**2007 Project Abstract**
For the Period Ending June 30, 2009

**PROJECT TITLE:** Improved River Quality Monitoring Using Airborne Remote Sensing
**PROJECT MANAGER:** Fei YUAN
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**FUNDING SOURCE:** Environment and Natural Resources Trust Fund
**LEGAL CITATION:** ML 2007, [Chap.30], Sec.[2], Subd.5(e).

**APPROPRIATION AMOUNT: $**159,000

## Overall Project Outcome and Results

To improve the study and monitoring of river water quality and riparian habitat in Minnesota this project proposed and successfully implemented a new and innovative research methodology, *airborne dynamic hyperspectral remote sensing* (remote sensing measures properties of the environment using sensors placed on aircraft or spacecraft). This study has more accurately and cost effectively identified water quality and critical sediment supply areas than possible through traditional or previously used monitoring methods. All methods and results developed here can readily be applied to other watersheds.

For the first time ever in the USA we employed the highly cost effective Civil Air Patrol (CAP) ARCHER (Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance) remote sensing system to monitor water quality in a river. In addition to successfully piloting this new methodology in the highly impacted Blue Earth River (BER) watershed, tangible results and products include:

- Located highly erodible lands in the BER riparian corridor.
- ARCHER can successfully identify Total Suspended Sediment, Turbidity and other water quality measures thus potentially reducing time and costs using traditional methods in any watershed.
- Identified locations of high sediment input areas and spatial and temporal patterns of river water quality.
- Developed a hydrologic model to predict amount and location of sediment and stream flow based upon the size and intensity of precipitation events.
- A Geographic Information System database was developed that contains all project data.
- Two full years of detailed water quality data collected from ARCHER flights, traditional field sampling methods and related laboratory analyses. Water samples were collected along the entire river system at the same time as ARCHER flyovers, during spring runoff and during nearly all rainfall events.
- Processed remote sensing imagery and laboratory data from this study is ready for use in future studies and management decisions.

## Project Results Use and Dissemination

The results and findings were documented in project updates to the LCCMR, through multiple conference presentations by the project scientists and their graduate students, three Minnesota State University (MSU) Geography Department master's theses, several academic articles, and further professional presentations are in preparation, with some of these items already available on the web. Partnerships established to complete the project include local, county, regional, state and federal agencies and scientists at those agencies and at other universities. Communication and outreach has flourished with the creation of a nation-wide ARCHER working group founded by this project's scientists: members include MSU, and professionals from 13 other state and federal agencies, universities, and the private sector. A meeting of the working group will take place April 2010 at the annual meeting of the Association of American Geographers (AAG) in Washington, DC.

To implement and complete the project we established partnerships with MPCA, Faribault & Martin Co. Soil & Water Conservation Districts, U.S. Army Corps of Engineers, and University of Minnesota. In 2008, we were contacted by USGS and Missouri (Mo) DNR who were interested in knowing more about our projects and findings. Thereafter, we formed an ARCHER working group to "provide a forum for agencies/researchers with on-going or anticipated projects using ARCHER imagery to collaborate, exchange information on promising applications and share analytical techniques" (http://rmgsc.cr.usgs.gov/awg/index.shtml). Besides us, other members include CAP, USGS, USFWS, EPA, FEMA, BLM, MoDNR, MoRAP (Missouri Resource Assessment Partnership), Space Computer Corporation, and other university and industry-based individuals. The working group holds monthly conference calls and exchanges lots of e-mail and phone communications. We have organized special sessions on ARCHER applications in the 2010 national conference of the AAG (Association of American Geographers) in Washington, DC.

Especially noteworthy is our partnership with the CAP (Civil Air Patrol). Based on methodologies we developed specifically for this project to pre-process ARCHER data, the CAP has now adopted our methods and has now supplied the needed software to all 16 ARCHER stations across the country. This is of great significance because of the potential for using ARCHER in environmental monitoring nationwide.

# Trust Fund 2007 Work Program Final Report

**Date of Report:** October 7, 2009
**Date of Work program Approval:** June 5, 2007; March 4, 2008; September, 2008
**Project Completion Date:** June 30, 2009

**I. PROJECT TITLE**: Improved River Quality Monitoring Using Airborne Remote Sensing

**Project Manager**: Fei Yuan
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**Location:** Blue Earth County, Blue Earth River (see Figure 1 in attached research addendum)

**Trust Fund 2007 Work Program Final Report**

| | Actually Spent** | Requested** |
|---|---|---|
| Total Trust Fund Project Budget: | 159,000.00 | 159,000.00 |
| Expenditures: | -146,812.22 | -158,872.00 |
| **Balance Remaining:** | **$12,187.78** | **$128.00** |

***Please see section III*

**Legal Citation: ML 2007, [Chap.30], Sec.[2], Subd.5(e).**
**Appropriation Language:**

Title: Improved River Quality Monitoring Using Airborne Remote Sensing
$159,000 is from the trust fund to Minnesota State University, Mankato, to monitor river water quality and riparian habitat through airborne dynamic hyperspectral remote sensing on the Blue Earth River.

**II. FINAL PROJECT SUMMARY**

To improve the study and monitoring of river water quality and riparian habitat in Minnesota this project proposed and successfully implemented a new and innovative research methodology, *airborne dynamic hyperspectral remote sensing* (remote sensing measures properties of the environment using sensors placed on aircraft or spacecraft). This study has more accurately and cost effectively identified water quality and critical sediment supply areas than possible through traditional or previously used monitoring methods. All methods and results developed here can readily be applied to other watersheds.

For the first time ever in the USA we employed the highly cost effective Civil Air Patrol (CAP) ARCHER (Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance) remote sensing system to monitor water quality in a river. In addition to successfully piloting this new methodology in the highly impacted Blue Earth River (BER) watershed, tangible results and products include:

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- Processed remote sensing imagery and laboratory data from this study is ready for use in future studies and management decisions.

## III. PROGRES SUMMARY

### Retroactive Amendment Request Update

The discrepancy in funds spent on the project, approximately $12,000, is due to a payroll request being submitted to the State payroll system after the deadline for previous fiscal years. However, the project scientists were unaware of separate payroll and project expense deadlines and began pursuing release of funds allocated to this project with the Minnesota Office of Management and Budget but have now abandoned those efforts. Thus, our total expenses are $12,187.78 less than total funds budgeted to this project. Complete details are described immediately below.

### Background and details:

In December 2008, due to unforeseen circumstances we discovered that our equipment and supply budgets were not sufficient to successfully complete the project so we applied for an amended budget which was approved. At the very end of the project, in May and June of 2009, we were pleasantly surprised to find that the costs for remote sensing provided by a vendor, in this case the Civil Air Patrol (CAP), were significantly less than originally anticipated and that our travel expenses were significantly less than budgeted. It also appeared that we were under the revised budget for personnel costs.

In our attempt to be good fiscal managers and to not overspend, we waited into July for all accounts to settle before requesting the final $12,059.37 in personnel costs to be paid to the project scientists for work performed in May and June, i.e. FY 09. All student salaries, equipment, supply and vendor costs were accounted for. We submitted paperwork to our university on July 22, which was received by our human resources office on July 24 and the request was entered in the university payroll system on Friday, July 31 which then rolled over to the State payroll system by the next working day, August 3.

Previously unbeknownst to us, the state has a deadline of noon on July 24 to submit payroll requests from the previous fiscal year to the State payroll system. Indeed, our request was late to the State but not to the university and we were acting in good faith to not overspend.

Unfortunately, this discrepancy has resulted in the university system (MnSCU) paying $12,059.37 in salary to the project scientists but MnSCU has not, in turn, been made whole by the State because of the late submission of the payroll request.

As of this writing we are supplying LCCMR both budget summaries for your information, however we are no longer pursing reimbursement. The two summaries:

| | 2007 Trust Funds actually spent | 2007 Trust Funds requested |
|---|---|---|
| Total Trust Fund Project Budget: | 159,000.00 | 159,000.00 |
| Expenditures: | -146,812.22 | -158,872.00 |
| **Balance Remaining:** | **$12,187.78** | **$128.00** |

## IV. OUTLINE OF PROJECT RESULTS*:*

### Result 1: Identify Critical Sediment and Riparian Management Areas.

**Description:**
We will develop a (GIS) integrating hyperspectral data, water quality and riparian characteristics that identify critical environmental management areas. Watershed characteristics to be included in the GIS data layers include soil survey data, digital elevation models (DEM's), vegetation, land use, and geology. Other remote sensing resources such as 30-m Landsat images and 1-m NAIP color aerial photographs can be obtained and used to classify land covers of the remainder of the watershed. A geodatabase will be created using ArcGIS and Arc Hydro software. Critical sediment and riparian management areas will then be identified.

| | | |
|---|---|---|
| **Summary Budget Information for Result 1:** | **Trust Fund Budget:** | **$ 72,936** |
| | **Amount Spent:** | **$ 68,165** |
| | **Balance:** | **$ 3,602** |

**Deliverable**
**1.** A two-year GIS geodatabase that allows the researchers to look for critical areas through the GIS watershed analyses will be deliverable by June 2009.
**2.** Files and maps of critical sediment and riparian management areas will be deliverable by the end of the project.
**Completion Date:** June 30, 2009

In a GIS and with standard statistical techniques we used results from accepted water sampling analyses and field-based mapping to "ground truth" results from remotely sensed data. This allowed us to successfully identify critical sediment supply and riparian management areas at the "patch" level. Patches are groups of pixels in the remotely sensed imagery and in a GIS; in this study each patches average 34 acres.

From various sources we collected existing GIS data layers for the State and the BER watershed including land use, high-resolution digital elevation data, soil survey data, and many others. From these we created a custom geodatabase within a GIS exclusively for the study area, the BER watershed.

From various time periods over the past 30 years, medium resolution (30m) Landsat images and high resolution (1m) NAIP color aerial photographs were obtained and used to classify land cover types along the BER mainstream buffer areas (Figure 1). Our results reveal more than 80% of the total lands in the BER watershed are croplands. Forest and natural grasslands are located mainly along the BER mainstem and two major tributaries.

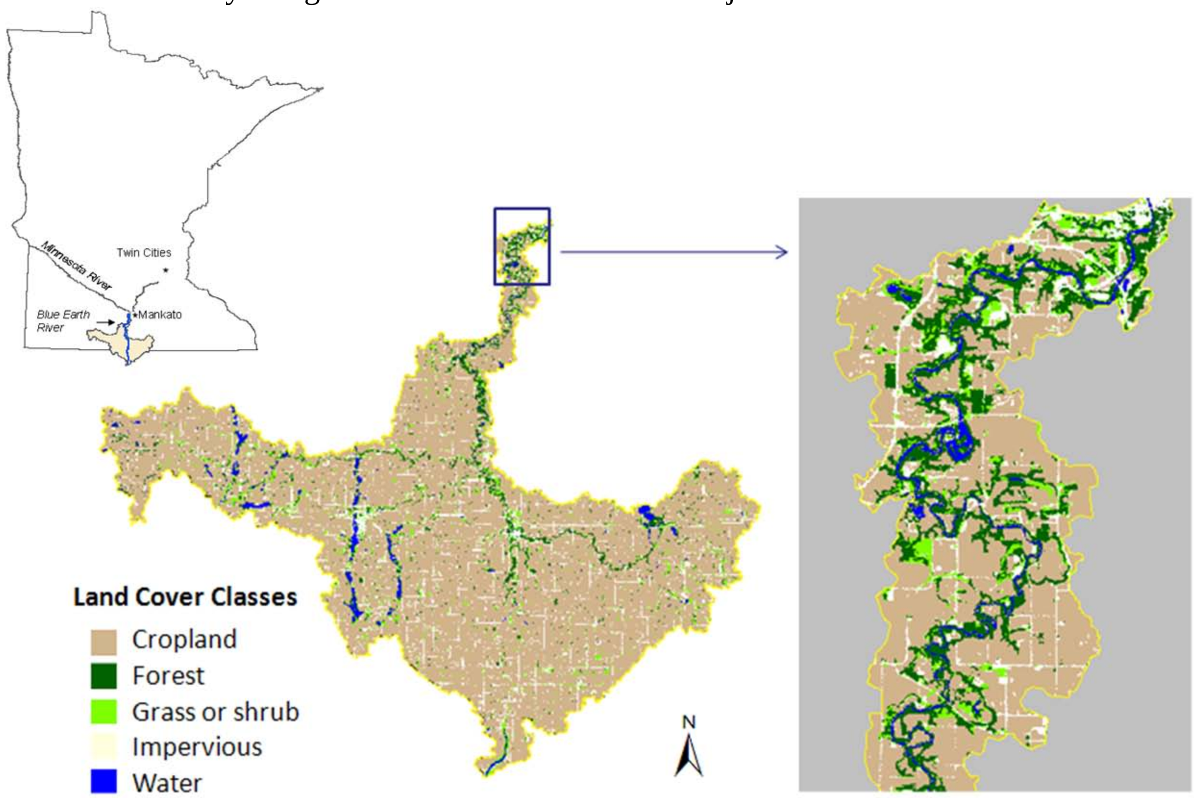
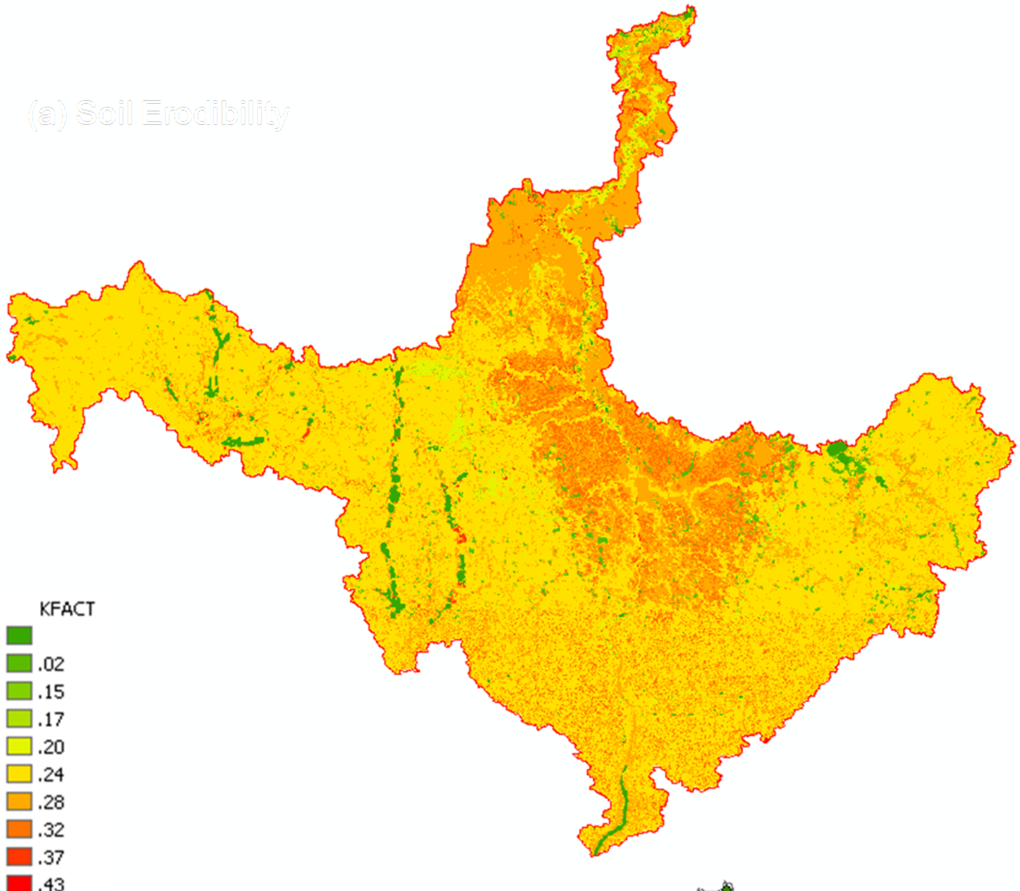



Figure 1. Land cover classification of the Blue Earth River Watershed. Stream flow is from south to north.

This land cover image was used in the next stage: analysis and modeling to identify the sources of pollution in the river  and critical riparian management areas.

Using our classified land use and other collected GIS layers of the riparian corridor, such as elevation, SSURGO (Soil Survey Geographic) data, precipitation, and land use practice data, we estimated annual soil loss for the BER watershed using the process-based RUSLE (Revised Universal Soil Loss Equation) model. Figure 2a shows the areas along the middle- and down-stream portions of the BER mainstem that have the highest erodibility values, or 'K' factor in the RUSLE model. Figure 2b indicates areas with the highest erosion rates which, of course, are of concern for river water quality management.  Areas of critical concern are also indicated on Figure 2b in the darkest color shade, some 29,000 acres located along steep riverbanks and fields immediately adjacent to those riverbanks (See Figure 3) where no soil conservation methods are currently employed. These areas of extremely high erosion are located on the BER mainstem downstream of the confluence with Elm Creek (sampling site FTC12).


(a) Soil Erodibility
KFACT
.02
.15
.17
.20
.24
.28
.32
.37
.43

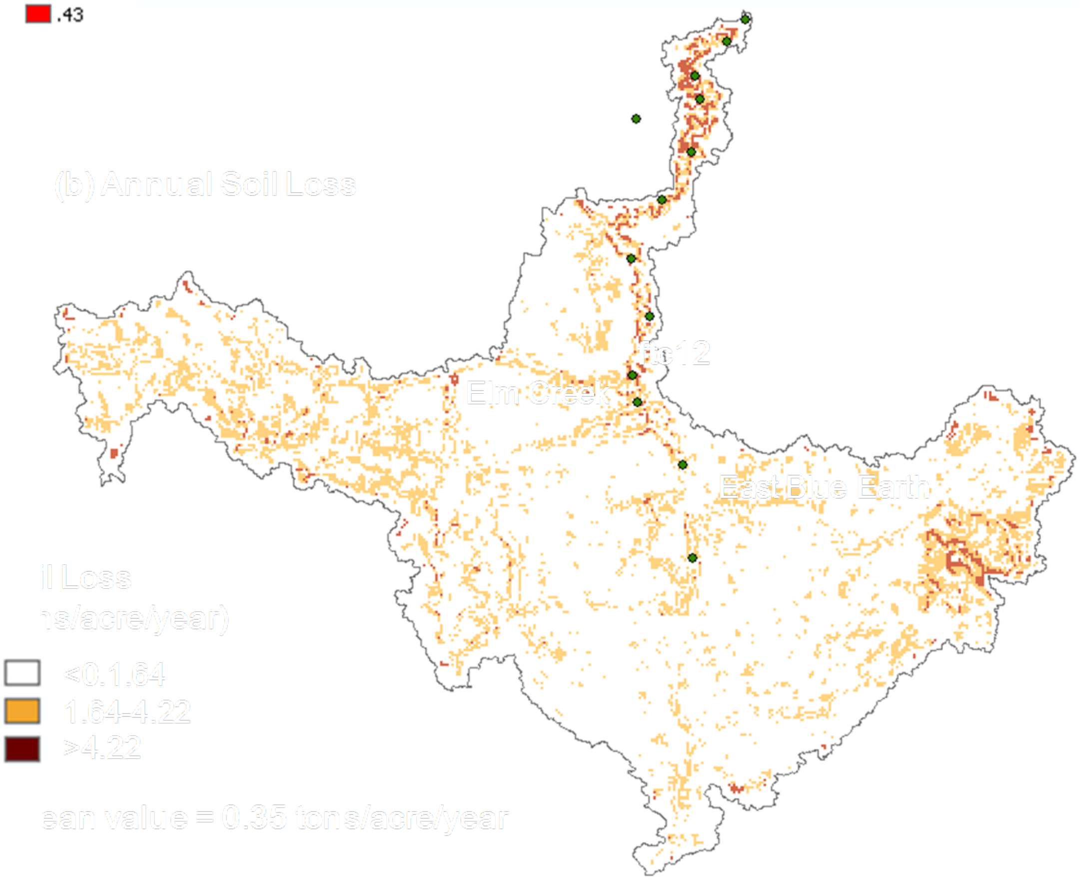

(b) Annual Soil Loss
Elm Creek
East Blue Earth
1.64-4.22
>4.22

Figure 2. (a). Soil erodibility factor in the Blue Earth River Watershed extracted from SSURGO soil data. (2) Calculated average annual soil erosion (tons/ac/yr) based on the RUSLE Model.

Figure 3. An example of crop fields immediately adjacent to the Blue Earth riverbanks

**<u>Result 2: Increased Knowledge of Dynamic Riverine & Riparian Systems</u>**

**Description:**

We will ascertain the seasonal variability of water quality by field sampling at twelve pre-determined river access points at the same time as airborne spectral measurements are flown. Samples will then be analyzed in the laboratory or field as appropriate for: total suspended solids (TSS), total suspended volatile solids (TSVS), turbidity, chlorophyll-a, phaeophytin-a, total phosphorus (TP), total Kjeldahl nitrogen (TKN), nitrates ($NO_3$), pH, and conductivity. Weather and solar radiation observations will help calibrate the hyperspectral imagery. Spectral and field data will be collected monthly from May to November 2007-2009.

| | | |
|---|---|---|
| **Summary Budget Information for Result 2:** | **Trust Fund Budget:** | **$ 71,768** |
| | **Amount Spent:** | **$ 67,681** |
| | **Balance:** | **$ 4,087** |

**Deliverable**

**1.** Remote sensing images will be collected regularly and delivered from the spring melt (March) through the first snows (November) during 2007- 2009.

**2.** Field sampling at twelve pre-determined river access points will be collected regularly and delivered from the spring melt (March) through the first snows (November) during 2007-2009.
**3.** Partial regression models that identify relationships between river quality and spectral data will be available in the spring of 2008; complete and refined models will be deliverable by June 2009.
**4.** A website for project results and data distribution will be deliverable by the end of the project.
**Completion Date:** June 30, 2009

Field water quality sampling was implemented on thirteen sites (five primary sites and eight secondary sites) throughout the monitoring seasons from 2007-2009 (Table 1). Sampling dates corresponded to rising, cresting, falling, and low-flow conditions. Hundreds of discrete measurements of physical, chemical, and biological water quality indicators were completed. Parameters recorded include pH, oxygen reduction potential (ORP), specific conductivity, total suspended solids (TSS), total volatile suspended solids (TSVS), turbidity, ammonia ($NH_3$), nitrite ($NO_2$), nitrate ($NO_3$), total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), sulfate ($SO_4$), chloride, and chlorophyll-a (Chl-a). All data were recorded in our database, which can be accessed and used very conveniently.

Table 1: Sample site names, locations, and elevations used for streamflow measurements and water quality sampling points.

| Site | Latitude (N) | Longitude (W) | USPLS | Subbasin No. | Datum |
|---|---|---|---|---|---|
| FTC4 | 43°34.37’ | 94°06.14’ | T101N, R27W, S5 | 2101 | Bridge BM 1049’ |
| FTC8 | 43°40.42’ | 94°07.13’ | T103N, R27W, S31 | 2201 | Bridge No. 22822 (1972) BM 1053’ |
| FTC10 | 43°44’25.11” | 94°11’12.21” | T103N, R28W, S10 | 2300 | Bridge No. 22554 (1981) BM 1044’ |
| FTC12 | 43°46’10.32” | 94°11’42.24” | T104N R28W, S33 | 2500 | Bridge BM 1030’ |
| FTC14 | 43°49.98’ | 94°10.27’ | T104N, R28W, S3 | 2500 | Bridge No. 7217 (1959) BM 1015’ |
| ST30 | 43°53.68’ | 94°11.88’ | T105N, R28W, S16 | 2500 | Bridge No. 07038 W Pier GL 995’ |
| BEC10 | 43°46’10.32” | 94°11’42.24” | T106N, R28W, S26 | 8901 | Bridge N Pier GL 973’ |
| BEC13BE | 44°00’38.59” | 94°06’41.08” | T106N, R27W, S6 | 9100 | Bridge SW Pier GL 929’ |
| BEC34 | 44°04.08’ | 94°06.09’ | T107N, R27W, S17 | 9100 | Bridge SE BM 901’ |
| BEC13W | 44°02’46.49” | 94°11’41.32” | T107N, R28W, S28 | | Info. maintained by USGS |
| BEC9 | 44°05’50” | 94°06’34” | T107N, R27W, S6 | 9201 | Info. maintained by USGS |
| BEC33 | 44°07.79’ | 94°03.74’ | T108N, R27W, S27 | 9201 | Bridge SE Pier GL 799’ |
| US169 | 44°09’16.1” | 94°01’58” | T108N, R27W, 14 | 9201 | Bridge SW Pier GL 790’ |

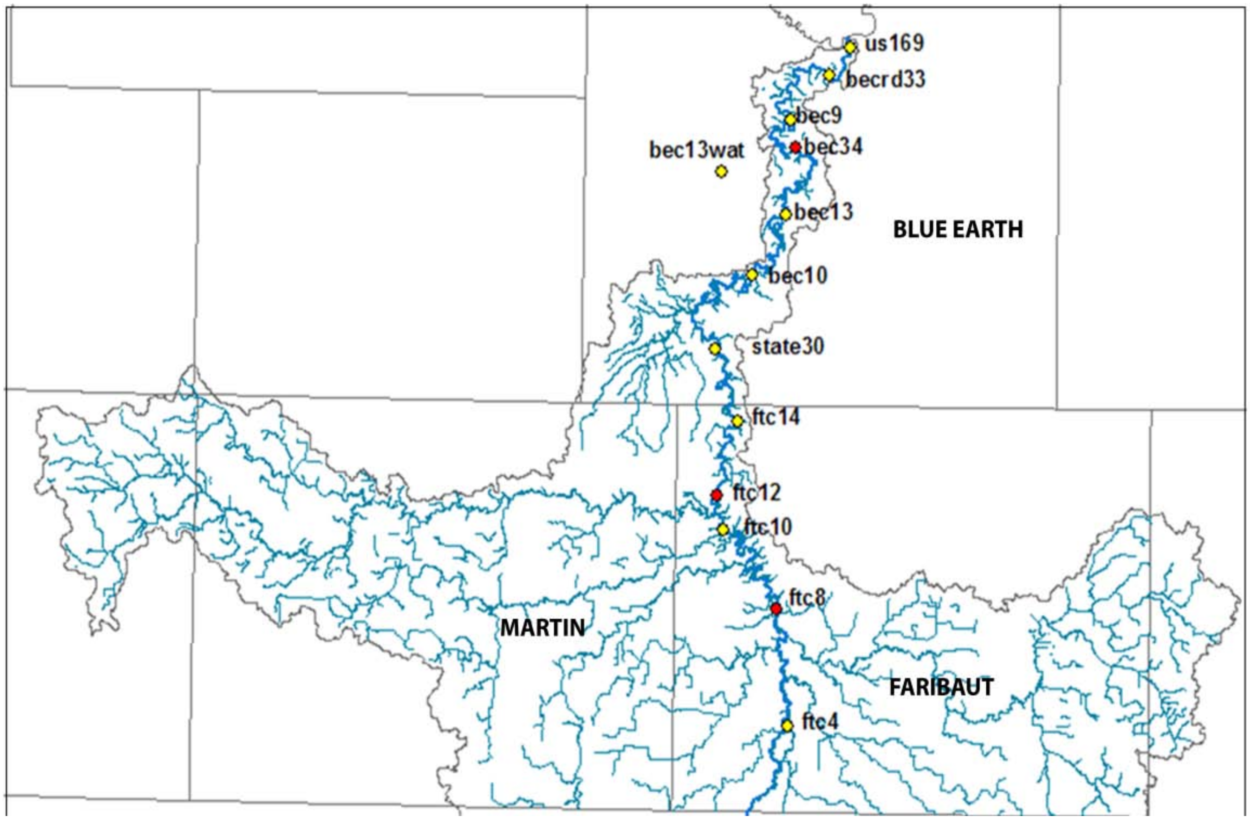


Figure 4. Sampling site map. Note sites FTC8, FTC12, BEC34, each are immediately below the three largest confluences in the watershed above Rapidan Dam. Stage height monitors were emplaced at these sites allowing us to generate new and more accurate rating curves.

Our data were merged with results from monitoring programs administered by the Minnesota Pollution Control Agency and Metropolitan Council on the Watonwan and Blue Earth rivers, respectively, to more fully characterize surface water quality throughout the watershed. An example of the recorded data is given in Table 2.

Table 2. An example of processed and recorded field water sample data.

| Site | Date | pH | Spec Cond. | TSS | TSVS | Turbidity | NH3 - Ammonia | NO2 - | NO3 - Nitrate | NO2+NO3 | TKN | TP Corrected | SRP | SO4 - Sulfate | Cl | ORP | Chl-a | Chl-a HL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BEC34 | 8/17/2007 | 8.05 | 1623 | 5.625 | 4.75 | 6.00 | 0.00 | 0.000 | 0.33 | 0.33 | 0.90 | 0.07 | 0.10 | 111.33 | 26.67 | 527.00 | 1.60 | 1.35 |
| BEC13 | 8/17/2007 | 8.23 | 2194 | 13.25 | 10.25 | 14.80 | 0.01 | 0.000 | 0.83 | 0.83 | 1.10 | 0.12 | 0.05 | 146.00 | 42.40 | 519.00 | 1.70 | 2.04 |
| BEC9 | 8/17/2007 | 8 | 1759 | 73.25 | 14.95 | 50.20 | 0.05 | 0.007 | 0.00 | 0.01 | 0.70 | 0.14 | 0.08 | 139.33 | 42.13 | 543.00 | 1.20 | 1.65 |
| BEC34 | 8/19/2007 | 7.77 | 730 | 199 | 18.00 | 228.00 | 0.13 | 0.000 | 1.33 | 1.33 | 1.00 | 0.17 | 0.27 | 138.00 | 24.00 | 479.00 | 5.00 | 2.15 |
| BEC13 | 8/19/2007 | 7.63 | 1129 | 139.5 | 25.50 | 116.10 | 0.14 | 0.250 | 2.10 | 2.35 | 1.60 | 0.30 | 0.15 | 268.00 | 31.07 | 553.00 | 2.50 | 1.23 |
| BEC9 | 8/19/2007 | 7.52 | 1037 | 163 | 27.00 | 133.50 | 0.28 | 0.011 | 1.07 | 1.08 | 1.00 | 0.25 | 0.03 | 134.67 | 29.87 | 551.00 | 2.50 | 1.14 |
| BEC34 | 8/21/2007 | 7.84 | 771 | 492 | 60.00 | 245.50 | 0.10 | 0.022 | 3.20 | 3.22 | 2.70 | 0.26 | 0.07 | 236.00 | 31.53 | 423.00 | 52.90 | 5.85 |
| BEC13 | 8/21/2007 | 7.7 | 830 | 139 | 25.50 | 94.80 | 0.05 | 0.027 | 5.50 | 5.53 | 1.40 | 0.21 | 0.32 | 252.00 | 25.53 | 526.00 | 2.50 | 1.54 |
| BEC9 | 8/21/2007 | 7.67 | 671 | 495 | 59.50 | 301.60 | 0.13 | 0.030 | 8.53 | 8.56 | 2.60 | 0.26 | 0.32 | 232.00 | 29.20 | 461.00 | 25.60 | 3.75 |
| BEC34 | 8/28/2007 | 8.05 | 682 | 121 | 19.00 | 85.10 | 0.02 | 0.024 | 3.80 | 3.82 | 1.40 | 0.27 | 0.15 | 134.00 | 22.80 | 307.00 | 6.30 | 3.32 |
| BEC13 | 8/28/2007 | 8.2 | 811 | 45.5 | 16.00 | 24.30 | 0.00 | 0.013 | 2.40 | 2.41 | 2.00 | 0.27 | 0.19 | 168.00 | 24.80 | 326.00 | 18.40 | 4.43 |
| BEC9 | 8/28/2007 | 8.11 | 706 | 125.5 | 21.00 | 100.10 | 0.05 | 0.018 | 4.10 | 4.12 | 1.70 | 0.28 | 0.17 | 130.00 | 21.20 | 323.00 | 8.70 | 3.44 |
| BEC34 | 9/11/2007 | 8.3 | 684 | 24.2 | 20.80 | 43.40 | 0.02 | 0.007 | 3.13 | 3.14 | 1.70 | 0.23 | 0.15 | 216.00 | 25.10 | 379.00 | 18.80 | 4.76 |
| BEC13 | 9/11/2007 | 8.37 | 828 | 9.1 | 5.60 | 2.50 | 0.01 | 0.085 | 3.43 | 3.52 | 1.40 | 0.15 | 0.25 | 164.00 | 40.20 | 398.00 | 13.70 | 2.06 |
| BEC9 | 9/11/2007 | 8.28 | 695 | 25.1 | 21.20 | 40.20 | 0.01 | 0.007 | 4.50 | 4.51 | 1.60 | 0.24 | 0.30 | 280.00 | 27.20 | 383.00 | 16.10 | 6.41 |

We established three new permanent stage-monitoring stations (FTC8, FTC12, BEC34, cf. Table 1 and Figure 4) within the channel of the BER mainstream immediately downstream of the confluences of the three main tributaries (Elm Creek, East Blue Earth River, Watonwan River) above the Rapidan Dam. By combining our data with MPCA and other stream flow data sources, rating curves were generated for all three sites. Discharge corresponding to severe drought conditions and record-breaking precipitation events were recorded. As one example of a hydrograph generated at the new stage-monitoring sites, Figure 5 shows the stage data for BEC34 during the two-year span. Correspondingly, the derived rating curve for BEC34 is displayed in Figure 6. Based on the rating curves, discharge hydrographs were calculated for all principal study sties. These hydrographs were also validated. An example of the validation is shown in Figure 7.

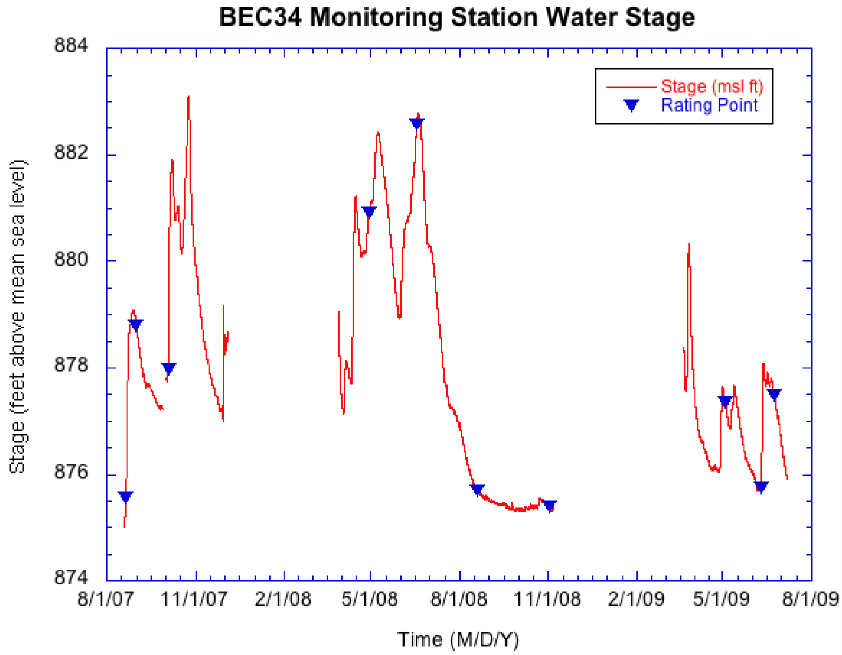



Figure 5. Stage data and rating points for BEC34, 2007-2009. Routine temporal spacing and good coverage of maximum and minimum flows imply that rating curves derived from these measurements should adequately predict discharge from continuous stage monitoring data.

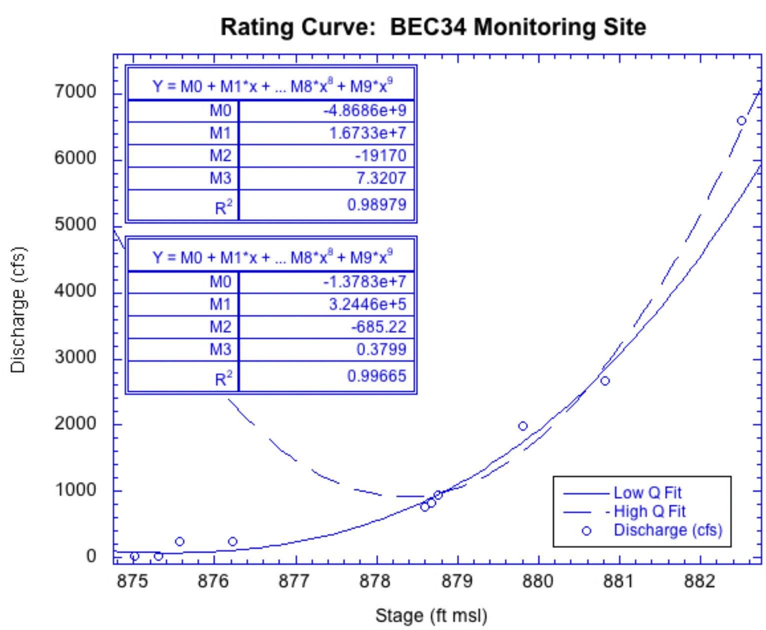



Figure 6. Rating curves for BEC34. A break-point of 880.5 ft marks the transition between two third-order polynomial equations needed to accurately portray discharges under low and high stage regimes.

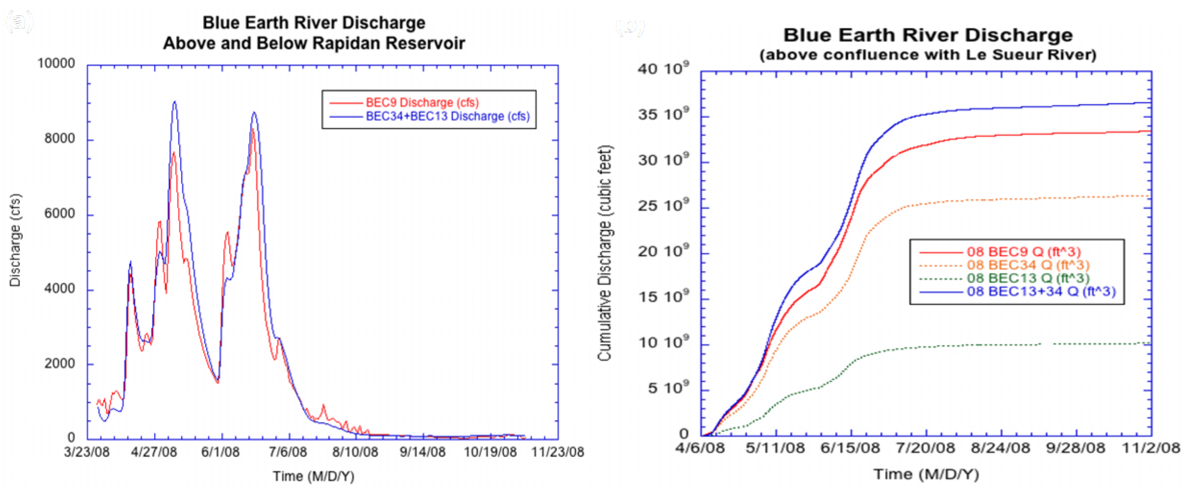



Figure 7. (a) the close temporal and reasonable matching discharge values for the site established and maintained through this grant and that maintained by the USGS at BEC9 (accepted here as the standard of accuracy) for the 2008 monitoring season. (b) the accuracy of discharge values at new monitoring station BEC34. Additive discharge at BEC34 and BEC13W exceed discharge at BEC9 by 8% (~3 billion cubic feet) for the 2008 monitoring season. Given possible groundwater and evapotranspirative losses presented by the channel bed and Rapidan Reservoir, the close agreement among these estimated discharges supports their validity.

Using the discharge hydrographs, we find the transit time for the reach of the BER from Blue Earth city (FTC8) to Mankato (BEC34) (cf. Figure 4 for a map of locations) is approximately 72 hours. Knowledge of this relationship is important to accurately track trends in water quality that develop as a result of first-flush characteristics versus localized contaminant contributions to mainstem discharges.

By analyzing the total cumulative discharge hydrographs, we also find for this period of study, northern Iowa and East Branch Blue Earth River tributaries deliver 41% of the cumulative discharge to the mainstem hydrologically above the monitoring station FTC8; the Elm Creek tributary system contributed an additional 4% of the cumulative discharge to the mainstem as gauged at FTC12. As shown by the wide separation of FTC 12 and BEC 34 cumulative discharge curves in Figure 8, the relatively small area of the watershed below FTC12 contributed approximately 53% of the total seasonal discharge for the period of monitoring.

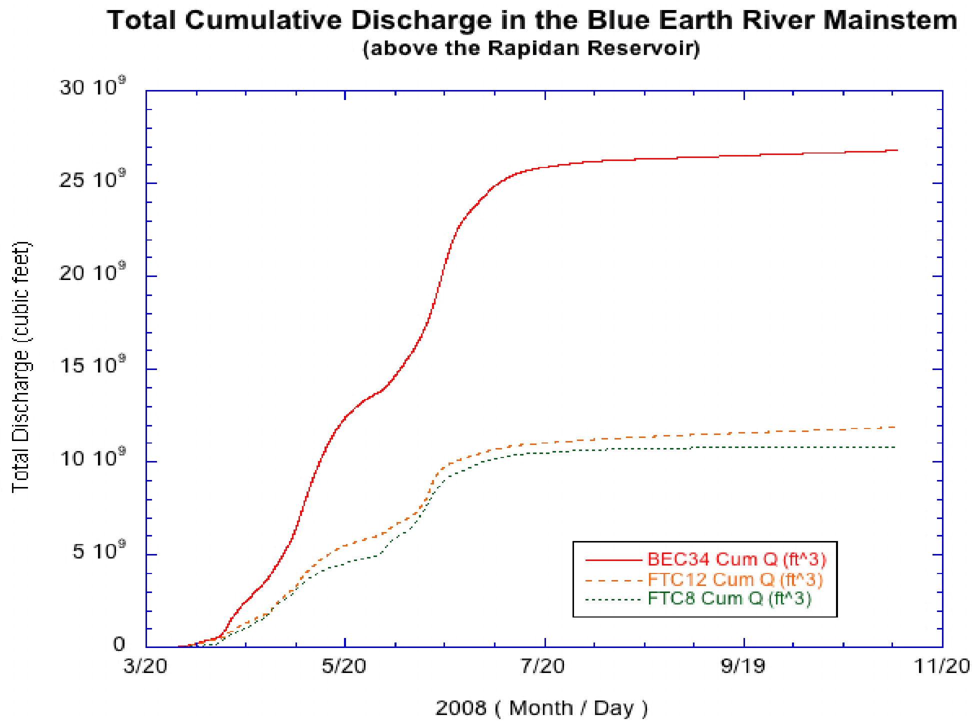



Figure 8. Total discharge variability in the BER mainstem above Rapidan Dam in 2008.

Sediment and nutrient loads in the Blue Earth River by reach were also calculated. Figure 9 is an example of total suspended loads and nitrogen loads for the March to November 2008 monitoring season at principle mainstem monitoring sites.

A most noteworthy finding from our results is - the relatively small basin areas between FTC12 and BEC34 contributes most significantly to the total TSS yield in the BER mainstem.

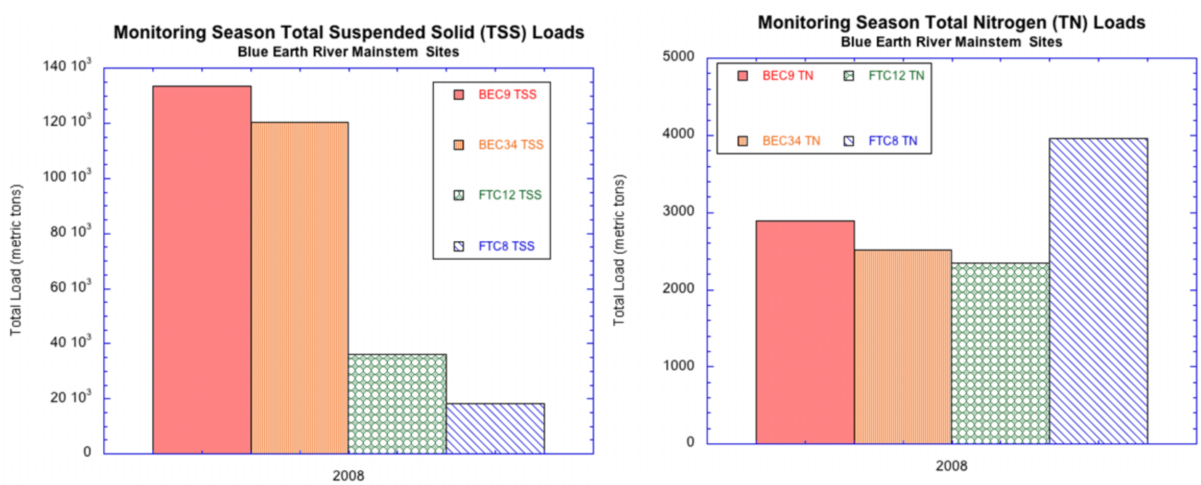



Figure 9. Total suspended solids loads for the 28 March to 6 November 2008 monitoring season at principal mainstem monitoring sites.

To map continuous water quality patterns we collected extensive field-based data and remote sensing data including ARCHER hyperspectral imagery, Landsat imagery, NAIP aerial photography and in-situ remote sensing data collected by hand-held spectrometer.

ARCHER hyperspectral data were obtained in six flight missions on 5/11/2008, 6/7/2008, 6/21/2008, 8/10/2008, 5/17/2009, and 5/30/2009. At the same time as airborne spectral measurements were flown, water quality samples were collected. ARCHER data includes both 1meter resolution hyperspectral (52 bands) imagery and 3 inch resolution panchromatic (black & white) imagery. Each flight mission took approximately 2 hours. Every minute the ARCHER sensor is in operation one hyperspectral data file and one panchromatic data file are generated. Six flights generated approximately 200 Gigabytes of remotely sensed data. To process these data into a useable format, the data volume nearly triples, thus creating 0.6 Terabytes of data to simply begin mapping and analyzing water quality. Figure 10 is one small example of a color composite image from the ARCHER sensor and its associated spectral profile. It is these spectral data that are necessary to correlate with and "ground truth" our field data.

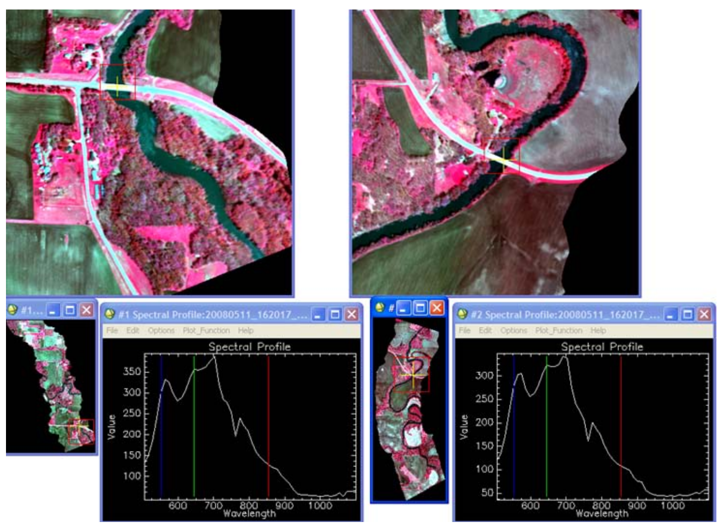



Figure 10. HSI Images at site "STATE30" and Site "FTC12" acquired on May 11, 2008 (Band 22, 13, &1 color composite).

Spectra profiles for all the water samples were extracted from the images and saved into spectral libraries (Cf. Figure 11). Based on the profiles, in all of our data sets, the strongest spectral response region were identified between 690 and 700nm (bands 17 & 18 of the ARCHER HSI data) and an absorption region around 600 and 610nm (bands 9 & 10).

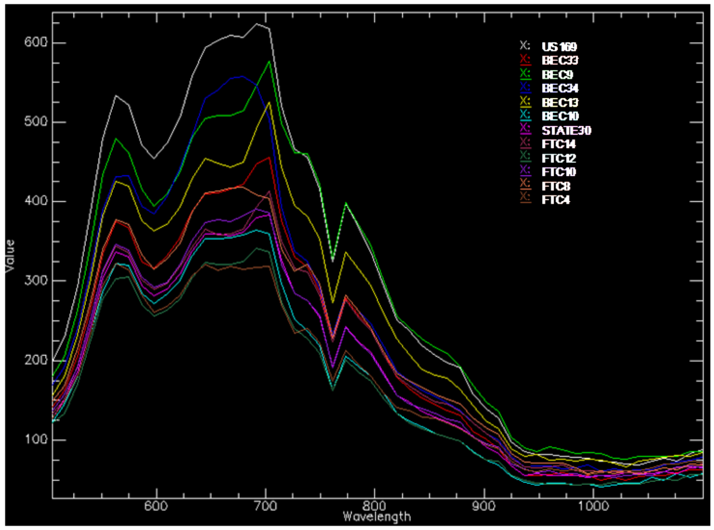



Figure 11. Spectra profiles of water samples (May 11, 2008).

Also most noteworthy, we found the higher the suspended sediment load in the river, the higher the peak spectral response around 690 - 700nm. By correlating those hyperspectral data against water quality parameters, we found the ratio of band 17 and band 9 can determine turbidity of the river effectively. While the exact equations change slightly from date to date, the general trend of the relationship between HSI spectra and Turbidity is similar (Figure 12).

Thus, the highly cost-effective ARCHER hyperspectral system can readily identify areas of increased turbidity in riverine systems thus allowing managers to identify high sediment input and hence polluted areas. This study is the first in the nation to employ ARCHER in this way, and to document its use in water quality monitoring and assessment. We believe the MnDNR could develop a most effective water quality monitoring program using ARCHER.

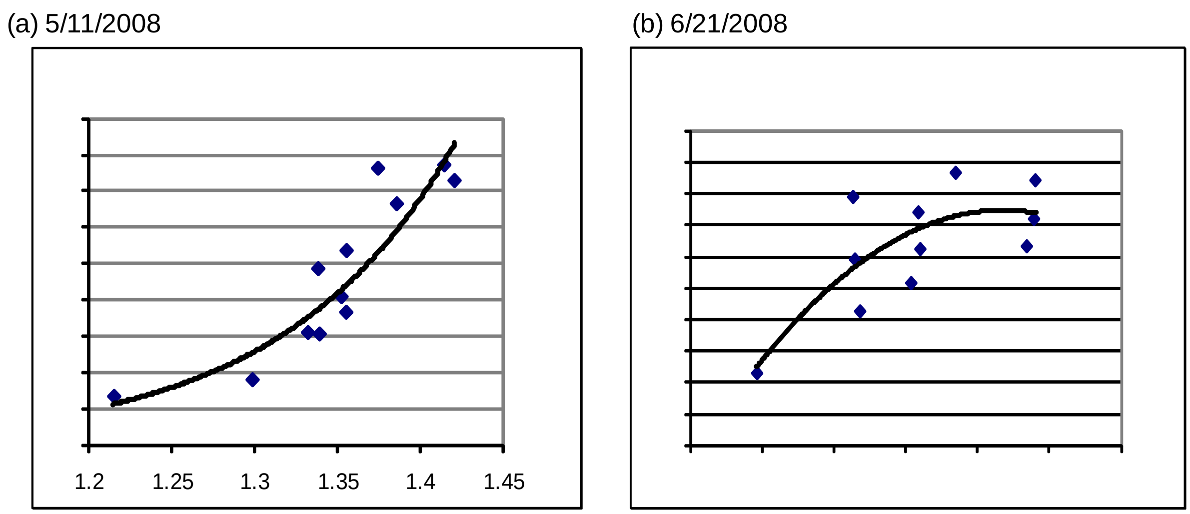



Figure 12. Relationship between HSI spectra (band 17/ban 9) and Turbidity for two different dates.

Based on these correlations and field water samples along the river, continuous water turbidity surfaces were mapped. As shown in Figure 13, different turbidity patterns can be identified. By comparing the turbidity patterns with the surrounding environment along the river, we found river reaches with narrower channel widths, shallow water, and less surrounding forest cover tend to have higher turbidity.

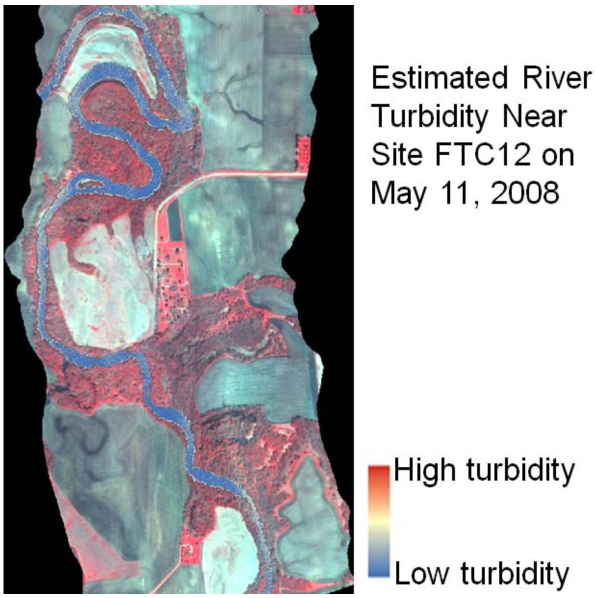



Figure 13. Estimated river turbidity map based on the regression equation overlaid with the false-color composite image of ARCHER HSI data.

Besides airborne hyperspectral data, we constructed a spectral reflectance database for samples of dried total suspended solids acquired from filtered water samples drawn from the BER during significant runoff events using a hand-held spectrometer. Figure 14 provides an example of the spectral reflectance curves of dry samples generated using the hand-held spectrometer. We found a strong absorption spectral region around 670 to 680 nm, indicating different chlorophyll concentrations in the river at different sites. Thus, the higher the amount of chlorophyll in the water, the stronger the absorption around this spectral region.

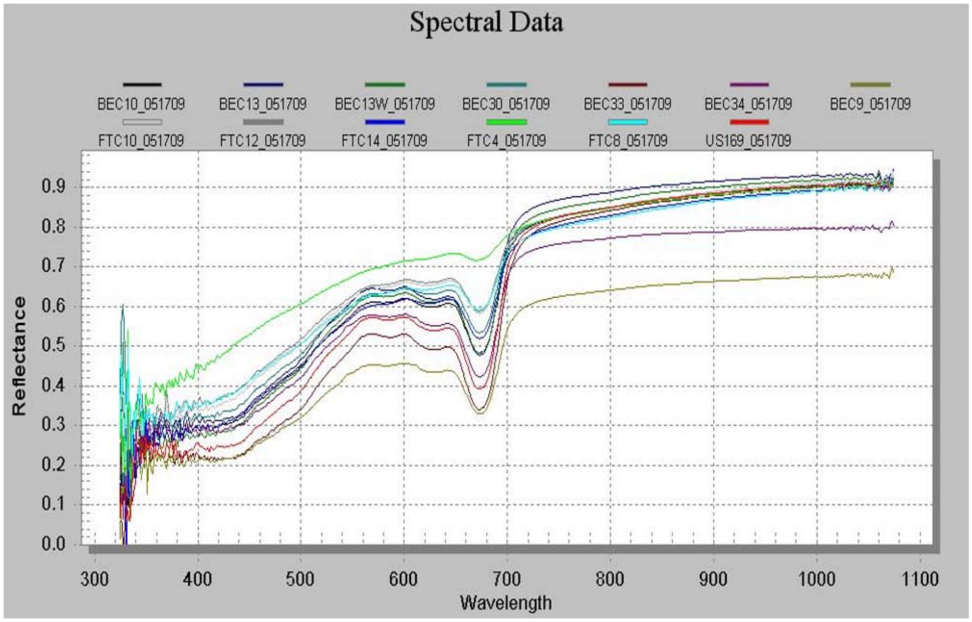



Figure 14. Spectral reflectance curve extracted from dye samples on 5/17/2009

Analyses were also performed to quantify the relationships among the hyperspectral reflectance curves and turbidity found in the water samples. We found spectral responses of the dry samples correlate well, especially in the 690 - 720nm region, with the field measurement values of river turbidity (Figure 15).

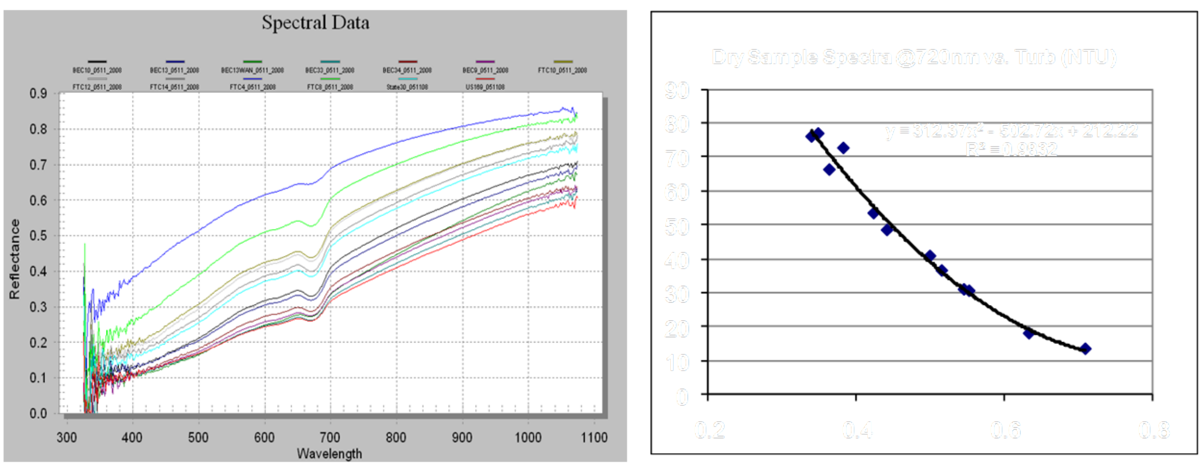



Figure 15. Spectral reflectance curve extracted from dye samples on 5/11/2008 and its correlation with the field-measured river water turbidity.

**Result 3: Correlate Water Quality with Riparian Characteristics**

**Description:**

Based on remote sensing and ground sampling data, spectral, water quality and riparian parameters will be correlated that identifies significant links between water quality and riparian environments. Corresponding land cover and precipitation data will be incorporated with available soil and topographic data to construct a numerical hydrologic model of the watershed using the distributed flow model, Vflo™. Calibrated to the continuous discharge and stage data from the new gaging stations, the model will form the basis for interpreting the origin and flow of discharging water throughout the Blue Earth River and its tributaries.

| | | |
|---|---|---|
| **Summary Budget Information for Result 3:** | **Trust Fund Budget:** | **$ 15,465** |
| | **Amount Spent:** | **$ 10,966** |
| | **Balance:** | **$ 4,499** |

**Deliverable**

**1.** A numerical hydrologic model with preliminary results will be deliverable by the end of the project.

**Completion Date:** June 30, 2009

To identify significant links between water quality and riparian environments, we constructed, tested, and calibrated a numerical hydrologic model of the watershed using the kinetic hydrological model, Vflo™. This results in the ability to predict amount and location of sediment and stream flow based upon the size and intensity of precipitation events.

We also measured cross-sectional widths and depths of the river's mainstem channel, levees, and surrounding floodplain at the three previously mentioned sites (FTC8, FTC12, BEC34, Figure 4). These measurements are necessary components of distributed flow hydrologic models and are key to linking computer-estimated stage and discharge estimates to those measured in the field using stage-recording instruments.

Land use, continuous flow discharge and stage data, along with topography, drainage networks, and infiltration data derived from a digital elevation model and SSURGO soil layers were input into the flow model to predict flow rate and depth. Figures 16 through 18 illustrate the hydrologic model, preliminary modeling and validation results.

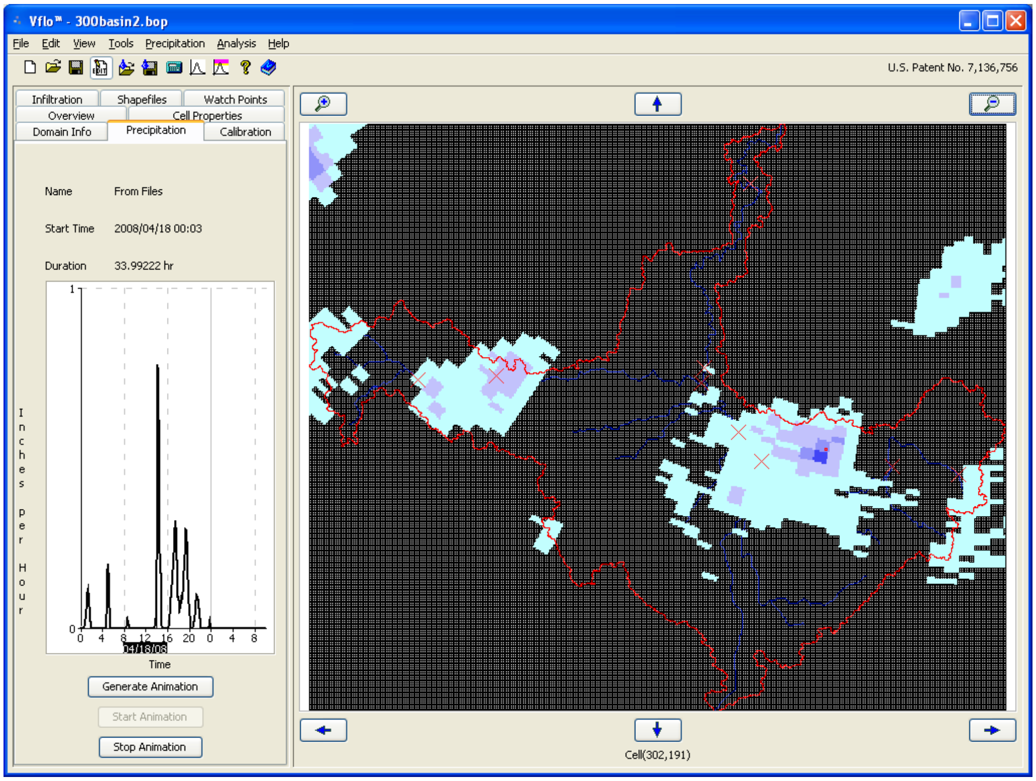



Figure 16. Illustration of the hydrologic model captured during the 28 March 2008 precipitation event. Screen capture images of Vflo model environment shows rainfall intensity for a single cell in the model while the larger window shows the spatial distribution of the rainfall for a single 15-minute period of a 24-hour-long precipitation event.

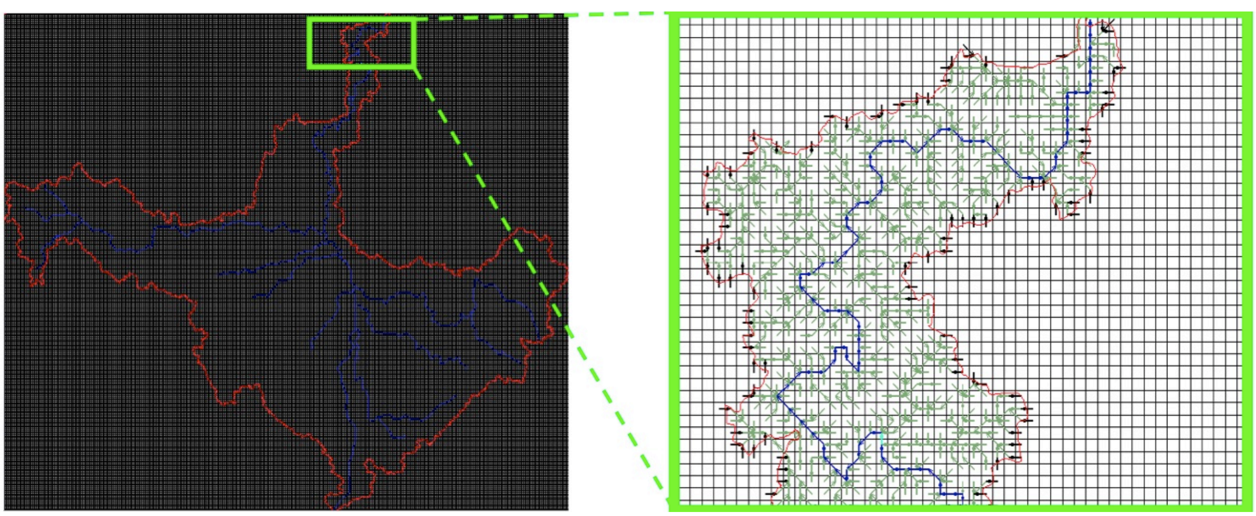


Figure 17. This figure showing hydrologic modeling results consists of a screen capture image of the 44,000 active modeling cells to the left with an expanded inset to the right that shows the detail of channel position (blue) and edited flow directions (green).

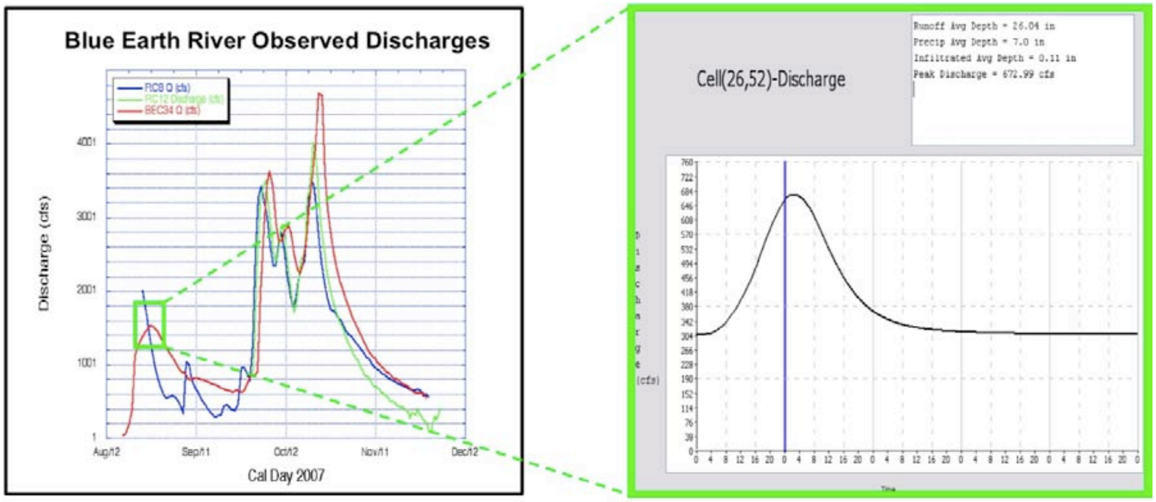



Figure 18. One example of model to hydrograph calibration are shown for discharge at BEC34 for the 19 through 21 August 2007 precipitation event and ensuing runoff. The figure on the left shows the discharge hydrograph developed through traditional methods while the figure on the right shows the hydrograph developed in the model environment.

Our stream flow modeling results indicate the model can simulate real world flow events accurately. With this model, dynamic flow discharges can be modeled accurately for any rainfall event at any location along the BER. This methodology can be readily applied to any watershed in Minnesota, or across the globe.

## V. TOTAL TRUST FUND PROJECT BUDGET:

| | |
|---|---|
| **Staff or Contract Services:**<br>• 12% of FTE per year for each of five faculty members<br>• Six student research assistants (2 Graduate & 4 Undergraduate)<br>• CAP ARCHER System aircraft flights with hyperspectral sensor | $120,729 |
| **Equipment and supplies:**<br>• Supplies, materials, and software for field sampling, laboratory analyses, and image analyses | $36,271 |
| **Travel:**<br>• Mileage, meals and lodging related to field work | $2,000 |
| **TOTAL TRUST FUNDS BUDGETED:** | $159,000 |
| **TOTAL TRUST FUND AMOUNT SPENT:** | **$146,812** |

## VI. OTHER FUNDS & PARTNERS:

**A. Project Partners:** In addition to the project scientists (Drs. Fei Yuan, Bryce Hoppie, Donald Friend, Ginger Schmid and Forrest Wilkerson) associated with the Earth Science Program at Minnesota State University, Mankato, to implement and complete the project we established partnerships with MPCA, Faribault & Martin Co. Soil & Water Conservation Districts, U.S. Army Corps of Engineers, and University of Minnesota. In 2008, we were contacted by USGS and Missouri (Mo) DNR who were interested in knowing more about our projects and findings. Thereafter, we formed an ARCHER working group to "provide a forum for agencies/researchers with on-going or anticipated projects using ARCHER imagery to collaborate, exchange information on promising applications and share analytical techniques" (http://rmgsc.cr.usgs.gov/awg/index.shtml). Besides us, other members include CAP, USGS, USFWS, EPA, FEMA, BLM, MoDNR, MoRAP (Missouri Resource Assessment Partnership), Space Computer Corporation, and other university and industry-based individuals. The working group holds monthly conference calls and exchanges lots of e-mail and phone communications. We have organized special sessions on ARCHER applications in the 2010 national conference of the AAG (Association of American Geographers) in Washington, DC.

Especially noteworthy is our partnership with the CAP (Civil Air Patrol). Based on methodologies we developed specifically for this project to pre-process ARCHER data, the CAP has now adopted our methods and has now supplied the needed software to all 16 ARCHER stations across the country. This is of great significance because of the potential for using ARCHER in environmental monitoring nationwide. We wish to laud and thank LCCMR for authorizing a change in our work plan that allowed the unforeseen but necessary expense to purchase specialized software needed to pre-process ARCHER data (GeoReg™ from Space Computer Corp.).

We would also like to mention that this project provided great opportunities for our students. Three MSU Mankato Geography graduate students developed MS theses from this research and several undergraduate students were actively involved in the project.

**B. Other Funds Spent during the Project Period:**

MSU Mankato has an existing geospatial laboratory that has all the hardware, software, and service that preexist for teaching and research. To include the funds of in-kind, we estimate:

$100,000: Existing remote sensing, GIS, GPS software and hardware at MSU

$10,000: Existing field & laboratory equipment for water sample collection and analysis at MSU

$16,000: Purchase of a hand-held spectrometer

**C. Past Spending:** None

**D. Time:** Two years, July 2007 through June 2009.

## VII. DISSEMINATION:

The results and findings were documented in project updates to the LCCMR, through multiple conference presentations by the project scientists and their graduate students, three Minnesota State University (MSU) Geography Department master's theses; several academic articles and further professional presentations are in preparation, and some results are already available on the web. Partnerships established to complete the project include local, county, regional, state and federal agencies and scientists at those agencies and at other universities. Communication and outreach has flourished with the creation of a nation-wide ARCHER working group founded by the project scientists: members include MSU, and professionals from 13 other state and federal agencies, universities and the private sector. A meeting of the working group will take place April 2010 at the annual meeting of the Association of American Geographers (AAG) in Washington, DC.

To date, the following presentations resulting from the study were given at national meetings of the AAG, at the state-wide MNGIS/LIS conference, at the regional level South Dakota State Geography Convention (SDSG), and at a Macalester College invited lecture series:

(1) "River Quality Monitoring Using Airborne Remote Sensing on the Blue Earth River, MN" (AAG, 2008);
(2) "Rapid Recharge of a Prairie Pothole Region Water Table Aquifer Following Severe Drought Conditions" (AAG, 2008)
(3) "Downstream Effects of Draining a Silted Reservoir: Rapidan Reservoir, Blue Earth County, Minnesota" (AAG, 2008)
(4) "Soil loss of the Blue Earth River riparian corridor and its effect on water quality" (MNGIS/LIS, 2008)
(5) "River Quality Mapping Using Hyperspectral Sensing and Field Methods, Blue Earth River, Minnesota, USA" (AAG, 2009)
(6) "Land Use Practices of the Blue Earth River Riparian Corridor and their Affect on Soil Loss using GIS and Remote Sensing" (AAG, 2009)
(7) "River Flow Modeling Using a Kinematic Wave Model for the Blue Earth River Watershed" (AAG, 2009 and SDSG, 2009)
(8) "Using GIS and Remote Sensing to Investigate the effects of Land Use on Soil Loss within the Blue Earth River Riparian Corridor" (SDSG, 2009)
(9) "Improved River Water Quality Monitoring Using Hyperspectral Remote Sensing" ("EnviroThursday" Lecture, Sponsored by the Environmental Studies Program, Department of Geography and Mellon Curricular Pathways, Macalester College, 2009)

**VIII. REPORTING REQUIREMENTS:**
**Periodic work program progress reports will be submitted not later than** March, 2008, August, 2008; January, 2009 **A final work program report and associated products will be submitted between June 30 and ~~August~~ September 1, 2009 as requested by the LCCMR**

**Attachment A:**
The attachment A is enclosed as Excel file in the same email.

Attachment A: Budget Detail for 2007 Projects - **Summary and a Budget page for each partner (if applicable)**

**Project Title:** *Improved River Quality Monitoring Using Airborne Remote Sensing 5(e)*

**Project Manager Name:** *Fei Yuan*

**Trust Fund Appropriation: $** *159,000*

**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**

| 2007 Trust Fund Budget | Result 1 Budget: | Result 1 REVISED REQUEST (Dec. '08) | Result 1 REVISED REQUEST (June '09) | Amount Spent (June 30, 2009) | Balance (June 30, 2009) | Result 2 Budget: | Result 2 REVISED REQUEST (Dec. '08) | Result 2 REVISED REQUEST (June '09) | Amount Spent (June 30, 2009) | Balance (June 30, 2009) | Result 3 Budget: | Result 3 REVISED REQUEST (Dec. '08) | Result 3 REVISED REQUEST (June '09) | Amount Spent (June 30, 2009) | Balance (June 30, 2009) | TOTAL BUDGET | REVISED TOTAL BUDGET REQUEST (Dec '08) | REVISED TOTAL BUDGET REQUEST (June '09) | TOTAL BALANCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Identify Critical Sediment and Riparian Management Areas | | | | | Increased Knowledge of Dynamic Riverine & Riparian Systems | | | | | Correlate Water Quality with Riparian Characteristics | | | | | | | | |
| **BUDGET ITEM** | | | | | | | | | | | | | | | | | | | |
| **PERSONNEL: wages and benefits** (12% of FTE per year for each of five faculty members; Six student research assistants (2 Graduate & 4 Undergraduate)) | 52,999 | 50,999 | 54,250 | 49,479 | 1,520 | 53,000 | 50,000 | 54,250 | 48,480 | 1,520 | 9,582 | 8,582 | 8,710 | 7,063 | 1,519 | 115,581 | 109,581 | 117,210 | 4,559 |
| **Vendors** (CAP ARCHER System for 14 aircraft flights with hyperspectral sensor) | 3,882 | 3,882 | 1,552 | 1,552 | 2,330 | 3,883 | 3,883 | 1,552 | 1,552 | 2,331 | 3,883 | 3,383 | 1,403 | 1,403 | 1,980 | 11,648 | 11,148 | 4,507 | 6,641 |
| **Equipment / Tools** *for field sampling, laboratory analyses, and image analyses (In-stream chlorophyll sensor peripherals; Field photospectrometer; specialized small remote sensing software and hydrologic modeling software)* | 4,925 | 9,925 | 9,326 | 9,326 | 599 | 4,925 | 9,925 | 9,326 | 9,326 | 599 | | 2,500 | 2,500 | 2,500 | 0 | 9,850 | 22,350 | 21,152 | 1,198 |
| **Other Supplies** *(Stream gaging; river water sampling; water testing; meteorological observations)* | 6,961 | 6,961 | 7,808 | 7,808 | -847 | 6,960 | 6,960 | 7,808 | 7,808 | -848 | | 0 | 0 | 0 | 0 | 13,921 | 13,921 | 15,616 | -1,695 |
| **Travel expenses in Minnesota** | 3,000 | 0 | 0 | 0 | 0 | 3,000 | 1,000 | 515 | 515 | 485 | 2,000 | 1,000 | 0 | 0 | 1,000 | 8,000 | 2,000 | 515 | 1,485 |
| **COLUMN TOTAL** | **$71,767** | **$71,767** | **$72,936** | **$68,165** | **$3,602** | **$71,768** | **$71,768** | **$73,451** | **$67,681** | **$4,087** | **$15,465** | **$15,465** | **$12,613** | **$10,966** | **$4,499** | **$159,000** | **$159,000** | **$159,000** | **$12,188** |