Mapping River Water Quality

Minnesota has more than 90,000 miles of rivers and streams, and the Minnesota Pollution Control Agency estimates that about 40 percent may have impaired water quality. Less than ~10 percent of Minnesota's river and stream miles have been assessed by ground-based sampling, however. We have explored the use of remote sensing as a cost-effective way to gather information for river water quality assessments. Compared with lakes, rivers and streams pose a more challenging set of problems for use of remote sensing techniques to assess water quality because:

- They are temporally more dynamic.
- The resolution of most satellites (e.g., Landsat, Sentinel) is too coarse (20-30 m) for small rivers and streams.
- A better set of spectral bands than those of Landsat is needed to measure all the water quality variables of interest.

One solution is to use airborne high-resolution hyperspectral imagery obtained from small aircraft flying over stretches of rivers with simultaneous collection of ground-based water quality data to calibrate the imagery. We conducted such measurements around the confluences of three large rivers in the metropolitan Minneapolis-St. Paul region that have different water quality characteristics – the Mississippi River, Minnesota River, and St. Croix River over three separate years, and the results were published in *Remote Sensing of Environment* (Olmanson et al. 2012). The Mississippi River drains a large fraction of northern and central Minnesota and has moderate levels of CDOM and nutrients. The Minnesota River drains agricultural land in the southern part of the state, and as a result it has high concentrations of nutrients (nitrogen and phosphorus) and often high levels of suspended sediment. The St. Croix River drains a predominantly forested region in east-central Minnesota and NW Wisconsin. It has generally good water quality although it is moderately stained by humic materials (CDOM) draining from forested wetlands in its watershed.

Methods

Overflights of various river segments were made in mid to late August of 2004, 2005, and 2007, and ground-based crews from Minnesota's Pollution Control Agency, Department of Natural Resources and Department of Agriculture, the Metropolitan Council Environmental Services, and University of Minnesota collected water samples and field data nearly concurrently with the overflights. We used an airplane and crew from the University of Nebraska's Center for Advanced Land Management Information Technologies (CALMIT) fitted with an AISA hyper-spectral imager to collect 1-3 m resolution imagery (depending on year and altitude of acquisition) in numerous narrow bands across the visible and near-IR (NIR) range. Water samples were analyzed by the Metropolitan Council and Minnesota Department of Health laboratories for various water quality constituents. Spectra were recorded for six river segments in 2004, 10 segments of the Mississippi River from Spring Lake (south of St. Paul) to Lake Pepin in 2005, and over a 100-km stretch from the Rum River to downstream of the St. Croix River in 2007. The in-situ water quality data and remotely sensed data were analyzed to determine the best retrieval model for each variable. Single band, band ratio and multiple band regression analysis models were used to create maps of water quality variables for each river segment.

Results

The results show strong relationships for several important water quality variables: chlorophyll, total suspended matter, volatile suspended matter (a surrogate for particulate organic matter), and turbidity. Using the best-fit models, we were able to map these variables for the river segments.

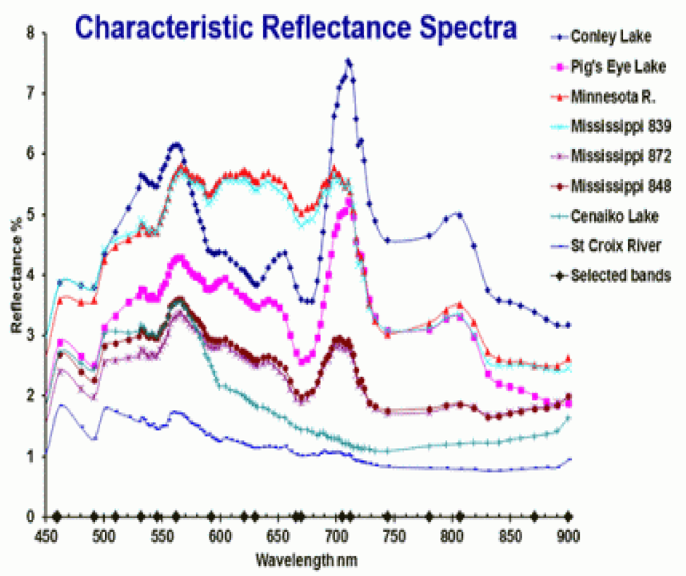
Two findings from this study are especially noteworthy. First, the high spatial resolution of the sensor revealed complex patterns of chlorophyll, turbidity, and suspended matter in the rivers in far greater detail than would be possible to achieve with a ground-based sampling program. The maps show the complex interactions of sediment and algae in the river segments.

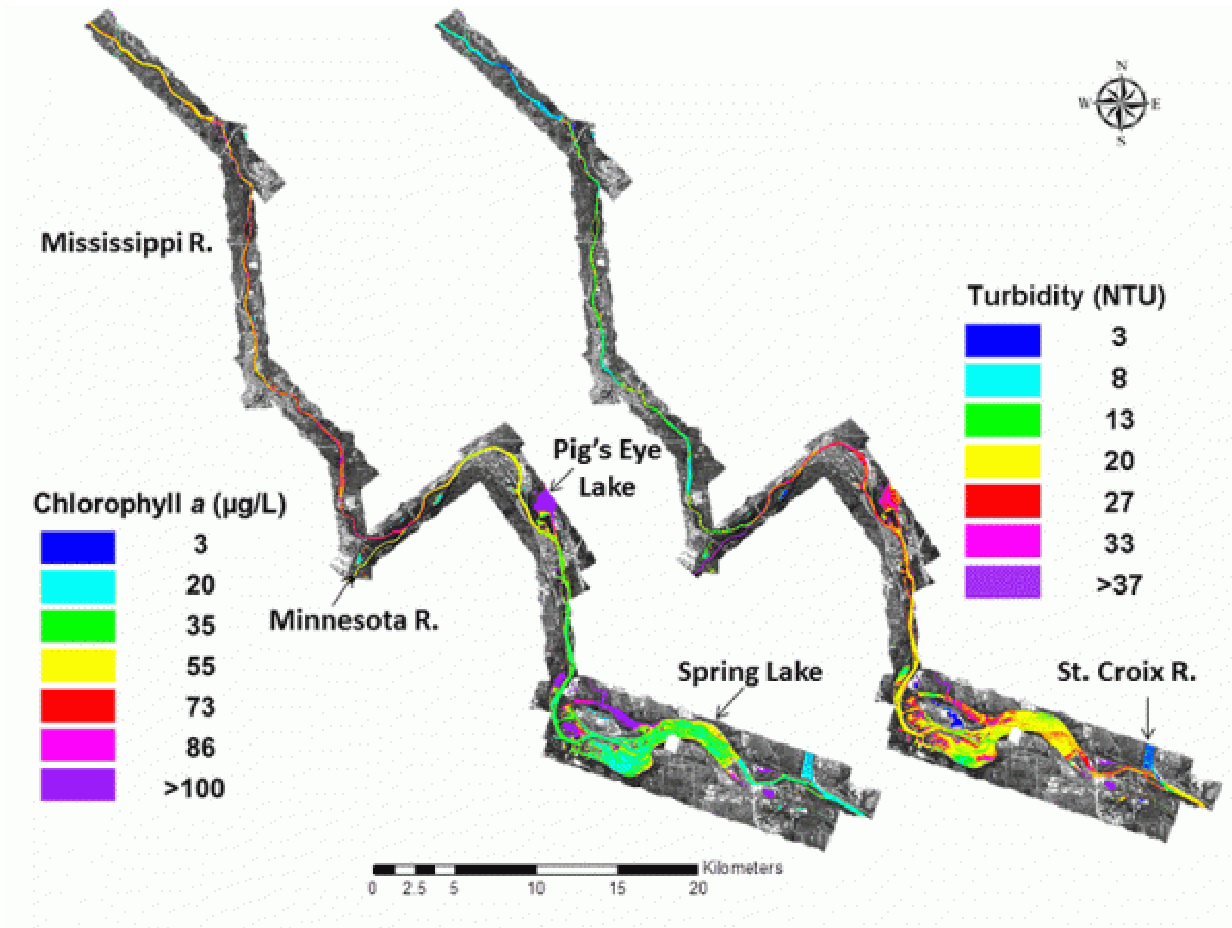
River Water Quality Model Development

LN of variable	Bands (nm)	r^2
T Tube (cm)	705	0.77 – 0.91
Turbidity (NTU)	705	0.77 – 0.93
TSS (mg/L)	705	0.77 – 0.93
VSS (mg/L)	705/670	0.80 – 0.94
Chl *a* (µg/L)	705/670 or 705/620	0.75 – 0.93
NVSS (mg/L)	705 & 705/670	0.85 – 0.97[a]
NVSS/TSS (%)	705 & 705/620	0.73 – 0.91[a]

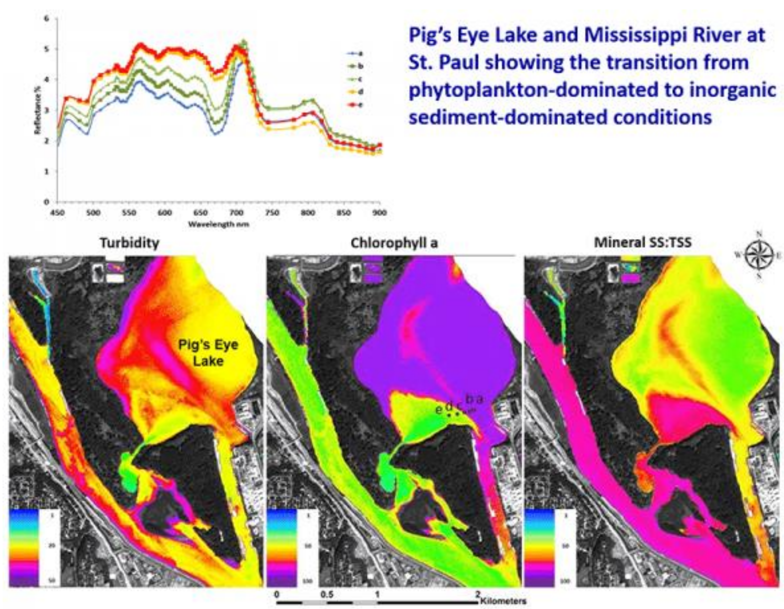
[a] R^2

Data from aircraft-mounted hyperspectral radiometer





Second, the high spectral resolution of the sensor allowed us to select narrow bands to develop unequivocal retrieval equations for each water quality variable. In particular, the so-called "red-edge" band around 705 nm was found to be a key metric that allowed development of models that differentiate chlorophyll from suspended matter. In contrast, the model typically used by oceanographers to retrieve chlorophyll concentrations from satellite images of the oceans does not use the red-edge band and cannot distinguish between chlorophyll and suspended matter.



Our findings demonstrate that remote sensing can be a useful tool to assess water quality in rivers. The approach provides much more detailed water information on spatial patterns than could be obtained otherwise. Remote sensing provides both “big picture” views of land and water resources and more detailed views of small, potential problem areas, thus facilitating the allocation of limited field monitoring resources to areas that need additional attention. Further discussion and interpretation of the results can be found in the article by Olmanson *et al*. (2013).

Acknowledgments

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Reference

Olmanson, L. G., M. E. Bauer, and P. L. Brezonik. 2013. Airborne hyperspectral remote sensing to assess spatial distribution of water quality characteristics in large rivers: The Mississippi River and its tributaries in Minnesota. Remote Sens. Environ. 130: 254-265. DOI:10.1016/j.rse.2012.11.023.