2005 Project Abstract
For the Period Ending June 30, 2008

PROJECT TITLE: Accelerating and Enhancing Surface Water Monitoring
PROJECT MANAGER: Daniel Helwig
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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

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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.

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[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.

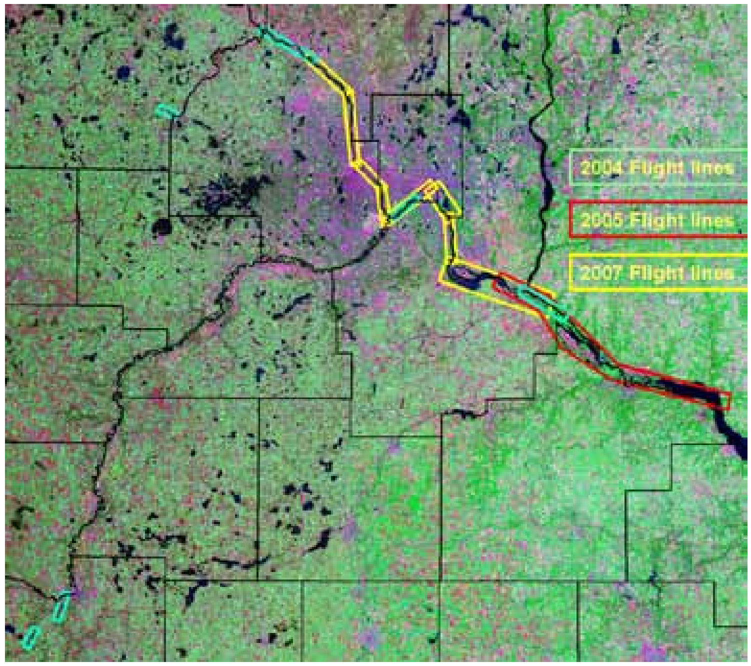


Table 1. Summary of data acquisition attributes, 2004.

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.

River	Site	Discharge mean (cfs)	August 19, 2004 Discharge (cfs) - Contribution	August 15, 2005 Discharge (cfs) - Contribution	August 30, 2007 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%

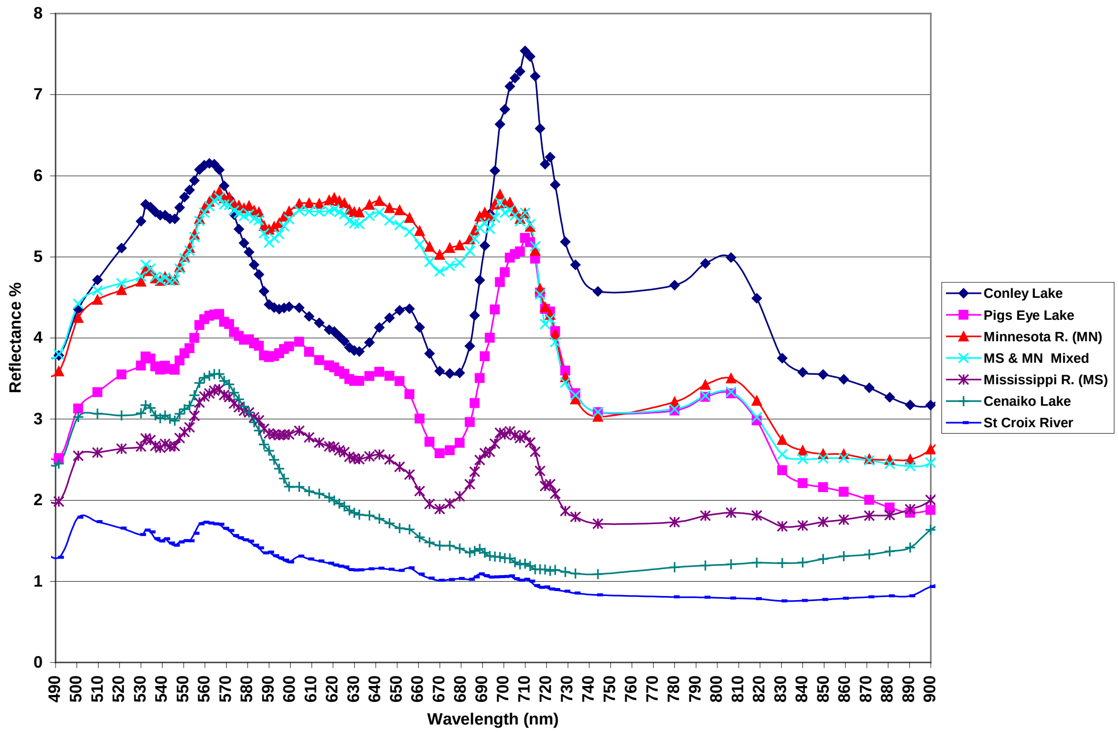
Spectral Characteristics of River Water Reflectance

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.

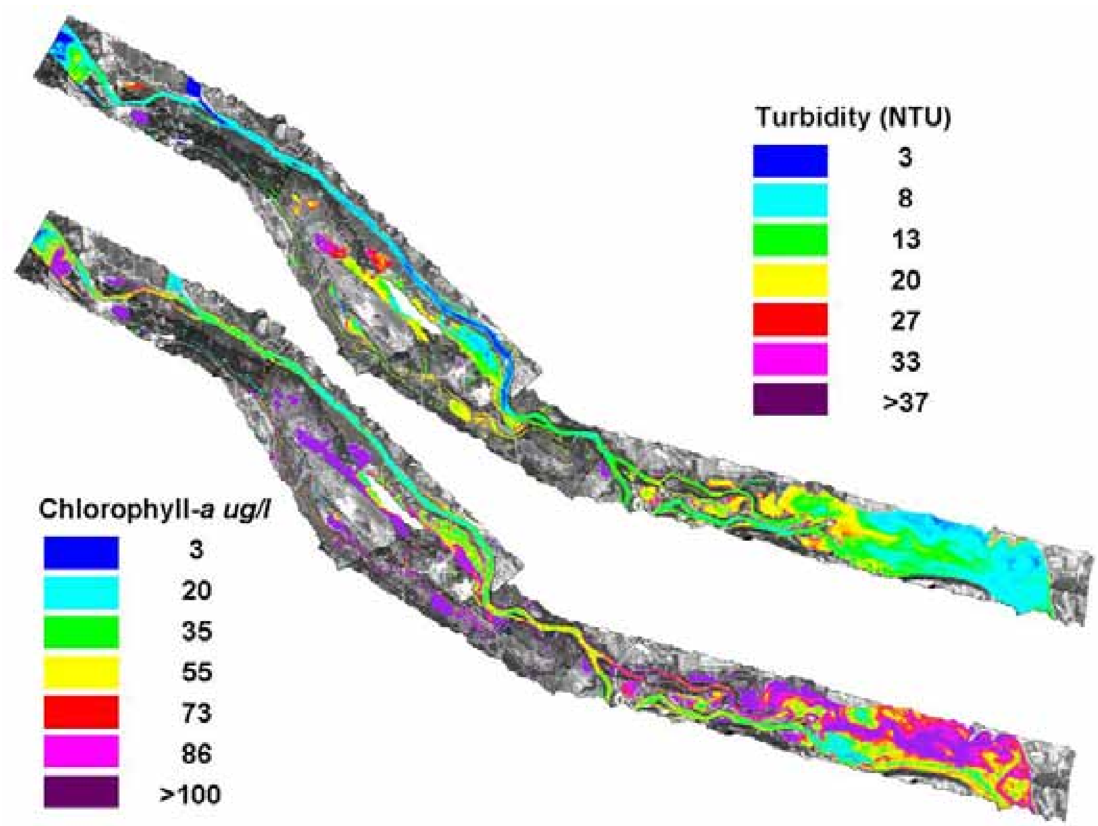


Figure 4 shows the classification of the August 30, 2007 imagery when the majority of the flow (52%) was from the Minnesota River, and Figure 5 is a blow up of the confluence of the Minnesota River with the Mississippi River. These results were obtained during the recovery efforts of the 35W bridge collapse 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.

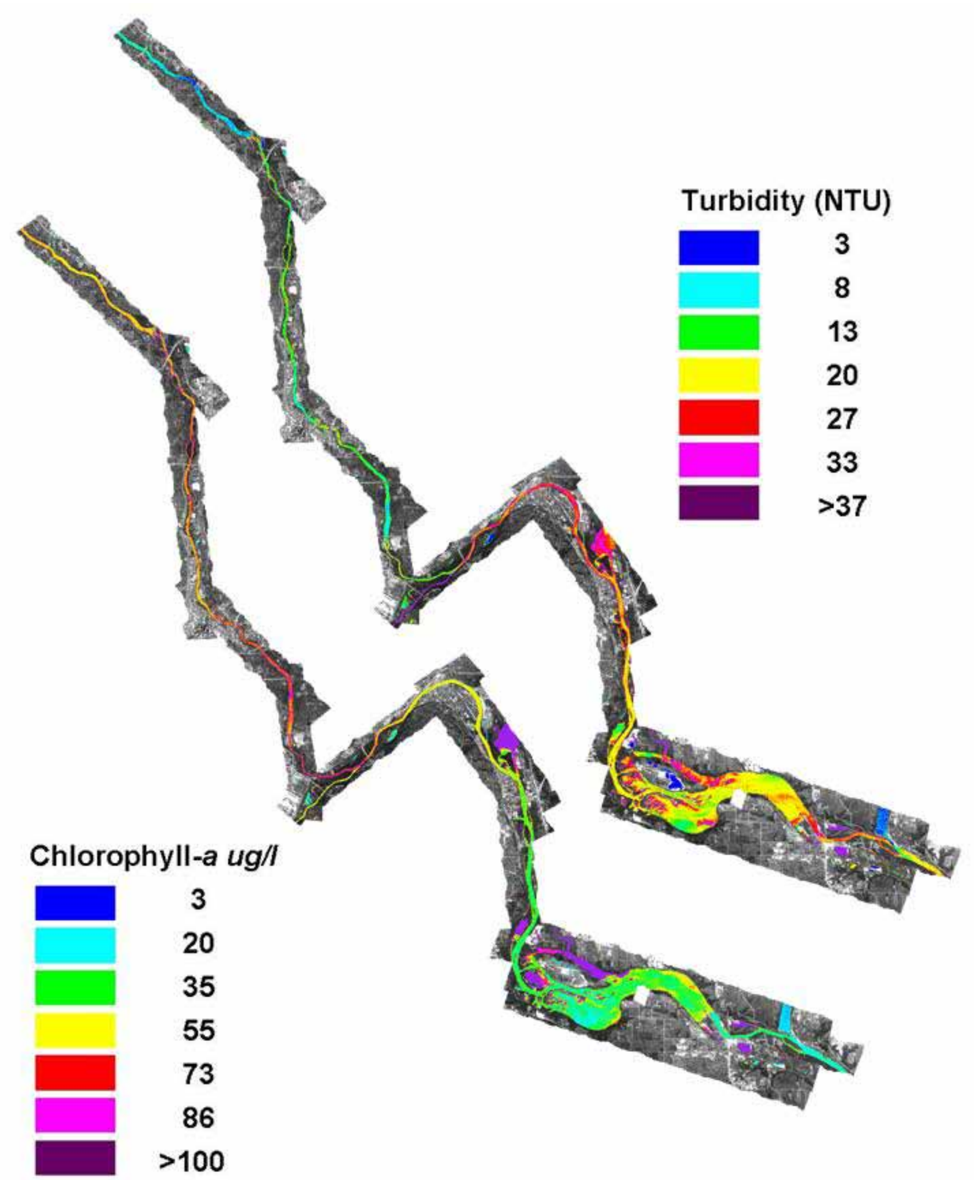
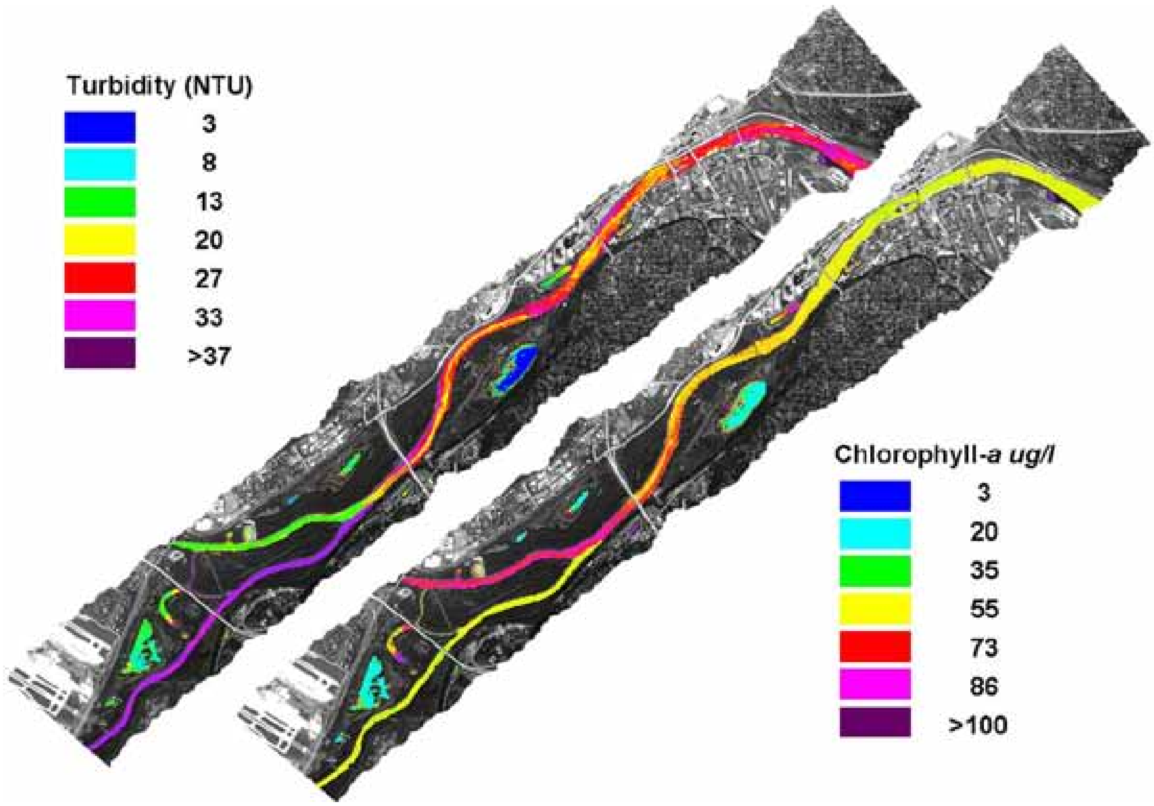


Figure 5. Example water quality maps (turbidity and chlorophyll-a). Confluence of the Minnesota River with the Mississippi River August 30, 2007.



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: ***<u>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.</u>***

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.

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[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:

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[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.