershed units,

2) obtain assessment data on all water quality indicators (aquatic life, aquatic recreation, and aquatic consumption),

3) locate impaired watersheds,

4) provide information for the completion of TMDL studies on impaired waters,

5) and to more efficiently use and integrate monitoring resources.

All 81 major watersheds within Minnesota will eventually undergo a similar effort in order to complete the cycle of monitoring statewide. In addition, the watershed monitoring strategy has a phase II component which will consist of follow up monitoring at all 11-digit HUC's determined to have impaired waters. This tailored intensive monitoring effort will be designed to collect the information needed to initiate the stressor identification process in order to identify the source(s) and cause(s) of impairment. The HUC-11 watershed units are of practical size for the development, management, and implementation of effective TMDL's and follows a similar approach used by the state of Ohio (Ohio EPA, 2005). Rather than develop TMDL's on a reach by reach basis, TMDL's can be developed at the watershed scale to address multiple impairments and more efficiently address the insidious effects of non-point source pollution. Phase II studies will be a coordinated effort between the MPCA's Environmental Analysis and Outcomes Division and the Regional Division as TMDL scheduling permits.

In the summer of 2006 a pilot study of this new monitoring strategy was conducted in the Snake River Watershed. Sixty-four sampling visits were conducted at a total of 57 discrete stations (Fig. 4) (Appendix 1). Some stations were sampled twice for quality assurance/quality control purposes. All sites were sampled for fish, invertebrates, physical habitat, and one-time water chemistry. Sampling locations representing the pour points of HUC-11 watersheds (n=11) were also sampled more extensively for water chemistry parameters. In addition, fish were collected for contaminant analyses at the site representing the pour point of the Snake River Watershed.

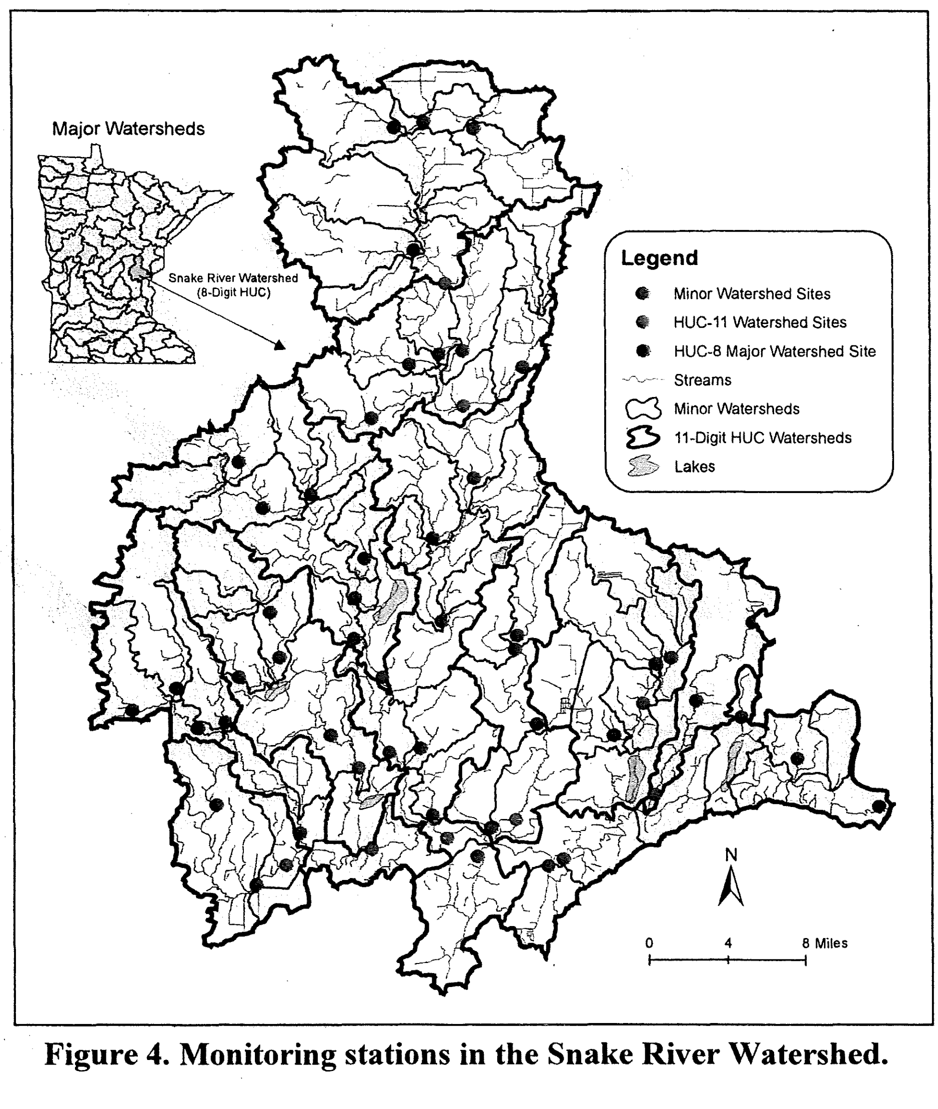


Figure 4. Monitoring stations in the Snake River Watershed.

Fish Community Assessment

Fish communities were sampled by electrofishing (pulsed DC) during base-flow conditions between June 19 and August 16, 2006. The reach length needed to collect a representative sample of fish followed guidance provided by Lyons (1992), and ranged from 150m to 500m. A single electrofishing pass was conducted at each site, sampling all available habitat types in the proportion that they occurred. Fish were processed in the field, and included identifying each individual to species, enumeration, batch weights by species, minimum and maximum total length of each species, and recording any external abnormalities. Discussion of the fish community methodology utilized can be found in Niemela and Feist (2000) or see MPCA Fish Community Sampling Protocol for Stream Monitoring Sites available at: www.pca.state.mn.us/water/biomonitoring/sf-sop-fish.pdf.

Macroinvertebrate Community Assessment

Macroinvertebrate communities were sampled during base-flow conditions between July 31 and September 6, 2006. A qualitative multi-habitat (QMH) sample was collected at each site to characterize the overall macroinvertebrate diversity of the sample reach. A D-frame dip net and sieve bucket (both 500 *u*m mesh) were the only equipment required for this sampling method. A total of 20 sampling efforts were collected at each site, sampling each of the major productive habitat types present within the reach in equal proportion. All material collected by the 20 sampling efforts was composited in a sieve bucket, transferred to 1 L plastic sample jars, and preserved in 100% denatured ethanol. The QMH sample was sub-sampled by a certified lab until a minimum of 300 organisms were collected. Any large and/or rare organisms were also sampled. All organisms sub-sampled were identified to the generic level if possible. A complete discussion of the methodology can be found in MPCA Invertebrate Sampling Procedures (http://www.pca.state.mn.us/water/biomonitoring/biomonitoring-invertebratesampling.pdf).

Physical Habitat Assessment

A quantitative habitat assessment was performed at each wadeable site to characterize the quality of habitat available at the stream reach and follows the procedures outlined in the MPCA Physical Habitat and Water Chemistry Assessment Protocol for Wadeable Stream Monitoring Sites (http://www.pca.state.mn.us/publications/wq-bsm3-01.pdf). The habitat assessment provides quantitative information concerning the substrate composition, cover for fish, riparian land use, and stream morphology. This information can be useful in the TMDL and stressor identification process to characterize potential stressors of the aquatic community.

Physical habitat is also evaluated at each site utilizing the Minnesota Stream Habitat Assessment (MSHA)(http://www.pca.state.mn.us/publications/wq-bsm3-02.pdf). The MSHA is a qualitative habitat assessment similar to Ohio's Qualitative Habitat Evaluation Index (QHEI)(Rankin 1989, 1995). Important attributes of the available habitat are evaluated and scored based on their overall importance to supporting viable aquatic communities. The MSHA rates the habitat at a stream reach based on surrounding land use, riparian zone quality and bank erosion, substrate and in-stream cover quality, and channel stability and complexity.

Water Chemistry Assessment

Surface water samples of total phosphorous (TP), ammonia nitrogen ($NH^3 + NH^4$), total suspended solids (TSS), and nitrite-nitrate ($NO^2 + NO^3$) were collected once at each site. Samples were collected into appropriate containers, preserved, and delivered to the Minnesota Department of Health for analysis within specified holding times. Field measurements were also performed for dissolved oxygen, pH, specific conductance, transparency, and water temperature using standard methods.

At the eleven sites representing the pour-point of each HUC-11 watershed within the Snake River Watershed, more extensive water chemistry sampling was conducted in order to provide additional information for the assessment of water quality condition and use support. In addition to the parameters indicated above, samples were taken for the analysis of chloride, sulfate, and *E. coli* bacteria using standard methods. Samples were taken twice each month from May through September for a total of ten samples over this period. Stations were established in Storet for all sites representing the HUC-11 watersheds.

In 1998, the Snake River Watershed Management Board (SRWMB) and its local partners established a long term monitoring program in an attempt to identify problem areas and provide a baseline of water quality information for future evaluation efforts in the Snake River Watershed. As part of this effort, twelve sample stations were established in strategic locations throughout the watershed to characterize localized water quality/quantity conditions. Samples were collected once per week for six weeks during spring melt (April – May), twice per month June – November, and two storm event samples over a ten year period. Water chemistry parameters collected were similar to those proposed for this study with the exception of chloride, sulfate, $NH^3 + NH^4$, and specific conductance. Additionally, fecal coliform data was collected in lieu of *E. coli*. In an effort to more efficiently use monitoring resources and collaborate with local partners it was determined that six of the existing SRWMB sampling locations could serve as the HUC-11 pour point station for the purposes of this study. The watersheds that were adequately represented by existing SRWMB stations included: the Upper Snake River, Knife River, Mission Creek, Groundhouse River, Pokegama Creek, and Mud Creek watersheds. The data collected by the SRWMB for these stations was used in lieu of the MPCA sampling these stations in 2006, the period of record and number of samples varies by station.

Fish Contaminants

The MPCA watershed monitoring strategy contains a component that requires the collection of fish at stations representing the pour point of the major watershed (8-digit HUC). The objective is to collect fish for the analysis of contaminants to assess whether or not the surface water is meeting the beneficial use of aquatic consumption. The acceptability of fish for human consumption is considered a beneficial use separate from aquatic life use support. Of the bioaccumulative pollutants that have been monitored in fish, mercury and PCBs are the primary contaminants found at levels of concern to human consumers of fish. Top carnivore species are particularly important for mercury analysis and rough fish species for PCB analysis.

It was determined that this sampling would only be conducted at the 8-digit HUC level due to the likelihood of being able to collect the fish necessary at this scale. Collecting top carnivores of edible size becomes less likely as you progress to smaller scale watersheds, as does the prospect of citizens fishing these surface waters for consumption purposes. Therefore, the station representing the pour point of the major 8-digit watershed (06SC007) will in effect characterize the entire watershed for the purposes of aquatic consumption use support.

An adequate size class distribution of smallmouth bass (top carnivore) and shorthead redhorse (rough fish) were collected at the station representing the pour point of the Snake River Watershed (06SC007) to assess the contamination level of mercury and PCBs in the watershed. Fish were preserved using appropriate methods, deposited and processed at the Minnesota Department of Natural Resources fish processing lab, and analyzed by the Minnesota Department of Health for the contaminants of concern.

Determining Use Attainment Status

Water quality standards are the fundamental benchmarks by which the quality of surface waters is measured. It is the water quality standards that are used to determine impairment. Use attainment status is a term describing the degree to which environmental indicators are either above or below criteria specified by the Minnesota Water Quality Standards (Minnesota Rules Chapter 7050). These standards can be numeric or narrative in nature and define the concentrations or conditions of surface waters that allow them to meet their designated beneficial uses, such as for drinking water, fishing (aquatic life), swimming (aquatic recreation), or human consumption. All surface waters in Minnesota, including lakes, rivers, streams, and wetlands are protected for aquatic life and recreation where these uses are attainable. Protection of aquatic life means the maintenance of healthy, diverse, and successfully reproducing populations of aquatic organisms, including fish and invertebrates. Protection of recreation means the maintenance of conditions suitable for swimming and other forms of water recreation.

Numeric water quality standards represent safe concentrations of specific pollutants in water that protect a specific designated use. Ideally, if the standard is not exceeded, the use will be protected. However, nature is very complex and variable, and the MPCA may use a variety of tools to fully assess beneficial uses. Assessment methodologies often differ by parameter and beneficial use, and consider multiple factors of the pollutants concentration; such as chronic value, maximum value, final acute value, magnitude, duration, and frequency. For additional information see: MPCA Guidance Manual for Assessing the Quality of Minnesota Surface Waters (http://www.pca.state.mn.us/publications/wq-iw1-04.pdf).

Narrative standards are statements of unacceptable conditions in and on the water, such as biological condition, that protect their designated uses. Narrative biological criteria are based on multi-metric biological indices including the Fish Index of Biological Integrity (F-IBI), which evaluates the health of the fish community, and the Macroinvertebrate Index of Biological Integrity (M-IBI), which evaluates the health of the aquatic invertebrate community. Each metric in an IBI denotes a quantifiable attribute of the biological assemblage that changes in a predictable way with varying levels of human influence. An index typically includes 8-12 metrics that fall into 3 broad categories: 1) species richness and composition, 2) trophic composition and reproductive function, and 3) abundance and condition. The unitless scores assigned to each metric quantify how far any particular metric value deviates from a range of reference values. When the metrics are summed together the resulting score characterizes the biological integrity or "health" of a site (Karr et al. 1986). Because the rivers and streams in Minnesota are physically, chemically and biologically diverse, the measured characteristics are compared to specific reference values for the type and size of river or stream within a geographic region that minimizes natural variablity. The index scores at reference sites provide the basis for establishing impairment thresholds and making determinations of aquatic life use support.

Biological data are used to assess stream reaches for impaired biological condition for both the 305(b) report and the 303(d) list. The period of record is the most recent decade of data and information. Biological assessments can be based on a single biological monitoring event on a given waterbody. Sites that have IBI scores above the threshold level of impairment are considered to be **fully supporting** of aquatic life. Sites that have IBI scores below the threshold level of impairment are considered **non-supporting** of aquatic life. Confidence limits (95%) have been applied to the reference site based IBI impairment thresholds. Sites with IBI scores within the confidence limits will be further evaluated by professional judgment teams. A **partial support** status may be assigned to a stream segment if multiple samples taken at sites within the assessment unit provide discrepant information. Reaches that are non-supporting or partially supporting of their aquatic life uses are identified as candidates for the 303(d) list. Preliminary impairment thresholds used to assess riverine surface waters in the St. Croix River Basin, which includes the Snake River Watershed , can be found in Table 1. Large rivers (> 270 mi^2) were not assessed due to a dataset currently insufficient for IBI calibration.

Table 1. Initial Assessment and Fish Community IBI Thresholds for the 305(b) Report and 303(d) List in the St. Croix River Basin.

	Use Support or Listing Category Based on IBI score		
Drainage Area	Full Support Not Listed	Partial Support Listed	Non-Support Listed
< 20 mi^2	IBI ≥ 46	Assessment unit has multiple sites with discrepant results	IBI < 46
20 mi^2 - 54 mi^2	IBI ≥ 68		IBI < 68
55 mi^2 - 270 mi^2	IBI ≥ 69		IBI < 69

Following the initial assessment based on the IBI scores, a final determination of impairment for 303(d) listing is based on an assessment of all available information. This information includes habitat quality, available water chemistry data, the biological condition of nearby upstream and downstream segments, local land use information, and other watershed data. The MPCA will present this information to the appropriate professional judgment team for the basin in which the reach is located to help make final determinations of use support for 303(d) listing.

Assessments of use support in Minnesota are made for individual waterbodies. The waterbody unit used for river system assessments is the river reach or "assessment unit". A river assessment unit usually extends from one significant tributary stream to another or from the headwaters to the first tributary and is variable in length. A reach may be further divided into two or more assessment reaches when there is a change in use classification (as defined in Minnesota Rules, Chapter 7050), or when there is a significant morphological feature such as a dam or lake within the reach. The MPCA is using the 1:24,000 scale High Resolution National Hydrologic Dataset (NHD) to define and index stream assessment units. Each river reach is identified by a unique waterbody identifier (known as it's AUID), comprised of the USGS eight digit hydrologic unit code plus a three character code that is unique within each HUC. It is for these specific reaches that the data are evaluated for potential use impairment.

To help refine the approach for assessing biological communities, US EPA is encouraging states to develop and adopt a tiered aquatic life use system (TALUS) for their waters. The MPCA began exploring TALUS development in earnest following the 2006 listing cycle. As part of that effort and through discussions with stakeholders, questions have been raised about the process for assessing ditches in Minnesota. In 2006, the MPCA engaged other state agencies and stakeholders in a discussion of the monitoring, assessment and listing process, including the approach for assessing ditches. An outcome of that discussion was the recommendation to defer listing any new ditches for aquatic life impairments, unless acutely toxic conditions are found, until appropriate thresholds are developed for ditches through the TALUS development effort.

4.0 Results and Discussion

Results are presented for each of the 11-digit HUC watershed units sampled within the Snake River Watershed in 2006, enabling us to assess all surface waters at one time and develop comprehensive TMDL studies on a watershed basis rather than the reach by reach approach historically used. This scale provides a robust assessment of water quality condition in the watershed unit and is a practical size for the development, management, and implementation of effective TMDL's. A list of all sampling sites by AUID, IBI score, and use attainment status is provided in Appendix 2.

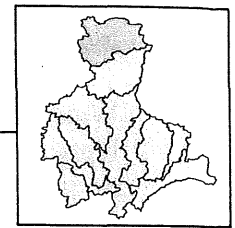
Fish contaminant results are reported separately because the data requirements and protocols used in the assessments are very different. The acceptability of fish for human consumption is considered a beneficial use separate from aquatic life use support. This is because the two uses are assessed independently; i.e., a waterbody may be impaired for one but not the other. In other words, toxicants may be at levels that have no ill effects on aquatic life (fully supporting), but due to bioaccumulation, the fish are not safe to eat (impaired for aquatic consumption). The graphics presented for each of the 11-digit HUC watershed units include impairments of aquatic consumption but are not discussed here because assessments are not typically made at the individual AUID level as they are for other beneficial uses.

Biological criteria has not yet been developed for all stream types, therefore, assessment of aquatic life use support was not possible at some sampling sites. Streams types that were not assessed include coldwater streams, large rivers, channelized streams or ditches, and streams characterized by a predominant wetland condition (wetland habitat, naturally low dissolved oxygen, and depauperate fish community). Information on the development and use of the St. Croix River Basin IBI can be found in Niemela and Feist (2000) available at: http://www.pca.state.mn.us/water/biomonitoring/sf-ibi-stcroix.pdf

Invertebrate data has not yet been assessed because of the drought conditions experienced in 2006 during the invertebrate sampling index period of August and September. MPCA staff are currently evaluating the effects of drought on invertebrate community structure in an effort to determine the applicability of these samples to characterize water quality condition. Information on the MIBI for streams of the St. Croix River Basin (Chirhart 2003) can be found at: http://www.pca.state.mn.us/publications/reports/biomonitoring-mibi-stcroix.pdf

Water chemistry results are presented in a summary table for each 11-digit HUC. The data, as presented, is not a determination of use support as the data requirements and assessment methodologies differ by parameter and any assessment of use support would utilize all available data on an AUID within the most recent 10-year period. In addition, not all water chemistry parameters of interest have developed water quality standards. McCollor and Heiskary (1993) developed ecoregion expectations for a number of water quality parameters that provide a good basis for evaluating water quality data and estimating attainable water quality for an ecoregion. The expectations were based on the 75th percentile from a long term dataset of least impacted streams. The intent of these summary tables is to present the data collected as part of this study and to highlight potential parameters of concern. Summary tables for existing SRWMB long term monitoring stations represent data collected over their period of record and typically contain multiple years of data.

Upper Snake River Watershed Unit – HUC 07030004010



The Upper Snake River Watershed Unit, located in southeast Aitkin County, drains an area of 129.3 square miles. The watershed forms the headwaters of the Snake River and consists of several low gradient, bog stained streams that originate in large alder, willow, and black spruce swamps. The upper Snake River flows in a westerly direction to the small community of Pliny, where it turns and flows south to McGrath. The entire watershed is largely undeveloped and consists predominantly of forest, shrub, and wetland land cover (Fig. 5). The pour point of this watershed unit is 2 miles SE of McGrath at the Hwy. 18 bridge, and is represented by site 06SC132.

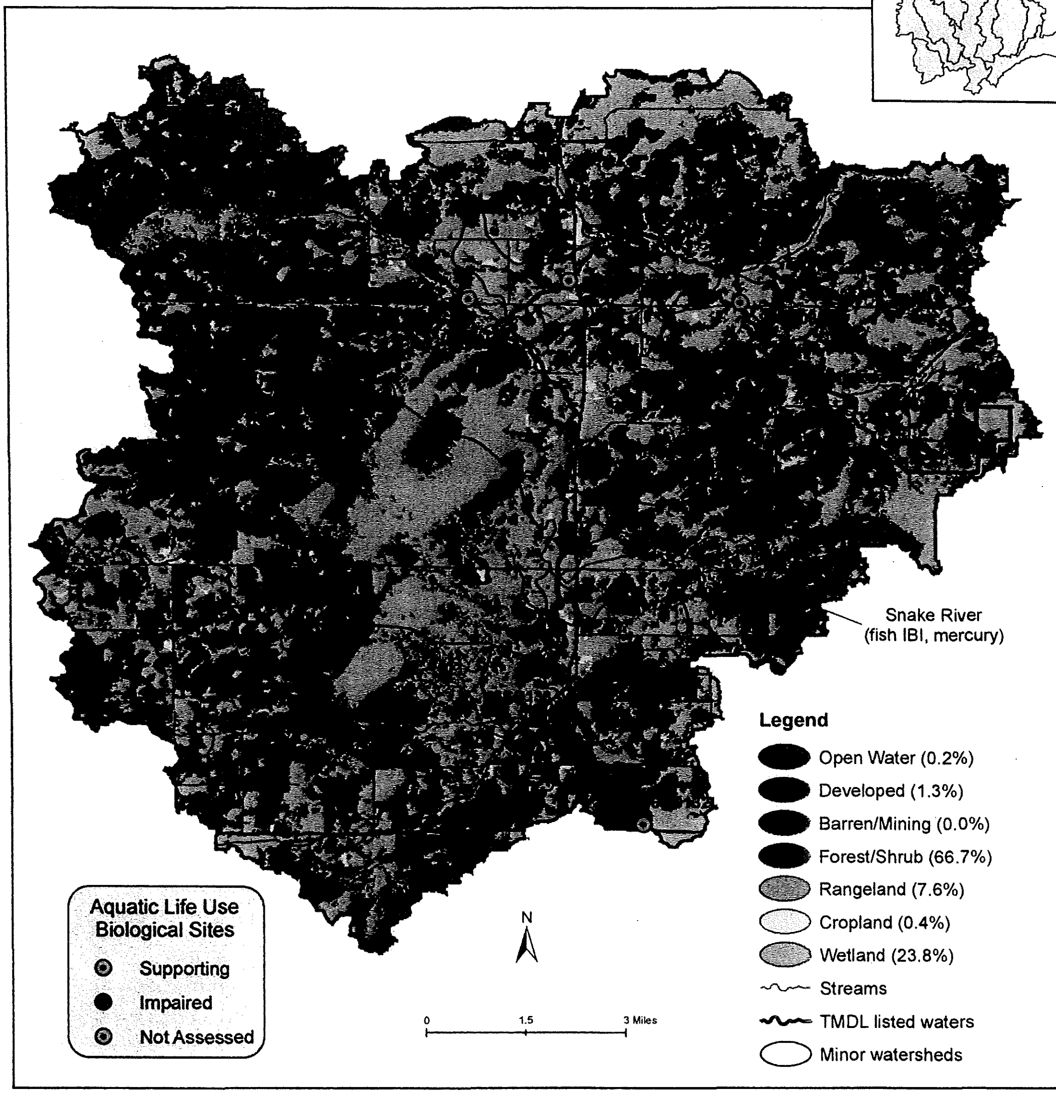


Figure 5. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Upper Snake River Watershed Unit.

Five biological sampling events were conducted at discrete stations within the Upper Snake River Watershed Unit in 2006. Two sites on the main-stem Snake River (96SC069 and 06SC132) have IBI scores of 86 and 69 respectively, and are fully supporting for aquatic life. However, the Snake River reach from the headwaters to Hay Creek (AUID 07030004-508) was listed as impaired for aquatic life (F-IBI) in a previous assessment cycle (2002). Available data on this AUID suggests that the impairment is likely due to the previous assessment of data from a channelized reach, as all IBI scores from stations exhibiting natural stream channels indicate full support. The station on Bear Creek in the town of McGrath (06SC133) has an IBI score of 33 and is not supporting for aquatic life. This is significantly below the biological criterion of IBI $\geq$ 68 for this stream type and Bear Creek (AUID 07030004-552) was added to the impaired waters list in the 2008 Assessment Cycle. Bear Creek was also listed in 2008 for pH based on available data from an existing SRWMB monitoring station. Two sites (06SC134, Trib. to Snake River and 06SC135, Snake River) were not assessed in this watershed during the 2008 Assessment Cycle due to the channelized condition of the stream channel within the sampling reach.

Water chemistry data was collected by the SRWMB at the station representing the pour point of the Upper Snake River Watershed Unit (06SC132) between 4/9/2001 and 9/28/2006. Results indicate that no parameters for which there is data are in potential violation of water quality standards or exceed ecoregion expectations (Table 2).

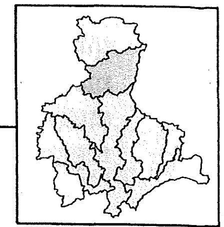
Table 2. Water chemistry results at the site representing the pour point of the Upper Snake River Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Snake River at HWY 18, 2 mi. SE of McGrath, MN											
Storet ID:	S001-727											
Station ID:	06SC132 – pour point of Upper Snake River HUC-11 Watershed (07030004-010)											
Parameter	Chloride	D.O.	Fecal Coliform	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples		21	16		19	21	39	38			49	67
Minimum		6.6	1		0.005	6.8	0.02	0.5			-.6	23
Maximum		13.3	1100		0.08	8.5	0.09	11.0			24.4	60
Mean[1]		9.4	42		0.016	7.3	0.04	2.7			11.6	57.9
Median		8.96	50		0.005	7.2	0.035	2.0			10.6	60
WQ standard	230	5.0	200/ 2000			6.5 - 9.0					30	20
# WQ exceedances[2]		0/21	0/16			0/21					0/49	0/67
NLF 75th percentile[3]				0.2	0.03	7.9	0.05	5.6	260		21.7	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

With the exception of Bear Creek, water quality conditions within the Upper Snake River Watershed Unit appear to be adequate and meeting their designated uses. Phase II monitoring in the watershed could be restricted to the Bear Creek sub-watershed in order to identify the source(s) and cause(s) of the impairment.

Lower Upper Snake River Watershed Unit – HUC 07030004020



The Lower Upper Snake River Watershed Unit, located in southeast Aitkin and northern Kanabec Counties, encompasses an area of 113.5 square miles. The watershed unit includes the Snake River main-stem from Hwy 18, 2 miles SE of McGrath to the confluence of Chelsey Brook. Like the Upper Snake River Watershed, it is largely undeveloped and consists predominantly of forest, shrub, and wetland land cover (Fig. 6). Named minor watersheds within this watershed unit include Bergman, Cowan's, and Chelsey brooks, and Hay Creek. The pour point of this watershed unit is represented by site 06SC123, on the Snake River.

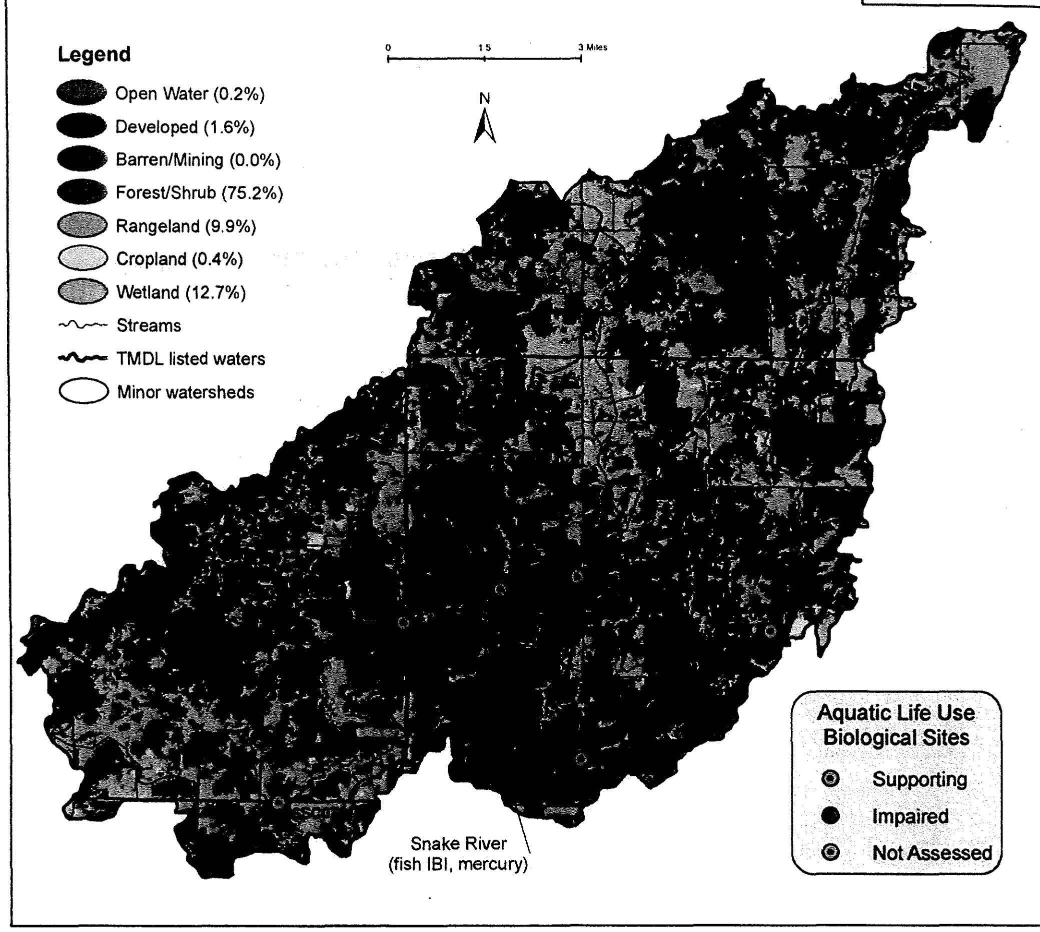


Figure 6. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Lower Upper Snake River Watershed Unit.

Six biological sampling events were conducted at discrete stations within the Lower Upper Snake River Watershed Unit in 2006. The two sites on the main-stem Snake River (06SC006 and 06SC123) have IBI scores of 74 and 75 respectively, and indicate full support for aquatic life. However, the two sampling stations fall on separate AUID's (07030004-508 and 07030004-523). The upper station (06SC006) is within the previously listed reach (F-IBI) of the Snake River (AUID 07030004-508, headwaters to Hay Creek). As previously mentioned, impairment of this reach is not widespread and is limited to a channelized section of the Snake River near the town of Pliny. Biological monitoring stations on Chelsey (06SC022), Cowan's (06SC131), and Bergman (99NF042) brooks all indicate full support for aquatic life; scoring 66, 68, and 77 respectively for biological integrity. The site on Hay Creek (96SC076) was not assessed in this watershed during the 2008 Assessment Cycle due to the channelized condition of the stream channel within the sampling reach.

Water chemistry data collected at the station representing the pour point of the Lower Upper Snake River Watershed Unit (06SC123) did not indicate any potential water quality problems within the watershed. Results indicate that no parameters for which there is data are in potential violation of water quality standards or exceed ecoregion expectations (Table 3), with the exception of pH. One of ten pH measurements was slightly below (6.1) the water quality standard range (6.5-9.0), which is likely attributed to the naturally low alkalinities found in the wetland dominated headwater streams of this region.

Table 3. Water chemistry results at the site representing the pour point of the Lower Upper Snake River Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Snake River at Olympic St., 3 mi. E of Woodland, MN											
Storet ID:	S004-067											
Station ID:	06SC123 – pour point of Upper Lower Snake River HUC-11 Watershed (07030004-020)											
Parameter	Chloride	D.O.	E. coli	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples	10	9	10	10	10	10	10	10	10	10	10	8
Minimum	1.9	6.5	4	<0.05	<0.05	**6.1**	0.014	<1.0	60	<5.0	10.0	>100
Maximum	5.1	10.0	64	0.12	<0.05	8.4	0.063	1.6	202	15	25.7	>100
Mean[1]	3.5	8.7	17	0.035	<0.05	7.5	0.031	0.9	156	8.1	20.8	>100
Median	3.3	9.1	18	<0.05	<0.05	7.7	0.029	0.9	172	7.7	22.3	>100
WQ standard	230	5.0	126/ 1260			6.5 - 9.0					30	20
# WQ exceedances[2]	0/10	0/9	0/10			1/10					0/10	0/8
NLF 75th percentile[3]				0.2	0.03	7.9	0.05	5.6	260		21.7	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

Overall, water quality conditions in the Lower Upper Snake River Watershed Unit appear to be adequate and meeting their designated uses. No intensive Phase II or follow up monitoring is recommended at this time.

Middle Snake River Watershed Unit – HUC 07030004030

The Middle Snake River Watershed Unit encompasses an area of 153.5 square miles. The watershed unit includes the Snake River main-stem from the Chelsey Brook to Mud Creek confluences. The river flows in a southerly direction almost the entire length of Kanabec County, before it turns and flows east just south of Mora. Named minor watersheds within this watershed unit include Snowshoe and Spring brooks, and Rice Creek. The upper half of this watershed remains largely forested while the lower half has been converted primarily to agricultural land uses (Fig. 7). The pour point of this watershed unit is represented by site 06SC112, on the Snake River near Brunswick.

Nine biological sampling events were conducted at eight discrete stations within the Middle Snake River Watershed Unit in 2006. Four stations in this watershed unit are located on the Snake River main-stem (06SC118, 06SC116, 06SC112, and 06SC115). IBI scores range from 71 – 94, all indicating good to excellent biological integrity. Station 06SC112 was sampled twice, scoring 91 and 94 successively. However, only station 06SC118 has a drainage area < 270 mi^2 and could be assessed for aquatic life using fish community biological criterion at this time. The IBI score of 86 indicates full support of the reach (AUID 07030004-506, Chelsey Brook to Knife River). Snowshoe Brook (06SC117) and an unnamed tributary to the Snake River (06SC113) score 73 and 68 respectively and are fully supporting for aquatic life. Spring Brook (06SC114) has an IBI score of 34 and is not supporting for aquatic life. This concurs with previous fish community sampling conducted at

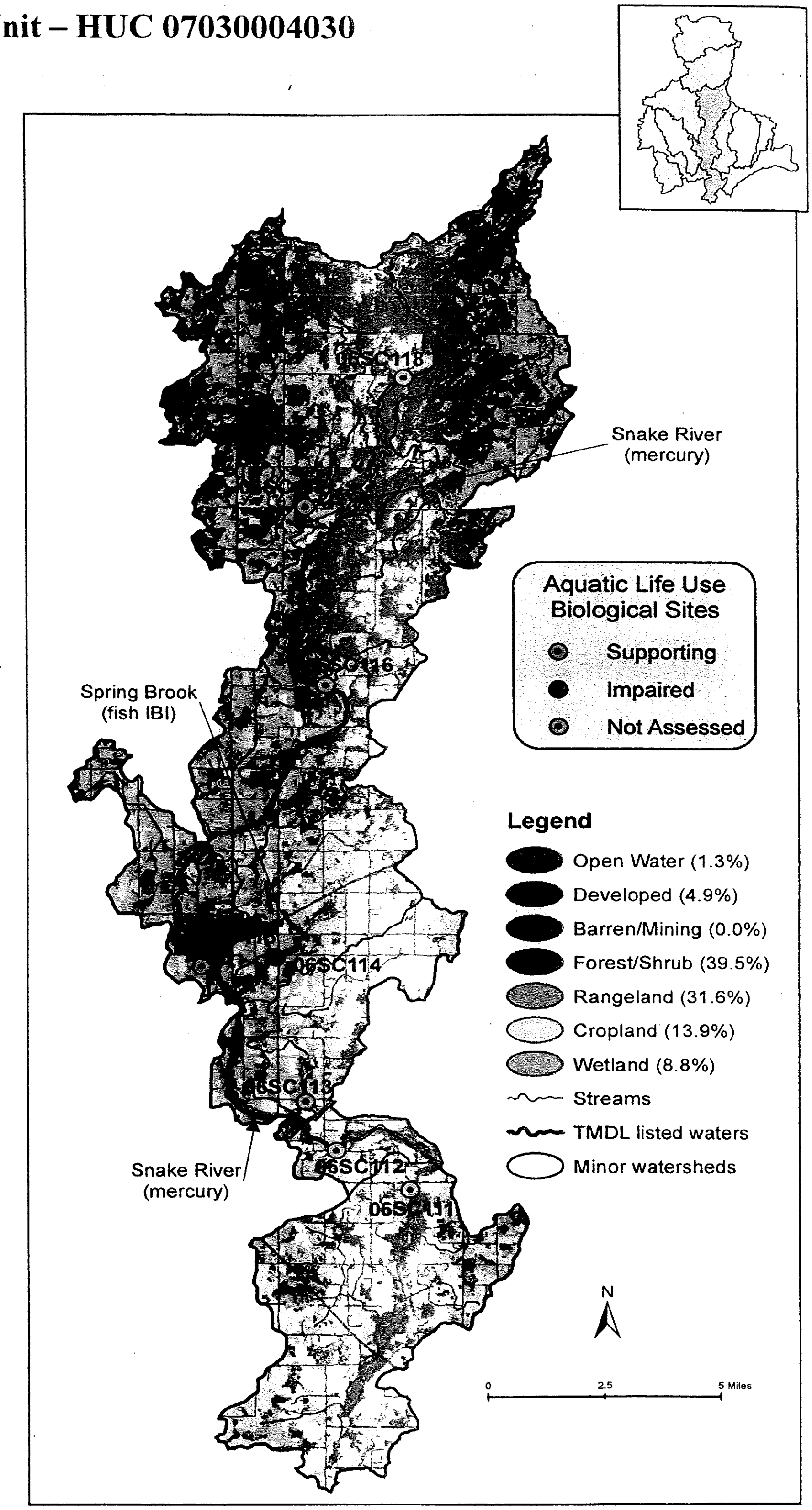


Figure 7. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Middle Snake River Watershed Unit.

another location that resulted in Spring Brook (AUID 07030004-515) being placed on the impaired waters list in 2002. The site on Rice Creek (06SC111) was not assessed in this watershed during the 2008 Assessment Cycle due to the channelized condition of the stream channel within the sampling reach.

Water chemistry data collected at the station representing the pour point of the Middle Snake River Watershed Unit (06SC112) did not indicate any potential water quality problems within the watershed with the exception of pH and nitrogen (NO^2+NO^3)(Table 4). Two of ten pH measurements were narrowly outside (6.1 and 9.5) the water quality standard range of 6.5-9.0. The mean nitrogen concentration is 0.21 mg/l and exceeds the ecoregion expectation of 0.12 mg/l. A potential source of the elevated levels could be the Groundhouse River, which also has elevated nitrogen, and enters the Snake River approximately two miles upstream of this site.

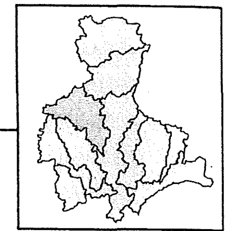
Table 4. Water chemistry results at the site representing the pour point of the Middle Snake River Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Snake River along 150th Ave., 3 mi. E of Brunswick, MN											
Storet ID:	S004-070											
Station ID:	06SC112 – pour point of Middle Snake River HUC-11 Watershed (07030004-030)											
Parameter	Chloride	D.O.	E. coli	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples	10	9	10	10	10	10	10	10	10	10	10	8
Minimum	4	5.9	8	<0.05	0.09	**6.1**	0.044	<1.0	142	<5.0	11.2	>100
Maximum	9.2	13.0	84	0.07	0.37	**9.2**	0.093	3.6	317	11	27.1	>100
Mean[1]	7.3	10.8	30	0.03	**0.21**	8.1	0.063	2.1	262	5.2	21.8	>100
Median	7.9	11.3	30	<0.05	0.21	8.3	0.059	1.8	279	5.3	22.9	>100
WQ standard	230	5.0	126/ 1260			6.5 - 9.0		100			30	20
# WQ exceedances[2]	0/10	0/9	0/10			2/10		0/10			0/10	0/8
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

With the exception of Spring Brook, water quality conditions within the Middle Snake Watershed Unit appear to be adequate and meeting their designated uses. Phase II monitoring in the watershed could be restricted to the Spring Brook sub-watershed in order to identify the source(s) and cause(s) of the impairment. Additional monitoring could also be conducted to determine if pH and nitrogen are of concern and to identify their sources. The SRWMB has an existing monitoring strategy in the Snake River Watershed that will provide valuable insight into the sources and contributions of pollutants within the watershed.

Knife River Watershed Unit – HUC 07030004040



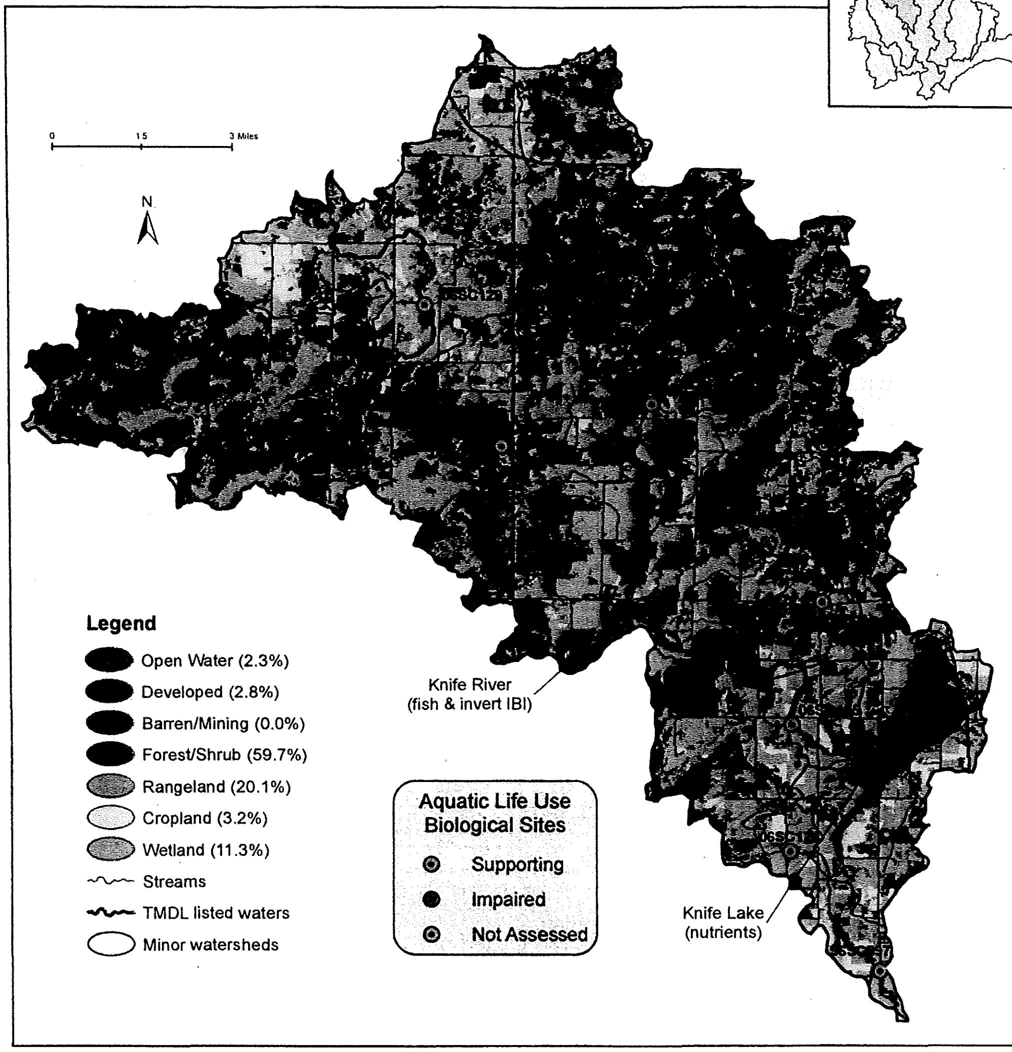


Figure 8. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Knife River Watershed Unit.

The Knife River Watershed Unit, located in northeast Mille Lacs and northwest Kanabec Counties, drains an area of 108.0 square miles. The headwaters originate within the Mille Lacs State Wildlife Management Area. The Knife River flows southeast through a matrix of wetland, forest, and rangeland land cover types to Knife Lake (Fig. 8). From Knife Lake the river flows south to its confluence with the Snake River just north of Mora. Agricultural land uses are more predominant in the lower portion of the watershed and the area surrounding Knife Lake is moderately developed. The pour point of this watershed unit is represented by site 96SC097.

Seven biological sampling events were conducted at discrete stations within the Knife River Watershed Unit in 2006. Three stations on the Knife River (06SC128, 06SC125, and 96SC097) have IBI scores of 82, 67, and 74 respectively, and indicate full support for aquatic life. The Knife River has been split into two assessment reaches (AUID 07030004-537, Dry Run to Knife Lake and 07030004-549, Knife Lake to Snake River). Previous biological sampling resulted in the upper Knife River reach (07030004-537) being listed as non-supporting for aquatic life use (F-IBI and M-IBI). Bean Brook (06SC126) has an IBI score of 77 and is fully supporting for aquatic life. Two unnamed tributaries to the Knife River (06SC127 and 06SC124) also indicate full support, scoring 91 and 68 respectively. The site on Dry Run (06SC129) was not assessed in this watershed during the 2008 Assessment Cycle due to a predominant wetland condition within the sampling reach.

Water chemistry data was collected by the SRWMB at the station representing the pour point of the Knife River Watershed Unit (96SC097) between 4/7/2004 and 11/22/2005. Results indicate a potential water quality problem with fecal coliform and to a lesser extent nitrogen (NO^2+NO^3)(Table 5). Two of fifteen fecal coliform samples exceeded the maximum standard of 2000 organisms per 100 milliliters. Additional bacteria data should be collected in order to calculate a monthly geometric mean to determine aquatic recreation use support. The mean nitrogen concentration is 0.13 mg/l and marginally exceeds the ecoregion expectation of 0.12 mg/l. A single dissolved oxygen (D.O.) value of forty-one measurements fell below (2.0 mg/l) the water quality standard (5.0 mg/l) and does not indicate a potential D.O. impairment (>10% violations, minimum 20 observations).

Table 5. Water chemistry results at the site representing the pour point of the Knife River Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Knife River at CR 77, 3 mi. N of Mora, MN											
Storet ID:	S003-528											
Station ID:	96SC097 – pour point of Knife River HUC-11 Watershed (07030004-040)											
Parameter	Chloride	D.O.	Fecal Coliform	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100 ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples		41	15		21	41	41	41			41	
Minimum		**2.0**	2		0.005	6.87	0.02	0.5			2.1	
Maximum		14.5	**6400**		0.6	8.66	0.1	27.0			28.9	
Mean[1]		10.4	47		**0.13**	7.6	0.06	4.5			13.9	
Median		10.23	20		0.07	7.6	0.06	4.0			13.3	
WQ standard	230	5.0	200/ 2000			6.5 - 9.0		100			30	20
# WQ exceedances[2]		1/41	2/15			0/41		0/41			0/41	
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

Knife Lake is also currently listed as non-supporting of aquatic recreation due to excess nutrients. Phase II intensive monitoring should be conducted in the Knife River Watershed Unit in order to assess use support status for all indicators and to determine what pollutant(s) and/or stressor(s) are causing or contributing to the impairments in the watershed.

Ann River Watershed Unit – HUC 07030004050

The Ann River Watershed Unit, located primarily within Kanabec County, drains an area of 84.2 square miles. The headwaters originate within the Mille Lacs State Wildlife Management Area and flows southeast as the Little Ann River through a mostly undeveloped wetland/forest matrix to Ann Lake (Fig. 9). From Ann Lake the Ann River flows southeast approximately eleven miles to Fish Lake through a landscape that has been primarily converted to pasture and other agriculture land uses. The confluence of the Ann and Snake Rivers is located just downstream of the Fish Lake outlet near Mora, MN. The pour point of this watershed unit is represented by site 06SC122.

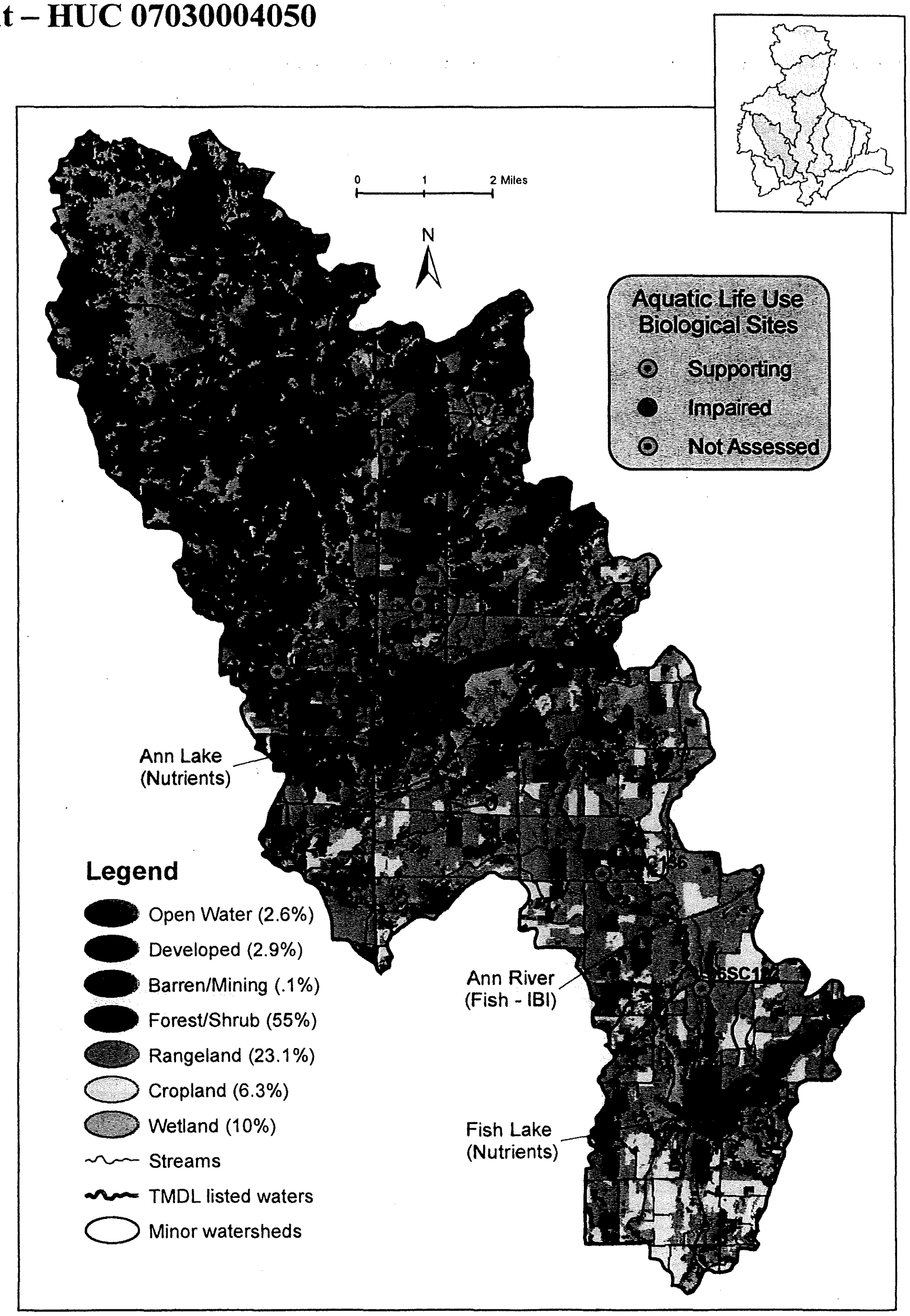


Figure 9. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Ann River Watershed Unit.

Six biological sampling events were conducted at five discrete stations within the Ann River Watershed Unit in 2006. Progressing from upstream to downstream in the watershed, the general trend is a decrease in IBI score. In the upper half of the watershed stations on Camp Creek (06SC137) and the Little Ann River (96SC004 and 06SC138) have fish community IBI scores ranging from 76-97, all indicating full support of their aquatic life use. The two stations on the Ann River main-stem (06SC136 and 06SC122) have IBI scores of 67 and 71 respectively, and narrowly meet their biological expectation for aquatic life use support. This trend seems to correlate with the change in land use from forest/wetland to pasture/agriculture in the southern half of the watershed.

However, previous biological sampling in this watershed (1996 and 1998) resulted in the Ann River reach (AUID 07030004-511) being listed as non-supporting for aquatic life use (F–IBI) and follows the trend of decreasing IBI scores progressing downstream. Available macroinvertebrate data also suggests impairment of the Ann River reach and will likely be listed as impaired for this indicator in the 2010 assessment cycle. In addition, both Ann and Fish Lakes are currently listed as non-supporting of aquatic recreation due to excess nutrients.

Water chemistry data collected at the station representing the pour point of the Ann River Watershed Unit (06SC122) indicated a potential water quality problem with e-coli bacteria and to a lesser extent dissolved oxygen and pH (Table 6). Six of ten samples taken between 5/25/2006 and 9/29/2006 exceeded the e-coli standard of 126 organisms/100ml. However, the water quality standard is based on a 30 day geometric mean with a minimum of 5 samples necessary to calculate. The geometric mean of 210 reported in Table 6 is a seasonal mean (May – Sept.) and is not sufficient for determination of aquatic recreation use support. This is considered screening level data and suggests a potential problem. Additional data should be collected to calculate a monthly geometric mean in order to determine aquatic recreation use support.

Additionally, one of nine dissolved oxygen measurements fell below (4.3 mg/l) the water quality standard of 5.0 mg/l and one of ten pH values fell outside (6.0) the water quality standard range of 6.5-9.0. Follow up monitoring should be conducted to determine if sufficient violations exist in order to assess use support status for these parameters and determine if they are causing or contributing to the biological impairment in the watershed.

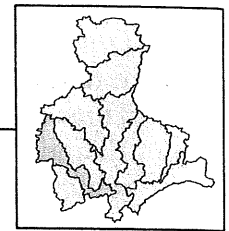
Table 6. Water chemistry results at the site representing the pour point of the Ann River Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Ann River at HWY 23, 2 mi. SW of Mora, MN
Storet ID:	S004-066
Station ID:	06SC122 – pour point of Ann River HUC-11 Watershed (07030004-050)

Parameter	Chloride	D.O.	E. coli	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples	10	9	10	10	10	10	10	10	10	10	10	8
Minimum	2.8	**4.3**	23	<0.05	<0.05	**6.0**	0.039	1.2	131	<5.0	10.1	91
Maximum	4.6	10.5	1100	0.11	0.15	7.9	0.094	3.2	368	8.6	23.3	>100
Mean[1]	3.6	6.8	**210**	0.034	0.05	7.2	0.064	2.2	266	4.3	18.9	97
Median	3.5	5.9	380	<0.05	<0.05	7.3	0.066	2.4	258	3.8	20.1	>100
WQ standard	230	5.0	126/ 1260			6.5 - 9.0		100			30	20
# WQ exceedances[2]	0/10	1/9	0/10			1/10		0/10			0/10	0/8
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

Groundhouse River Watershed Unit – HUC 07030004060



The Groundhouse River Watershed Unit, located in eastern Mille Lacs and southwest Kanabec Counties, encompasses an area of 87.7 square miles. The headwaters originate in a mostly undeveloped wetland/forest matrix, much of which is located within Rum River State Forest. Several small tributaries drain into the Groundhouse River, most notably the West and South Fork Groundhouse rivers. Agricultural land uses are more predominant in the lower portion of the watershed unit (Fig. 10). Significant development is sparse within the watershed unit, with the greatest density in the town of Ogilvie. The pour point of this watershed unit is represented by site 06SC061.

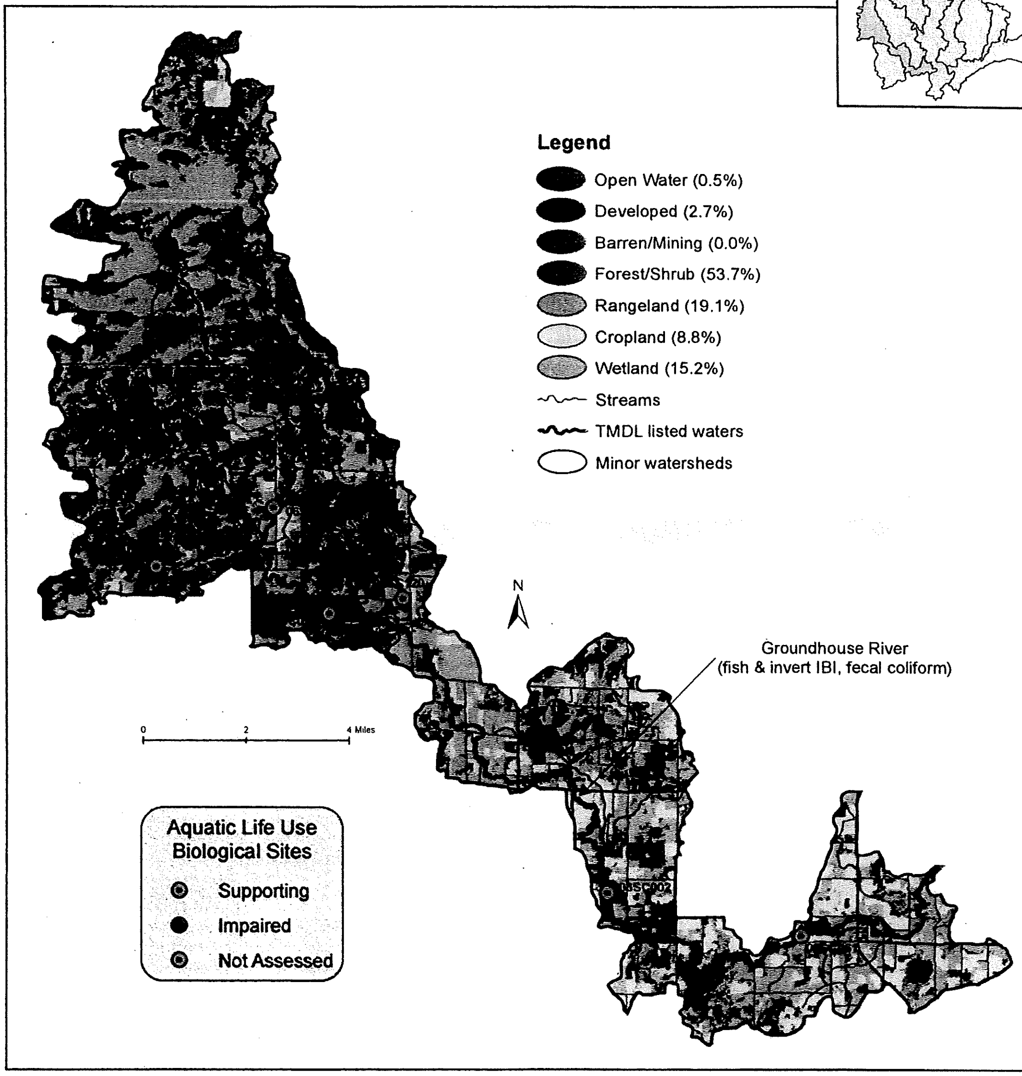


Figure 10. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Groundhouse River Watershed Unit.

Six biological sampling events were conducted at discrete stations within the Groundhouse River Watershed Unit in 2006. The Groundhouse River is split into two assessment reaches (AUID 07030004-513, headwaters to S.F. Groundhouse River and 07030004-512, S.F. Groundhouse River to Snake River). Two stations (06SC121 and 96SC070) on the upper reach (07030004-513) have IBI scores of 86 and 83 respectively, and are fully supporting for aquatic life. Another station (03SC002) scores below (66) the threshold of 69 but is within the 95% confidence limit. Previous biological sampling in this watershed resulted in the upper Groundhouse River reach being listed as non-supporting for aquatic life use (F-IBI and M-IBI). The station (06SC061) on the lower Groundhouse River reach (07030004-512) has an IBI score of 70, narrowly meeting the biological expectation for use support. The West Fork Groundhouse River (06SC029) and an unnamed tributary (06SC120) also are full supporting, scoring 79 and 82 respectively.

Water chemistry data was collected by the SRWMB at the station representing the pour point of the Groundhouse River Watershed Unit (06SC061) between 4/7/2004 and 10/25/2005. Results indicate fecal coliform and nitrogen (NO^2+NO^3) are parameters of concern in this watershed unit (Table 7). Three of thirty-three fecal coliform samples exceeded the maximum standard of 2000 organisms per 100 milliliters, including one extremely high observation of 25,000 organisms on 10/5/2005. These results concur with previously available data, as the Groundhouse River was listed as impaired for aquatic recreation in the 2002 Assessment Cycle. The mean nitrogen concentration is 0.44 mg/l and significantly exceeds the ecoregion expectation of 0.12 mg/l. A single dissolved oxygen (D.O.) value out of forty-seven measurements fell below (2.2 mg/l) the water quality standard (5.0 mg/l) and does not indicate a potential D.O. impairment (>10% violations, minimum 20 observations).

Table 7. Water chemistry results at the site representing the pour point of the Groundhouse River Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

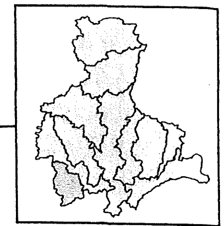
Station location:	Groundhouse River at HWY 65, 1 mi. W of Brunswick, MN
Storet ID:	S003-532
Station ID:	06SC061 – pour point of Groundhouse River HUC-11 Watershed (07030004-060)

Parameter	Chloride	D.O.	Fecal Coliform	NH_3 + NH_4	NO_2 + NO_3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100 ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples		47	33		11	44	23	36			47	
Minimum		**2.2**	20		.005	6.6	0.05	1.0			5.5	
Maximum		14.28	**25000**		1.5	8.6	0.2	38.0			23.9	
Mean[1]		9.5	157		**0.44**	7.5	0.08	5.9			14.5	
Median		9.5	110		0.3	7.5	0.07	3.5			15.2	
WQ standard	230	5.0	200/ 2000			6.5 - 9.0		100			30	20
# WQ exceedances[2]		1/47	3/33			0/44		0/36			0/47	
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

Phase II intensive monitoring is not necessary as TMDL studies in the Groundhouse River are currently underway to identify the pollution sources causing and contributing to the impairments and to develop implementation plans for restoration. Lane and Cormier (2004) concluded that excessive fine sediment is the leading cause of the biological impairment. Agricultural animal operations are the primary source of fecal coliform in the watershed unit (Tetra Tech, 2008).

South Fork Groundhouse River Watershed Unit – HUC 07030004070



The South Fork Groundhouse River Watershed Unit, located primarily within southwest Kanabec Counties, drains an area of 51.3 square miles. The headwaters originate in a wetland/ forest matrix within the Rum River State Forest. The river flows in a southerly direction for approximately ten miles before it turns and flows northeast to its confluence with the Groundhouse River three miles southeast of Ogilvie. Agricultural land uses (pasture and cultivated cropland) are predominant in the watershed (Fig. 11). Although there are several small unnamed tributaries in this watershed, none are delineated as 14-digit HUC minor watersheds. The pour point of this watershed unit is represented by site 03SC003.

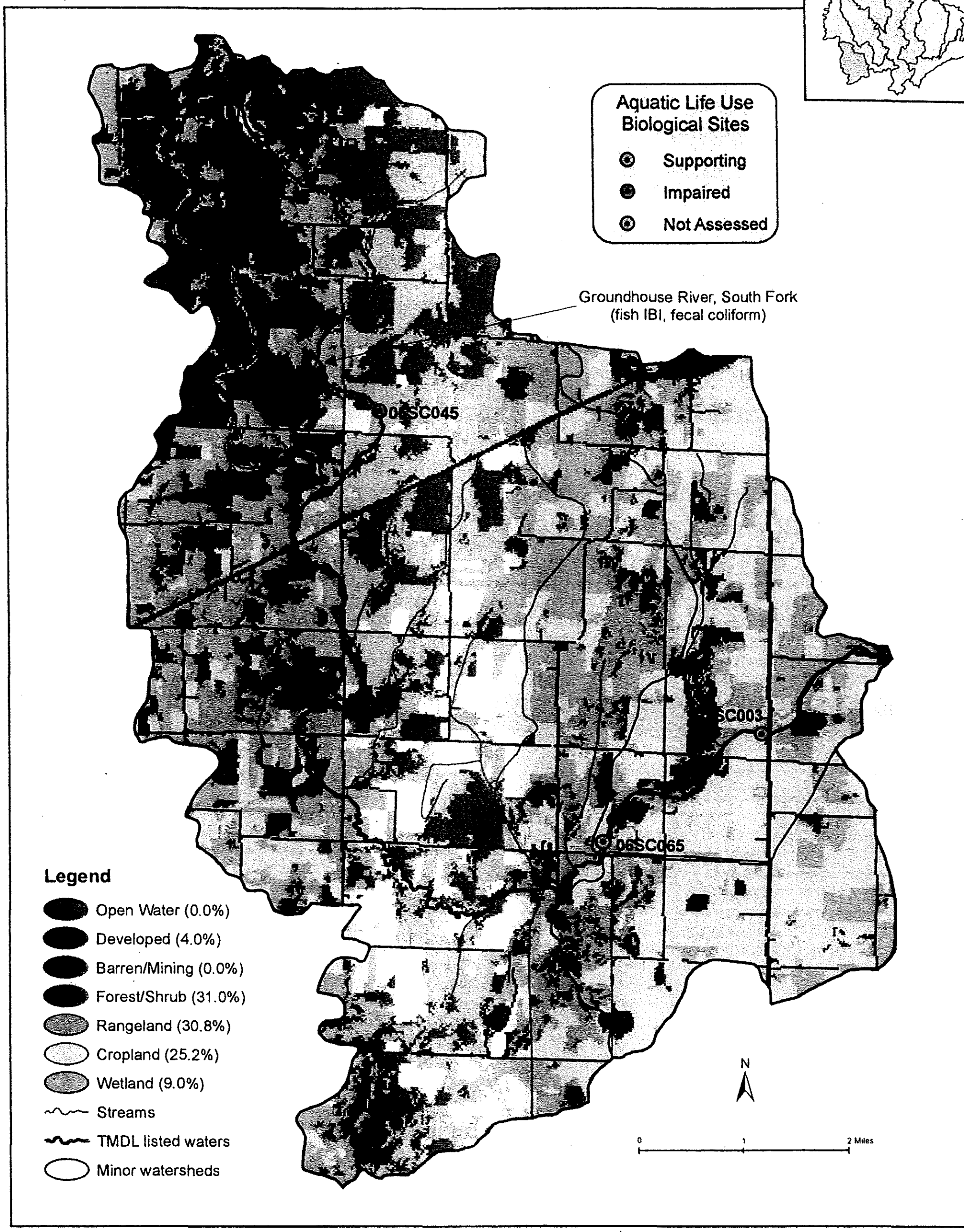


Figure 11. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the South Fork Groundhouse River Watershed Unit.

Five biological sampling events were conducted at three discrete stations within the South Fork Groundhouse River Watershed Unit in 2006. Station 06SC045 was sampled twice, scoring 19 and 13 successively, and is not supporting for aquatic life. Both results are significantly below the biological criterion of IBI ≥ 46 for this stream type and the South Fork Groundhouse River (AUID 07030004-573) was added to the impaired waters list in the 2008 Assessment Cycle. This AUID was also listed in a previous assessment cycle as impaired based on the macroinvertebrate assemblage (M-IBI). Data from stations 06SC045 and 03SC003 on the South Fork Groundhouse River were not assessed for aquatic life in the 2008 Assessment Cycle due to the channelized condition of the stream channel within the sampling reach.

Water chemistry data collected at the station representing the pour point of the South Fork Groundhouse River Watershed Unit (03SC003) indicated a potential water quality problem with e-coli bacteria and nitrogen (NO^2+NO^3)(Table 8). Five of ten samples taken between 5/25/2006 and 9/29/2006 exceeded the e-coli standard of 126 organisms/100ml. The water quality standard is based on a 30 day geometric mean with a minimum of 5 samples necessary to calculate. The geometric mean of 130 reported in Table 8 is a seasonal mean (May – Sept.) and is not sufficient for determination of aquatic recreation use support by itself. However, other data available during the 2008 Assessment Cycle resulted in this AUID being listed as impaired for aquatic recreation.

The mean nitrogen concentration of 1.3 mg/l significantly exceeds the ecoregion expectation of 0.12 mg/l. Single violations of water quality standards were observed for dissolved oxygen (3.8 mg/l) and pH (6.4). The mean specific conductance (337 *u*S/cm) slightly exceeded the ecoregion expectation of 310 *u*S/cm. Follow up monitoring should be conducted to determine if sufficient violations exist in order to assess use support status for these parameters and determine if they are causing or contributing to the biological impairment in the watershed.

Table 8. Water chemistry results at the site representing the pour point of the South Fork Groundhouse River Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	South Fork Groundhouse River at HWY 47, 3.6 mi. S of Ogilvie, MN											
Storet ID:	S003-638											
Station ID:	03SC003 – pour point of SF Groundhouse River HUC-11 Watershed (07030004-070)											
Parameter	Chloride	D.O.	E. coli	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples	10	9	10	10	10	10	10	10	10	10	10	8
Minimum	5.3	**3.8**	40	<0.05	0.27	**6.4**	0.068	<1.0	247	6.1	10.4	54
Maximum	14	15.5	470	0.11	3.2	8.0	0.140	13	404	17	22.8	>100
Mean[1]	9.1	9.9	**130**	0.047	**1.3**	7.5	0.101	4.4	**337**	9.5	19.1	92
Median	9.1	9.5	123	<0.05	1.2	7.5	0.100	2.8	346	9.0	20.1	>100
WQ standard	230	5.0	126/ 1260			6.5 - 9.0		100			30	20
# WQ exceedances[2]	0/10	1/9	0/10			1/10		0/10			0/10	0/8
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

Mud Creek Watershed Unit – HUC 07030004080

The Mud Creek Watershed Unit, located within southwest Kanabec and southeast Pine Counties, drains an area of 64.9 square miles. Mud Creek is a low gradient stream that flows in a southerly direction over its course for approximately twenty three miles to its confluence with the Snake River near Grasston. Land use is predominantly pastured rangeland with scattered areas of forest, shrub, and wetland throughout (Fig. 12). Row crop agricultural land uses become more prevalent in the lower portion of the watershed. Tributaries to Mud Creek consist of several small channelized streams or ditches. The pour point of this watershed unit is represented by site 06SC107.

Five biological sampling events were conducted at discrete stations within the Mud Creek Watershed Unit in 2006. Mud Creek is split into two assessment reaches (AUID 07030004-566, headwaters to Quamba Lake and 07030004-567, Quamba Lake to Snake River). One station (06SC110) on the upper reach has an IBI score of 68 and indicates full support. However, previous biological sampling resulted in the upper Mud Creek reach (07030004-566) being listed as non-supporting for aquatic life use (F-IBI and M-IBI). The lower Mud Creek reach (07030004-567) was sampled at two locations (06SC109 and 06SC107) and has IBI scores of 86 and 56 respectively. Multiple but discrepant results on an AUID indicate partial support of aquatic life. This AUID was also listed in a previous assessment cycle as impaired based on macroinvertebrate and fish assemblage data (M-IBI and F-IBI). Two sites (06SC018, Trib. to Mud Creek and 06SC108, County Ditch #4) were not

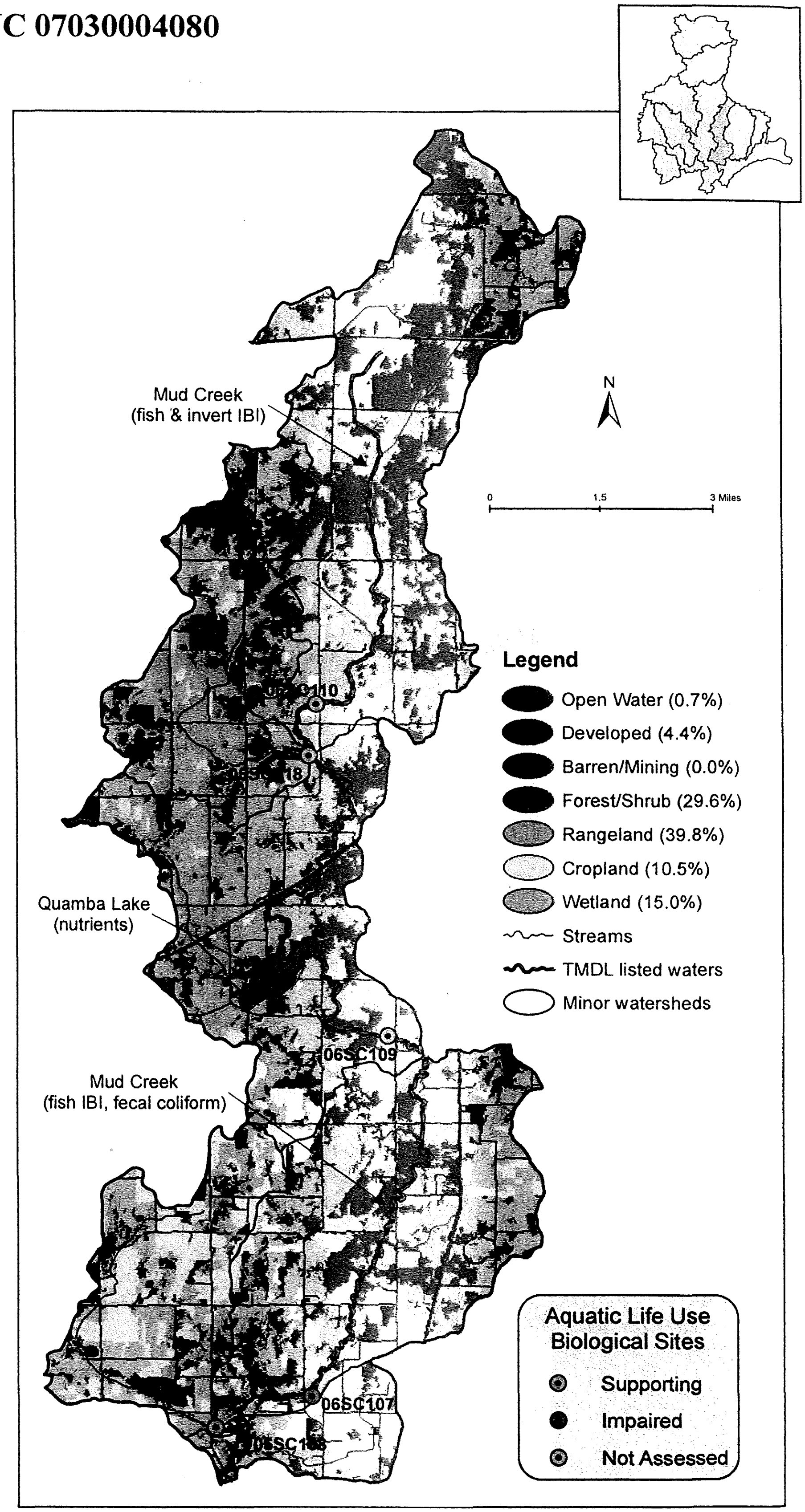


Figure 12. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Mud Creek Watershed Unit.

assessed in this watershed during the 2008 Assessment Cycle due to the channelized condition of the stream channel within the sampling reach.

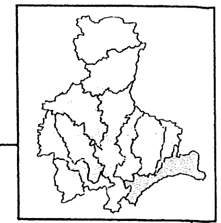
Water chemistry data was collected by the SRWMB at the station representing the pour point of the Mud Creek Watershed Unit (06SC107) between 4/7/2004 and 4/19/2006 (Table 9). Results indicate Mud Creek (AUID 07030004-567) is impaired for aquatic recreation (fecal coliform). More than 10 percent (7 of 20) individual fecal coliform values exceeded the 200 organisms per 100 ml standard. Two of twenty fecal coliform values exceeded the maximum standard of 2000 organisms per 100 milliliters, including one extremely high observation of 16,000 organisms on 10/5/2005. Two of thirty-nine pH values were below (6.2) the water quality standard range of 6.5 - 9.0 but does not indicate impairment (>10% violations, minimum 20 observations).

Table 9. Water chemistry results at the site representing the pour point of the Mud Creek Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Mud Creek at CR 5, 1 mi. NW of Grasston, MN											
Storet ID:	S003-533											
Station ID:	06SC107 – pour point of Mud Creek HUC-11 Watershed (07030004-080)											
Parameter	Chloride	D.O.	Fecal Coliform	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100 ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples		39	20		22	39	39	39			39	
Minimum		6	18		0.005	**6.2**	0.05	1.0			1.2	
Maximum		15.9	**16000**		0.3	8	0.2	17.0			26.6	
Mean[1]		9.2	139		0.05	7.3	0.09	6.6			14.4	
Median		8.7	91		0.04	7.37	0.08	6			14.3	
WQ standard	230	5.0	200/ 2000			6.5 - 9.0		100			30	20
# WQ exceedances[2]		0/39	2/20			2/39		0/39			0/39	
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

Quamba Lake is also currently listed as non-supporting of aquatic recreation due to excess nutrients. Phase II intensive monitoring should be conducted in the Mud Creek Watershed Unit in order to identify the source(s) and cause(s) of the impairments.



Lower Snake River Watershed Unit – HUC 07030004090

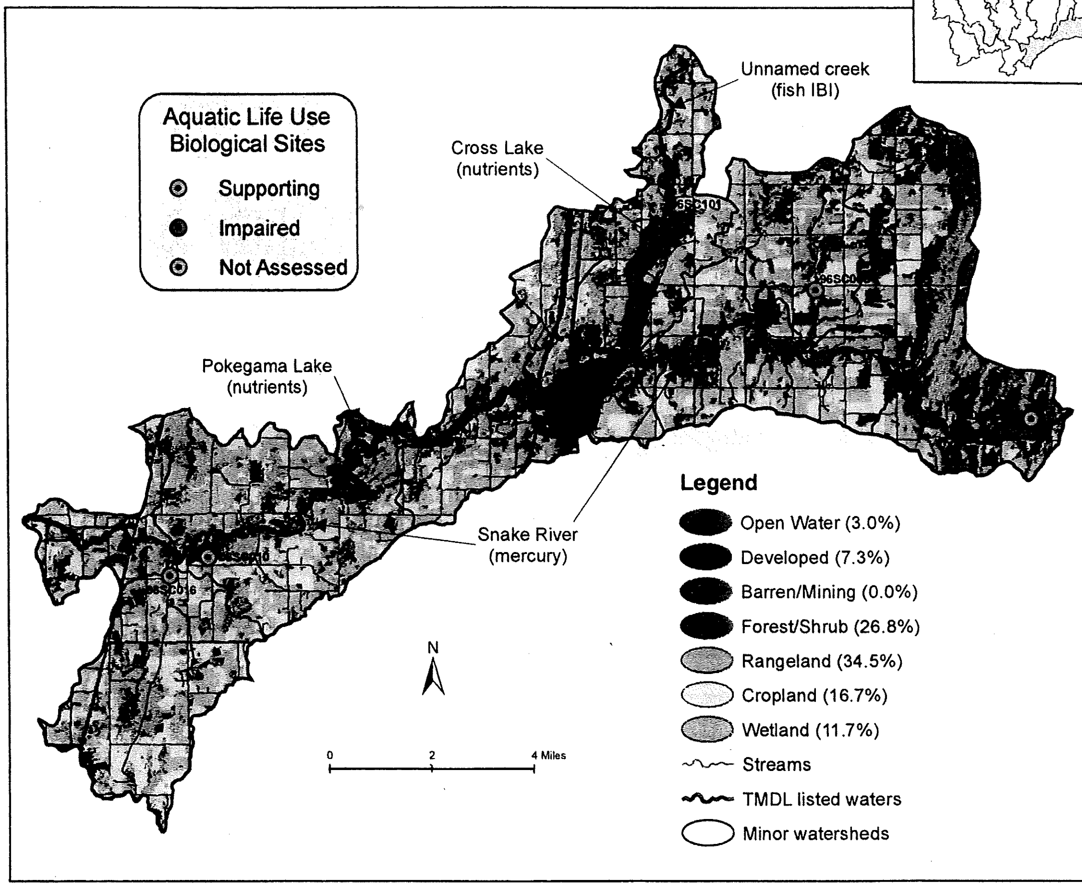


Figure 13. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Lower Snake River Watershed Unit.

The Lower Snake River Watershed Unit, located in southern Pine County, encompasses an area of 90.0 square miles. The watershed unit includes the Snake River main-stem from Mud Creek to its confluence with the St. Croix River. The river flows in an easterly direction through a wide farming valley to Cross Lake in Pine City. After flowing through Cross Lake and over the dam that maintains the lake level, the river continues east past wooded bluffs to its confluence. Considerable development of homes and cabins exist on this lower section, however, the last three miles of the river is protected within Chengwatana State Forest. Land cover is variable in the watershed unit; with a prevalence of agricultural land uses in the upper portion, areas of significant development in and around Pine City, and predominantly forest/shrub in the lower portion (Fig. 13). The pour point of this watershed unit is represented by site 06SC007.

Six biological sampling events were conducted at five discrete stations within the Lower Snake River Watershed Unit in 2006. Two stations in this watershed unit are located on the Snake River main-stem (06SC010 and 06SC007). IBI scores range from 73 – 89, all indicating good to excellent biological integrity. Station 06SC007 was sampled twice, scoring 74 and 89 successively. However, large river sites (drainage area > 270 mi^2) are not currently being assessed for aquatic life using fish community data in the St. Croix River Basin. Bear Creek (96SC068) has an IBI score of 62 and is fully supporting for aquatic life. A tributary to Cross Lake (06SC101) has an IBI score of 28 and is not supporting for aquatic life. This is significantly below the biological criterion of IBI ≥ 46 for this stream type and the reach (AUID 07030004-577) was added to the impaired waters list in the 2008 Assessment Cycle. The site on Hay Creek (98SC068) was not assessed in this watershed during the 2008 Assessment Cycle due to the channelized condition of the stream channel within the sampling reach.

Water chemistry data collected at the station representing the pour point of the Lower Snake River Watershed Unit (06SC007) did not indicate any potential water quality problems within the watershed. Results indicate that no parameters for which there is data are in potential violation of water quality standards or exceed ecoregion expectations (Table 10), with the exception of pH. One of ten pH measurements was below (5.8) the water quality standard range (6.5-9.0), but is not sufficient data to indicate impairment (>10% violations, minimum 20 observations).

Table 10. Water chemistry results at the site representing the pour point of the Lower Snake River Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Snake River near mouth, 9 mi. E of Pine City, MN											
Storet ID:	S000-128											
Station ID:	06SC007 - pour point of Lower Snake River HUC-11 Watershed (07030004-090)											
Parameter	Chloride	D.O.	E. coli	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples	10	9	10	10	10	10	10	10	10	10	10	8
Minimum	4.4	6.3	<4	<0.05	<0.05	**5.8**	0.040	2.0	130	<5.0	11.3	67
Maximum	7.3	13.4	28	<0.05	0.16	9.0	0.098	9.3	263	9.2	25.8	>100
Mean[1]	6.2	8.7	10	<0.05	0.11	7.4	0.063	4.5	216	4.4	20.4	93
Median	6.2	8.2	9	<0.05	0.12	7.6	0.061	4.2	222	3.8	22.6	98
WQ standard	230	5.0	126/ 1260			6.5 - 9.0		100			30	20
# WQ exceedances[2]	0/10	0/9	0/10			1/10		0/10			0/10	0/8
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

With the exception of the tributary to Cross Lake (06SC101), water quality conditions within the Lower Snake Watershed Unit appear to be adequate and meeting their designated uses. Phase II monitoring in the watershed could be restricted to this sub-watershed in order to identify the source(s) and cause(s) of the impairment. Existing volunteer monitoring data indicates *E. coli* bacteria may be a parameter of concern. Cross Lake is also listed as non-supporting of aquatic recreation due to excess nutrients in this watershed unit.

Pokegama Creek Watershed Unit – HUC 07030004100

The Pokegama Creek Watershed Unit, located in eastern Kanabec and southern Pine Counties, drains an area of 90.4 square miles. Pokegama Creek is a low gradient stream that flows in a southerly direction over its course for approximately nineteen miles to Pokegama Lake. Only a very short stream segment exists between the lake and Pokegama Creek's confluence with the Snake River. Land use is predominantly pastured rangeland with scattered areas of forest/shrub (Fig. 14). Wetlands are also prevalent throughout the watershed. Significant tributaries include East Pokegama Creek and an unnamed creek. The pour point of this watershed unit is located above the lake in order to characterize the stream condition and is represented by site 06SC042.

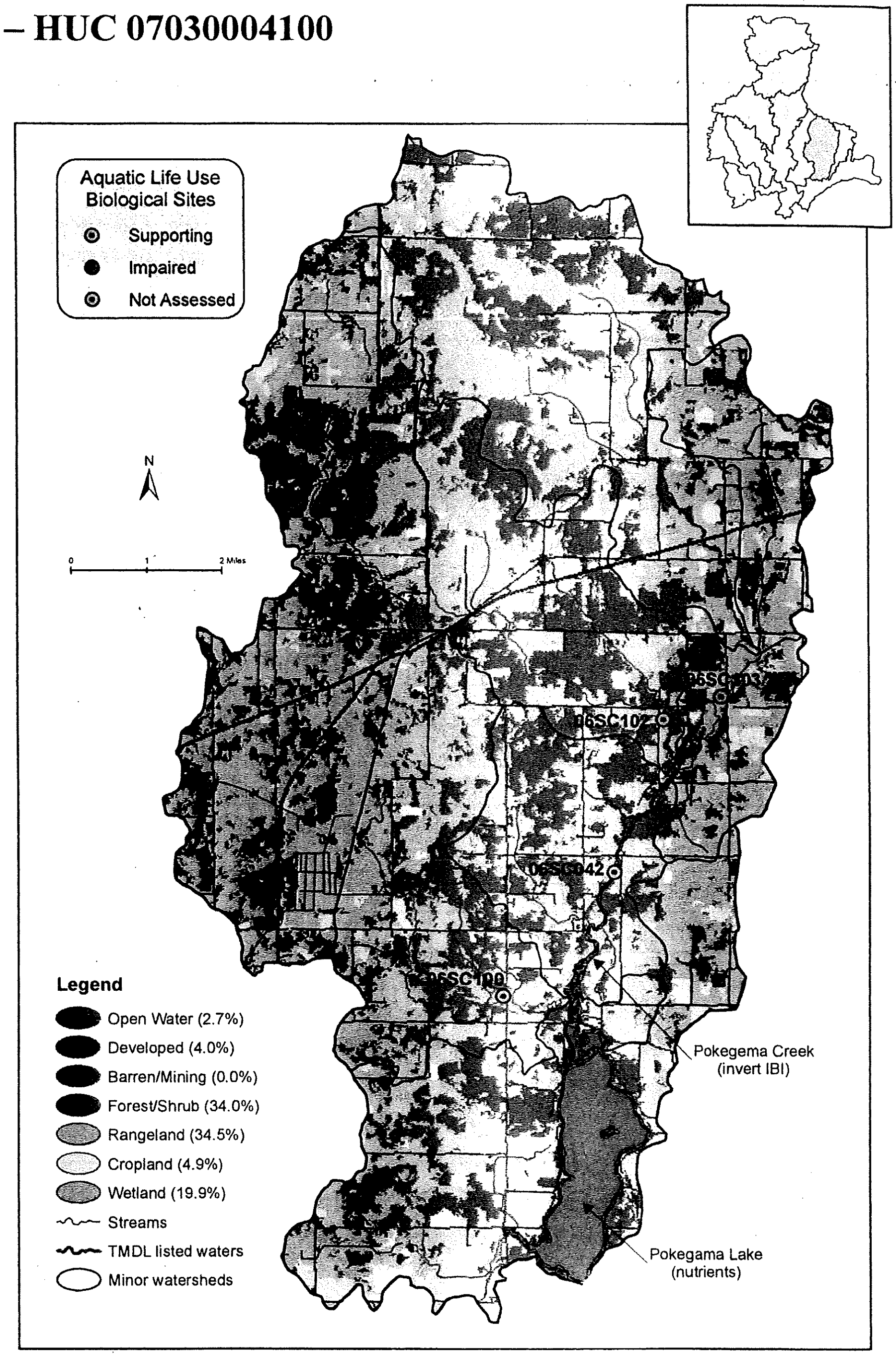


Figure 14. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Pokegama Creek Watershed Unit.

Five biological sampling events were conducted at four discrete stations within the Pokegama Creek Watershed Unit in 2006. A station (06SC102) on an upper reach of Pokegama Creek has an IBI score of 74 and indicates full support of aquatic life. The lower station (06SC042) has an IBI score below (64) the threshold of 68 but is within the 95% confidence limit. This lower reach (AUID 07030004-532, East Pokegama Creek to unnamed creek) was listed in a previous assessment cycle as impaired based on the macroinvertebrate assemblage (M-IBI). East Pokegama Creek has an IBI score of 70 and is fully supporting of aquatic life. Station 06SC100 (Trib. to Pokegama Creek) was sampled twice, scoring 51 and 42 successively, and is assessed as fully supporting. The score of 42 is below the impairment threshold of 46 for this stream type, but is within the 95% confidence limit.

Water chemistry data was collected by the SRWMB at the station representing the pour point of the Pokegama Creek Watershed Unit (06SC042) between 4/6/2004 and 4/19/2006. Results indicate that no parameters for which there is data are in potential violation of water quality standards or exceed ecoregion expectations (Table 11), with the exception of pH. Two of forty pH measurements were below (6.32 and 6.35) the water quality standard range (6.5-9.0), but does not indicate impairment (>10% violations, minimum 20 observations).

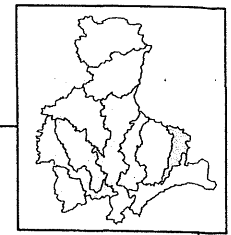
Table 11. Water chemistry results at the site representing the pour point of the Pokegama Creek Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Pokegama Creek at CR 14, 6 mi. NW of Pine City, MN											
Storet ID:	S002-542											
Station ID:	06SC042 – pour point of Pokegema Creek HUC-11 Watershed (07030004-100)											
Parameter	Chloride	D.O.	Fecal Coliform	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100 ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples		45	19		24	40	47	47			44	
Minimum		5.6	20		.005	**6.32**	.032	1.0			1.5	
Maximum		16.7	800		.13	8.5	.21	25.0			25.85	
Mean[1]		9.2	120		.023	7.3	.076	4.9			13.28	
Median		9.1	140		.01	7.3	.062	3.0			13.04	
WQ standard	230	5.0	200/ 2000			6.5 - 9.0		100			30	20
# WQ exceedances[2]		0/45	0/19			2/40		0/47			0/44	
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

Pokegama Lake is also currently listed as non-supporting of aquatic recreation due to excess nutrients. Phase II intensive monitoring should be conducted in the Pokegama Creek Watershed Unit in order to identify the source(s) and cause(s) of the impairments.

Mission Creek Watershed Unit – HUC 07030004110



The Mission Creek Watershed Unit, located in southern Pine County, drains an area of 36.7 square miles. The headwaters of Mission Creek originate just southwest of Hinckley. The creek flows in a mostly southwest direction to its confluence with the Snake River 2.5 miles west of Pine City. Land use is predominantly pastured rangeland with scattered areas of row crop agriculture (Fig. 15). Wetlands are also prevalent throughout, particularly in the middle reaches of the watershed. A roughly 2.5 mile reach in the upper section of Mission Creek is currently designated as a trout stream. No minor watersheds are delineated within the watershed. The pour point of this watershed unit is represented by site 06SC104.

Four biological sampling events were conducted at three discrete stations within the Mission Creek Watershed Unit in 2006. The three stations are located on two AUID's (07030004-547 and 07030004-548). Two stations (06SC106 and 06SC105) on the upper reach have IBI scores of 49 and 43 respectively and the reach is considered partial supporting for aquatic life. In addition, this AUID was listed in previous assessment cycles as impaired based on macroinvertebrate and fish assemblage data (M-IBI and F-IBI). Station 06SC104 was sampled twice on the lower reach (AUID 07030004-548), scoring 13 and 11 successively. These results are significantly below the biological criterion of IBI $\geq$ 68 for this stream type and the reach was added to the impaired waters list in the 2008 Assessment Cycle.

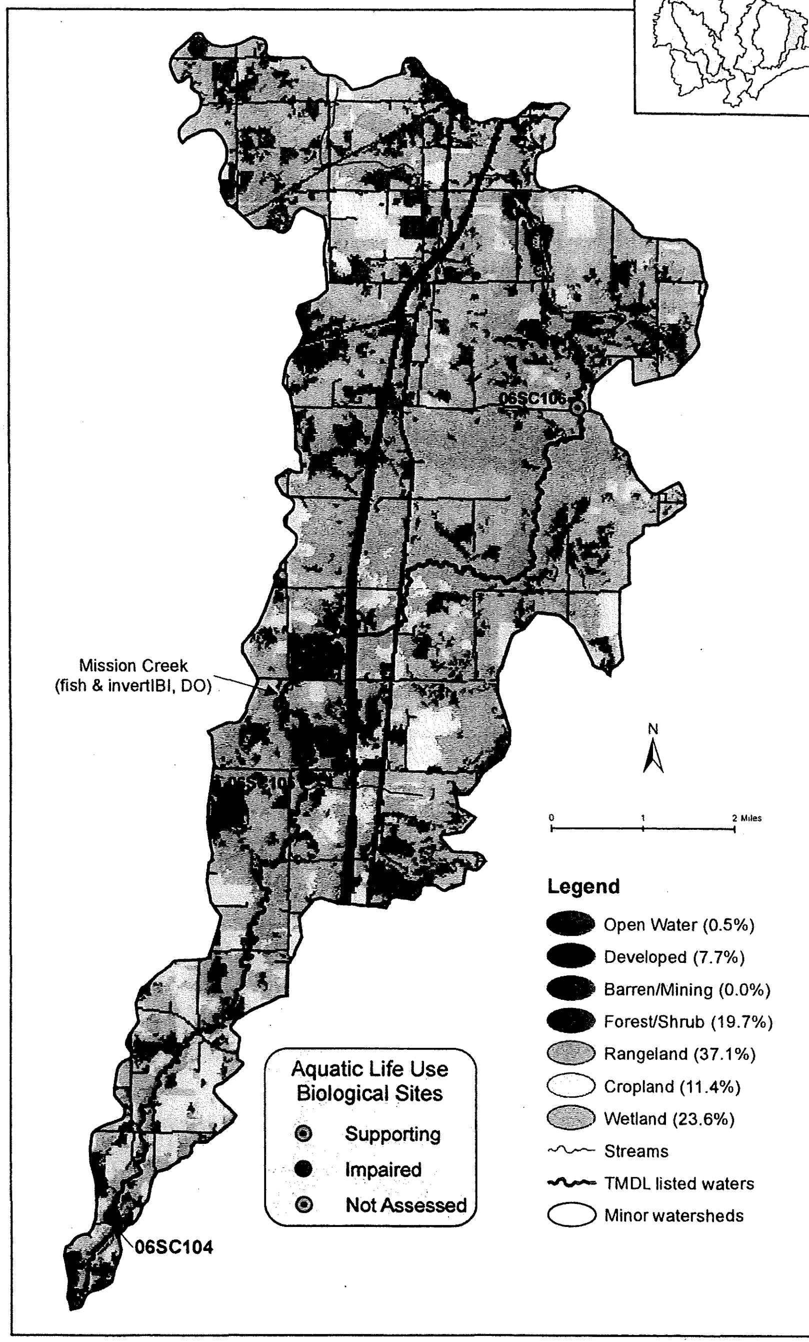


Figure 15. Sampling locations and their use support status, land use characteristics, minor watersheds, and currently listed impaired waters in the Mission Creek Watershed Unit.

Water chemistry data was collected by the SRWMB at the station representing the pour point of the Mission Creek Watershed Unit (06SC104) between 4/6/2004 and 4/19/2006. Results indicate dissolved oxygen is a parameter of concern in this watershed, and to a lesser extent fecal coliform (Table 12). Twelve of forty-six values violated the minimum D.O. standard of 5.0 mg/l. The data set was sufficient (>10% violations, minimum 20 observations) to list Mission Creek (AUID 07030004-548) as non-supporting of aquatic life for this parameter in the 2008 Assessment Cycle. One of twenty fecal coliform values exceeded (7300) the maximum standard of 2000 organisms per 100 milliliters. However, the results are not sufficient to assess the reach as non-supporting for aquatic recreation. Three of forty-five pH measurements were outside (6.05, 6.14 and 9.75) the water quality standard range (6.5-9.0), but does not indicate an impairment (>10% violations, minimum 20 observations).

Table 12. Water chemistry results at the site representing the pour point of the Mission Creek Watershed Unit. Bold values indicate potential exceedances of a water quality standard or ecoregion expectation.

Station location:	Mission Creek at CR 53, 2 mi. W of Pine City, MN											
Storet ID:	S003-531											
Station ID:	06SC104 – pour point of Mission Creek HUC-11 Watershed (07030004-110)											
Parameter	Chloride	D.O.	Fecal Coliform	NH3 + NH4	NO2 + NO3	pH	TP	TSS	Spec. cond.	Sulfate	Temp.	T-tube
Units	mg/l	mg/l	#/100 ml	mg/l	mg/l		mg/l	mg/l	uS/cm	mg/l	Deg C	cm
# Samples		46	20		22	45	43	39			46	4
Minimum		**.05**	10		0.005	6.05	0.04	0			0.5	65
Maximum		13.8	**7300**		.66	**9.75**	0.5	22.0			26.6	100
Mean[1]		7.4	104		0.07	7.12	0.1	4.4			13.8	81
Median		7.3	60		0.005	7.11	0.08	3.0			13.8	79
WQ standard	230	5.0	200/ 2000			6.5 - 9.0		100			30	20
# WQ exceedances[2]		12/46	1/20			3/45		0/39			0/46	0/4
NCHF 75th percentile[3]				0.20	0.12	8.4	0.17	18	310		24	

[1]Geometric mean of all samples is provided for E. coli or fecal coliform.
[2]Represents exceedances of individual maximum standard for *E. coli* (1260/100ml) or fecal coliform (2000/100ml).
[3]Based on 1970-1992 summer data; see *Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota's Seven Ecoregions* (McCollor and Heiskary 1993).

Water quality conditions within the Mission Creek Watershed Unit are not meeting the designated use of aquatic life for a number of parameters (F-IBI, M-IBI, and D.O.). Phase II intensive monitoring should be conducted in order to identify the source(s) and cause(s) of the impairments.

11-Digit HUC Watershed	Watershed Unit Name	Stream Name	Field Number[1]	Sample Type[2]	Location	County	Latitude[3]	Longitude[3]
07030004010	Upper Snake River							
		Snake River	96SC069	BIO	CR 2, 2.5 mi. E. of Pliny	Aitkin	46.33351178	-93.21024405
		Trib. to Snake River	06SC134	BIO	Upstream of CR 2, 1 mile W. of Pliny	Aitkin	46.33421939	-93.29524226
		Bear Creek	06SC133	BIO	Upstream of CR 9 bridge in McGrath	Aitkin	46.24203748	-93.27374259
		Snake River	06SC135	BIO	Downstream of Hwy 65, just N. of Pliny	Aitkin	46.33821189	-93.26348876
		Snake River	06SC132	WQ	@ Hwy 18, 2 miles SE of McGrath	Aitkin	46.21717723	-93.24076083
07030004020	Lower Upper Snake River							
		Bergman Brook	99NF042	BIO	~0.15 miles W of Hwy 65, 3 mi. N of Woodland	Kanabec	46.15631843	-93.27859721
		Hay Creek	96SC076	BIO	Upstream of S.H. 27, 2 miles W. of Woodland	Kanabec	46.11534647	-93.31944493
		Cowan's Brook	06SC131	BIO	Downstream of CR 61, 5 miles NE of Woodland	Aitkin	46.16682831	-93.22207628
		Chelsey Brook	06SC022	BIO	Upstream of CR 85, 5 miles SW of Giese	Kanabec	46.15444195	-93.15853863
		Snake River	06SC006	BIO	Snake River County Park, 3 miles NE of Woodland	Aitkin	46.16396925	-93.2469512
		Snake River	06SC123	WQ	Upstream of CR 61, 3 miles NE of Woodland	Kanabec	46.12530824	-93.22106157
07030004030	Middle Snake River							
		Spring Brook	06SC114	BIO	Downstream of CR 11 @ Jct. with CR 1, 1 mile SE of Mora	Kanabec	45.86737617	-93.26737223
		Trib. to Snake River	06SC113	BIO	Downstream of CR 17, 4 miles SE of Mora	Kanabec	45.81666211	-93.25363909
		Snowshoe Brook	06SC117	BIO	Accessed right off CR 3, 3 miles SE of warman	Kanabec	46.02539136	-93.25395202
		Rice Creek	06SC111	BIO	Hwy 70, 3 miles W. of Grasston	Kanabec	45.78587023	-93.20706932
		Snake River	06SC118	BIO	South of CR 24, 3 miles E of Warman	Kanabec	46.07085995	-93.20999132
		Snake River	06SC116	BIO	Upstream of CR 19, 6 miles NE of Mora	Kanabec	45.96289896	-93.24498754
		Snake River	06SC115	BIO	Upstream of Hwy 65 in Mora	Kanabec	45.86410366	-93.30030805
		Snake River	06SC112	WQ	Along 150th Ave., 4 miles SE of Mora	Kanabec	45.79950946	-93.23993674
07030004040	Knife River							
		Trib. to Knife River	06SC124	BIO	Downstream of CR 76, 5 miles NW of Mora	Kanabec	45.9494527	-93.33830279
		Bean Brook	06SC126	BIO	Upstream of CR 3, 4 miles SW of Warman	Kanabec	46.01003957	-93.32720948
		Knife River (Dry Run)	06SC129	BIO	Downstream of CR 115, 4 miles S. of Isle	Mille Lacs	46.08192804	-93.46296674
		Trib. to Knife River	06SC127	BIO	Upstream of CR 15, 5 miles W of Warman	Kanabec	46.05807021	-93.38481885
		Knife River	06SC128	BIO	Upstream of Hwy 47, 7 miles W. of Warman	Mille Lacs	46.04765136	-93.43646229
		Knife River	06SC125	BIO	Downstream of CR 88, 6 miles N. of Mora	Kanabec	45.98005116	-93.33776856
		Knife River	96SC097	WQ	@ C.R. 77, 3 mi. N. of Mora	Kanabec	45.92042601	-93.30815473
07030004050	Ann River							
		Camp Creek	06SC137	BIO	Downstream of Hwy 26, 2 miles NW of Ann Lake	Kanabec	45.92027102	-93.46227281
		Little Ann River	96SC004	BIO	@ Hwy. 47, 4 mi. N. of Ann Lake	Kanabec	45.9687383	-93.42882213
		Little Ann River	06SC138	BIO	Upstream of CR 26, 3 miles N of Ann Lake	Kanabec	45.93514053	-93.41889173
		Ann River	06SC136	BIO	Upstream of CR 12, 3 miles W. of Mora	Kanabec	45.87688956	-93.36360914
		Ann River	06SC122	WQ	Downstream of Hwy 23, 2 miles SW of Mora	Kanabec	45.85221191	-93.33348075
07030004060	Groundhouse River							
		Trib. to Groundhouse River	06SC120	BIO	Upstream of CR 56, 2 miles SW of Ann Lake	Kanabec	45.88594877	-93.47731033
		West Fork Groundhouse River	06SC029	BIO	1/2 mile N. of CR 116, 9 miles NE of Milaca	Mille Lacs	45.89459805	-93.57687359
		Groundhouse River	06SC121	BIO	Downstream of CR 24, 5 miles W. of Ann Lake	Kanabec	45.91140163	-93.52954107
		Groundhouse River	96SC070	BIO	@ Rum River State Forest	Kanabec	45.88154621	-93.50687055
		Groundhouse River	03SC002	BIO	downstream of 150th Ave., 2 mi. S.E. of Ogilvie	Kanabec	45.80275568	-93.39621925
		Groundhouse River	06SC061	WQ	Upstream of Hwy 65, 1 mile W. of Brunswick	Kanabec	45.79076485	-93.31921389
07030004070	South Fork Groundhouse River							
		South Fork Groundhouse River	06SC045	BIO	Upstream of CR 13, 3 miles W. of Ogilvie	Kanabec	45.82364442	-93.48639625
		South Fork Groundhouse River	06SC065	BIO	Upstream of CR 4, 5 miles S. of Ogilvie	Kanabec	45.76333236	-93.44286949
		South Fork Groundhouse River	03SC003	WQ	upstream of Hwy. 47, 4 mi. S. of Ogilvie	Kanabec	45.77863473	-93.41125281
07030004080	Mud Creek							
		County Ditch #4	06SC108	BIO	Downstream of CR 17, 2 miles NW of Grasston	Kanabec	45.80720867	-93.19286361
		Trib. to Mud Creek	06SC018	BIO	Downstream of CR 73, 1 mile N. of Quamba	Kanabec	45.941911	-93.16702456
		Mud Creek	06SC110	BIO	Downstream of CR 5, 4 miles W. of Brook Park	Kanabec	45.95227843	-93.16465768
		Mud Creek	06SC109	BIO	Upstream of CR 120, 1 mile NW of Henriette	Kanabec	45.885801	-93.14466114
		Mud Creek	06SC107	WQ	Upstream of CR 5, 1 mile NW of Grasston	Kanabec	45.81355093	-93.16625992

11-Digit HUC Watershed	Watershed Unit Name	Stream Name	Field Number[1]	Sample Type[2]	Location	County	Latitude[3]	Longitude[3]
07030004090	Lower Snake River							
		Trib. to Cross Lake	06SC101	BIO	Upstream of CR 125, 2 miles SE of Beroun	Pine	45.89059138	-92.92916862
		Bear Creek	96SC068	BIO	CR 10, 4 mi. N.E. of Pine City	Pine	45.85945541	-92.86947265
		Hay Creek	98SC016	BIO	Just downstream of CSAH 5, 9 mi. NW of Rock Creek	Pine	45.77863208	-93.13240963
		Snake River	06SC010	BIO	Downstream of Hwy 107, just E. of Grasston	Pine	45.78387423	-93.11657658
		Snake River	06SC007	FC	Downstream of CR 9, 9 miles E. of Pine City	Pine	45.82285821	-92.78311475
07030004100	Pokegama Creek							
		Trib. to Pokegama Creek	06SC100	BIO	CR 13, 3 miles E. of Henriette	Pine	45.87712199	-93.06333152
		Pokegama Creek	06SC102	BIO	CR 130, 2 miles SE of Brook Park	Pine	45.93101038	-93.01930984
		East Pokegama Creek	06SC103	BIO	Downstream of CR 131, 4 miles SE of Brook Park	Pine	45.93550769	-93.00344095
		Pokegama Creek	06SC042	WQ	Downstream of CR 14, 6 miles NW of Pine City	Pine	45.90124269	-93.03293882
07030004110	Mission Creek							
		Mission Creek	06SC106	BIO	CR 16, 2 miles SE of Mission Creek	Pine	45.96213186	-92.91632063
		Mission Creek	06SC105	BIO	CR 14, 1 mile W. of Beroun	Pine	45.90316224	-92.97708884
		Mission Creek	06SC104	WQ	Upstream of CR 53, 2 miles W. of Pine City	Pine	45.83294022	-93.0214004

[1] Field number assigned to each station to designate a unique sampling location.

[2] Indicates level of sampling effort at each station. BIO=one time biological, physical habitat, and water chemistry; WQ=site represents pour point of HUC-11 watershed, 10x sampling of water chemistry (in addition to BIO); FC=site represents pour point of Snake River Watershed, fish contaminants sampling (in addition to BIO & WQ).

[3] Latitude and Longitude are formatted in WGS84 decimal degrees.

11-Digit HUC Name	AUID[1]	Stream Name	Field Number	Drainage Area (mi²)	Sample Date	Channel Condition[2]	MSHA[3]	Fish IBI[4]	Assessment[5]	TMDL Status[6]
Upper Snake River										
	07030004-552	Bear Creek	06SC133	30.0	07/17/06	NA	70.8	33	NS	AL[F-IBI(08), pH(08)]
	07030004-557	Trib. to Snake River	06SC134	19.8	07/17/06	OC	47.0	19	N/A	
	07030004-508	Snake River	96SC069	16.5	07/11/06	NA	70.1	86	FS	AL[F-IBI(02)], AC[Hg(98)]
	07030004-508	Snake River	06SC135	34.5	07/11/06	OC	44.5	37	N/A	AL[F-IBI(02)], AC[Hg(98)]
	07030004-508	Snake River	06SC132	133.6	07/12/06	NA	76.6	69	FS	AL[F-IBI(02)], AC[Hg(98)]
Lower Upper Snake River										
	07030004-508	Snake River	06SC006	142.2	06/21/06	NA	81.6	74	FS	AL[F-IBI(02)], AC[Hg(98)]
	07030004-507	Chelsey Brook	06SC022	28.4	07/24/06	NA	61.5	66	FS*	
	07030004-509	Hay Creek	96SC076	13.0	07/06/06	OC	59.5	88	N/A	
	07030004-517	Cowan's Brook	06SC131	14.5	07/18/06	NA	59.8	68	FS	
	07030004-523	Snake River	06SC123	200.2	07/12/06	NA	79.2	75	FS	AC[Hg(98)]
	07030004-541	Bergman Brook	99NF042	11.5	07/17/06	NA	55.0	77	FS	
Middle Snake River										
	07030004-506	Snake River	06SC118	249.3	07/06/06	NA	85.0	86	FS	AC[Hg(98)]
	07030004-506	Snake River	06SC116	298.6	08/02/06	NA	71.0	71	N/A	AC[Hg(98)]
	07030004-515	Spring Brook	06SC114	5.7	07/18/06	NA	57.3	34	NS	AL[F-IBI(02)]
	07030004-524	Snake River	06SC112	665.1	06/20/06	NA	56.5	91	N/A	AC[Hg(98)]
	07030004-524	Snake River	06SC112	665.1	08/09/06	NA	60.5	94	N/A	AC[Hg(98)]
	07030004-525	Snake River	06SC115	434.5	06/21/06	NA	69.9	91	N/A	AR[FC(08)], AC[Hg(98)]
	07030004-558	Snowshoe Brook	06SC117	22.4	07/11/06	NA	61.8	73	FS	
	07030004-569	Trib. to Snake River	06SC113	7.6	06/20/06	NA	66.0	54	FS	
	07030004-575	Rice Creek	06SC111	23.8	07/19/06	OC	54.7	49	N/A	
Knife River										
	07030004-537	Knife River (Dry Run)	06SC129	10.3	07/07/06	NA	48.5	16	N/A	AL[M-IBI(06)]
	07030004-549	Knife River	06SC128	29.6	07/18/06	NA	80.6	82	FS	AL[F-IBI(02),M-IBI(04)]
	07030004-549	Knife River	06SC125	80.7	07/19/06	NA	79.8	67	FS*	AL[F-IBI(02),M-IBI(04)]
	07030004-551	Knife River	96SC097	107.6	07/11/06	NA	76.0	74	FS	
	07030004-559	Trib. to Knife River	06SC127	15.8	07/07/06	NA	83.0	91	FS	
	07030004-560	Bean Brook	06SC126	8.0	07/06/06	NA	83.2	77	FS	
	07030004-562	Trib. to Knife River	06SC124	6.3	07/11/06	NA	63.5	68	FS	
Ann River										
	07030004-511	Ann River	06SC136	64.3	07/17/06	NA	77.4	67	FS*	AL[F-IBI(02)]
	07030004-511	Ann River	06SC122	71.8	06/20/06	NA	57.5	71	FS	AL[F-IBI(02)]
	07030004-518	Little Ann River	96SC004	20.0	06/19/06	NA	78.7	84	FS	
	07030004-518	Little Ann River	06SC138	27.8	07/17/06	NA	73.4	97	FS	
	07030004-571	Camp Creek	06SC137	4.5	07/18/06	NA	69.3	76	FS	
	07030004-571	Camp Creek	06SC137	4.5	08/09/06	NA	76.9	94	FS	
Groundhouse River										
	07030004-512	Groundhouse River	06SC061	126.7	07/18/06	NA	75.4	70	FS	AR[FC(08)]
	07030004-513	Groundhouse River	06SC121	19.2	07/07/06	NA	65.8	86	FS	AL[F-IBI(02),M-IBI(04)], AR[FC(02)]
	07030004-513	Groundhouse River	96SC070	42.4	07/06/06	NA	73.7	83	FS	AL[F-IBI(02),M-IBI(04)], AR[FC(02)]
	07030004-513	Groundhouse River	03SC002	69.1	07/11/06	NA	87.4	66	FS*	AL[F-IBI(02),M-IBI(04)], AR[FC(02)]
	07030004-538	W.F. Groundhouse River	06SC029	12.1	07/17/06	NA	54.4	79	FS	
	07030004-570	Trib. to Groundhouse River	06SC120	12.0	06/19/06	NA	64.9	82	FS	

11-Digit HUC Name	AUID[1]	Stream Name	Field Number	Drainage Area (mi²)	Sample Date	Channel Condition[2]	MSHA[3]	Fish IBI[4]	Assessment[5]	TMDL Status[6]
SF Groundhouse River										
	07030004-573	S.F. Groundhouse River	06SC045	5.8	07/17/06	NA	47.7	19	NS	AL[M-IBI(04),F-IBI(08)], AR[FC(08)]
	07030004-573	S.F. Groundhouse River	06SC045	5.8	08/16/06	NA	51.6	13	NS	AL[M-IBI(04),F-IBI(08)], AR[FC(08)]
	07030004-573	S.F. Groundhouse River	06SC065	36.3	07/19/06	OC	49.0	91	N/A	AL[M-IBI(04),F-IBI(08)], AR[FC(08)]
	07030004-573	S.F. Groundhouse River	06SC065	36.3	08/09/06	OC	50.8	89	N/A	AL[M-IBI(04),F-IBI(08)], AR[FC(08)]
	07030004-573	S.F. Groundhouse River	03SC003	47.9	07/07/06	OC	70.6	86	N/A	AL[M-IBI(04),F-IBI(08)], AR[FC(08)]
Mud Creek										
	07030004-563	Trib. to Mud Creek	06SC018	7.2	07/17/06	OC	61.9	53	N/A	
	07030004-566	Mud Creek	06SC110	18.8	07/13/06	NA	49.7	68	FS	AL[F-IBI(02),M-IBI(04)]
	07030004-567	Mud Creek	06SC109	41.3	07/18/06	NA	78.2	82	PS	AL[F-IBI(02)], AR[FC(08)]
	07030004-567	Mud Creek	06SC107	66.5	07/13/06	NA	69.8	56	PS	AL[F-IBI(02)], AR[FC(08)]
	07030004-568	County Ditch #4	06SC108	7.0	06/20/06	OC	59.0	21	N/A	
Lower Snake River										
	07030004-503	Snake River	06SC010	789.6	08/07/06	NA	64.0	73	N/A	AC[Hg(98)]
	07030004-514	Bear Creek	96SC068	6.5	07/10/06	NA	67.0	62	FS	
	07030004-522	Hay Creek	98SC016	11.6	06/19/06	OC	50.0	52	N/A	
	07030004-577	Trib. to Cross Lake	06SC101	3.3	06/22/06	NA	53.0	28	NS	AL[F-IBI(08)]
	07030004-587	Snake River	06SC007	972.0	07/05/06	NA	84.0	89	N/A	AC[Hg(98)]
	07030004-587	Snake River	06SC007	972.0	08/10/06	NA	85.9	74	N/A	AC[Hg(98)]
Pokegama Creek										
	07030004-530	Pokegama Creek	06SC102	19.1	07/10/06	NA	80.1	77	FS	
	07030004-531	East Pokegama Creek	06SC103	22.8	07/10/06	NA	65.7	70	FS	
	07030004-532	Pokegama Creek	06SC042	47.2	06/22/06	NA	57.2	64	FS*	AL[M-IBI(04)]
	07030004-534	Trib. to Pokegama Creek	06SC100	9.2	06/19/06	NA	68.0	51	FS	
	07030004-534	Trib. to Pokegama Creek	06SC100	9.2	08/07/06	NA	58.0	42	FS*	
Mission Creek										
	07030004-547	Mission Creek	06SC106	11.3	07/10/06	NA	52.5	49	PS	AL[F-IBI(02),M-IBI(04)]
	07030004-547	Mission Creek	06SC105	29.4	07/13/06	NA	46.5	43	PS	AL[F-IBI(02),M-IBI(04)]
	07030004-548	Mission Creek	06SC104	38.8	07/10/06	NA	55.0	13	NS	AL[F-IBI(08),DO(08)]
	07030004-548	Mission Creek	06SC104	38.8	08/07/06	NA	41.0	11	NS	AL[F-IBI(08),DO(08)]

[1] Assessment Unit Identifier (AUID) - unique waterbody code comprised of 8-digit HUC plus unique three digit identifier within HUC.

[2] The condition of the stream channel within the sampling reach. NA=natural channel, OC=old channelization.

[3] MPCA Stream Habitat Assessment (MSHA) score for each site. Scores range from 0 (poor habitat) to 100 (excellent habitat).

[4] IBI score based on the fish community assessment of the site. Scores range from 0 (lowest biological integrity) to 100 (highest biological integrity).

[5] Assessment of aquatic life use support for each AUID based only on 2006 fish community data collected as part of this study.
FS=full support, FS*=full support (below IBI threshold score but within confidence interval), PS=partial support, NS=non-support, N/A=not assessed.
Potential reasons for N/A include: coldwater stream, channelized stream condition, wetland habitat, or large river site (>270 mi²drainage area).

[6] The assessment history of impaired reaches (TMDL listed AUID's) based on all available data. Indicates the impaired use, pollutant or stressor, and the year listed.
Impaired designated use codes - AL=aquatic life, AR=aquatic recreation, AC=aquatic consumption
Pollutant or stressor codes - F-IBI=fish index of biological integrity, M-IBI=macroinvertebrate index of biological integrity, FC=fecal coliform, DO=dissolved oxygen, Hg=mercury in fish tissue