Environment and Natural Resources Trust Fund
2014 Request for Proposals (RFP)

Project Title: **ENRTF ID:** **042-B**

Remote Sensing Characterization to Improve Water Quality Monitoring

Category: B. Water Resources

Total Project Budget: $ 207,000

Proposed Project Time Period for the Funding Requested: 3 Years, July 2014 - July 2017

Summary:

Provide new remote sensing tools for comprehensive measurement of surface water quality in Minnesota, improving efficiency and effectiveness of monitoring and management under changing climate and land use conditions.

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Sponsoring Organization: U of MN

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Location

Region: Statewide

County Name: Statewide

City / Township:

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ Employment	_____ TOTAL _____%

PROJECT TITLE: Remote sensing characterization to improve water quality monitoring

I. PROJECT STATEMENT

Water clarity of lakes and rivers can be monitored from space using remote sensing, enabling cost effective and comprehensive assessment of current conditions and changes over time in a large majority Minnesota's surface waters. Water clarity is an important indicator of water quality for humans and wildlife, but ***much more information could be gained by measuring the specific factors that control water clarity***. With increasing availability of enhanced satellite imagery, there is potential to distinguish between the three major factors that determine water clarity: algae, colored dissolved organic matter (hereafter "dissolved organic matter"), and inorganic suspended sediments. Each of these has specific, distinct effects on water quality. Understanding their individual contributions to remotely sensed observations of water clarity is essential in interpreting water clarity-water quality relationships, and the ability to monitor these characteristics across Minnesota's surface waters will be highly useful to natural resource managers. Our objective is to develop cost-effective remote sensing procedures to measure algae (as chlorophyll pigments), dissolved organic matter and suspended sediments routinely. Newly available, increasingly sophisticated satellite sensors make this objective both feasible and timely; the abundance of surface water in the state, and complex controls over water quality make this an important step in detecting and managing changing surface water quality conditions. For example, dissolved organic carbon controls the availability of mercury to aquatic food webs, yet is highly varied in space and time, so the ability to monitor this parameter on a statewide basis will assist management of mercury contamination. Furthermore, these methods can be used to distinguish the influence and extent of sediment contamination (from landscape erosion) and algal blooms (resulting from eutrophication). The objective will be accomplished through concurrent sampling and remote sensing measurements on ~50 lakes selected to encompass a wide range of optical and biogeochemical properties. Data thus obtained will be used to develop predictive relationships for chlorophyll, dissolved organic matter, and suspended sediments, which also will lead to more robust, physically-based predictions of water clarity (measured as Secchi depth). The results will be validated with an independent dataset, and their usefulness will be assessed by analyzing imagery from four satellites sensors (MODIS, Landsat 8, Sentinel, and HICO sensors) which now can potentially provide surface water quality information for rivers and lakes at a frequency of up to twice a week.

II. DESCRIPTION OF PROJECT ACTIVITIES

Activity 1: Develop physically-based predictive relationships for chlorophyll, dissolved organic matter, and sediments using remote sensing reflectance data and test them in simple and optically complex waters. Field measurements include hyperspectral reflectance and light scattering and attenuation coefficients as a function of depth in the water column, as well as important water quality variables and optical properties. **Budget: $207,000**

Outcome	Completion
1. *Evaluate spectral and spatio-temporal variability of water quality variables to be predicted; field studies to measure water quality parameters concurrent with acquisition of satellite imagery*	*Fall 2015*
2. *Complete sample and imagery analyses*	*Winter 2016*
3. *Develop predictive relationships and models*	*Spring 2016*
4. *Validate models in new lakes and rivers; prepare reports*	*Winter 2016*

III. PROJECT STRATEGY

A. Project Team/Partners

Our multidisciplinary team based the University of Minnesota has broad expertise on water quality issues of concern for Minnesota's lakes and application of remote sensing tools to monitor lake and river conditions.

- Project manager Jacques Finlay, Assoc. Prof. of Ecology, Evolution and Behavior, is an aquatic ecologist specializing in nutrient and organic matter cycling in lakes and streams. Aside from project management, he will oversee field and lab studies and participate in data analysis and development of publications.
- Patrick Brezonik, Prof. Emeritus, Environmental Engineering, has over 40 years of experience studying water quality and chemistry and has focused on applying remote sensing to water quality monitoring in Minnesota since 1998. He will provide scientific guidance and participate in all aspects of the project.
- Leif Olmanson, Research Associate, UMN Remote Sensing and Geospatial Analysis Lab, has expertise in GIS and remote sensing. He has worked for 15+ years in developing remote sensing techniques for water quality. He will acquire/process satellite imagery and participate in data analysis.
- Prof. Marvin Bauer, a world-renowned expert on remote sensing, is the editor of its leading journal, *Remote Sensing of Environment*. He will provide guidance on satellite imagery developments and processing techniques and participate in data analysis and report writing.

The first three scientists will receive ENRTF funds; Prof. Brezonik will contribute a month per year of his own time to the project. In lake selection and some sampling we will collaborate with PCA scientists (see attached letter) studying organic matter and mercury contamination and the statewide lake assessment monitoring program. UMN undergraduates and a graduate student would be trained in during the project, and Finlay's longtime lab manager Sandra Brovold will oversee laboratory analyses.

B. Timeline Requirements

Our project is for three years. Collection of field data over three summers is needed to (i) evaluate inter-annual variability in water quality, (ii) insure clear atmospheric conditions for imagery collection concurrent with ground-based measurements over the range of lakes on which we will make measurements, and (iii) provide time to collect images and ground data to validate models we develop. We expect to fully achieve the project's objective to develop measurement procedures and predictive relationships in the 36-month project duration.

C. Long-Term Strategy and Future Funding Needs

With increasing GIS expertise in local and state natural resource agencies, increasing availability of high-quality satellite imagery at no cost, and increased ease of processing such imagery, the tools that we will develop will be widely accessible for use by state and local agencies to help address their water quality monitoring needs related to managing eutrophication, mercury pollution, excess sediment, and emerging contaminant issues in Minnesota lakes. We will disseminate our results at state conferences (e.g., GIS and Water Resources conferences), by seminars at state and regional agencies (e.g., PCA and DNR), on our web site (http://water.umn.edu), and by publications in the peer-reviewed literature. Once the new procedures are developed and validated at the end of our 3 year project, a small follow-up implementation project of 1-2 years would be desirable to: (i) demonstrate the capabilities of the new techniques for statewide and local-to-regional scale water quality evaluations that need chlorophyll, dissolved organic matter and suspended solids measurements, and (ii) develop and hold training workshops for agency staff and other potential users.

IV. CONCLUSION

By developing methods to inexpensively measure concentrations of chlorophyll, suspended solids, and dissolved organic matter in Minnesota's freshwaters using remote sensing, we will provide powerful tools for resource managers to detect patterns and change in water quality in the state's lakes, allowing improved efficiency and effectiveness of management and monitoring programs in the face of climate and land use changes. Our past development of remote sensing methods for water clarity has allowed statewide monitoring of > 10,000 Minnesota lakes. Expansion of these capabilities to include algal abundance (measured as chlorophyll), dissolved organic matter, and suspended sediments through the studies we propose will greatly improve and expand remote sensing capabilities to monitor, manage and understand Minnesota's freshwater ecosystems. Algae, dissolved organic matter and suspended sediments are key "master" variables that control many other properties of freshwater ecosystems.

2014 Detailed Project Budget

Project Title: Remote sensing characterization to improve water quality monitoring

IV. TOTAL ENRTF REQUEST BUDGET *3* **years**

BUDGET ITEM	AMOUNT
Note: research team is based at the University of Minnesota	
Personnel: Jacques Finlay, Associate Prof. 2 months total (2/3 mo. salary in each summer) to oversee the project ($27,000; 75%salary, 25%fringe)	$ 27,000
Personnel: Leif Olmanson, Research associate, 6 months total , to conduct satellite image analyses and coordinate imagery with field sampling. ($35,000; 75%salary, 25% fringe)	$ 35,000
Personnel: Patrick Brezonik, Prof. Emeritus, 2 months total to analyze dissolved organic carbon data, and develop empirical models for satellite-based water quality ($25,000; 93% salary, 7% fringe)	$ 25,000
Personnel: Graduate Student (2 semesters) ($40,000; 52% salary, 48% fringe) to assist in all aspects of the project, and to develop thesis research aligned with the project goals	$ 40,000
Personnel: Undergraduate assistants (2) to conduct field/lab studies for 4 months each ($16,000=$8000 x 2; 91% salary, 9%benefits)	$ 16,000
Personnel: Sandra Brovold, Research Scientist (Finlay lab). 6mo. to coordinate field sampling & laboratory analyses ($35,000; 60% salary, 40% benefits)	$ 35,000
Contracts: None	$ -
Equipment/Tools/Supplies: **Portable field spectroradiometer** ($12,000). The ability to accurately perform field reflectance and radiometric measurements is critical to understanding the optical properties of natural water bodies that are needed for image calibration. The dual OceanOptics USB2000+ will allow us to get the most out of our field time because we will be able to collect data even when sky conditions are not optimal because of shifting cloud cover. This instrument would be used throughout the duration of the project for both model development and validation. **Supplies for sampling and analyses** (e.g. bottles, filters, sampling pump, gases for analyzers, consumable reagents) ($13,000)	$ 25,000
Acquisition (Fee Title or Permanent Easements):	$ -
Travel: Vehicle rental: 25 days @$61/day and 0.23/miles from UMN fleet services for travel to field sites for sample collection in Minnesota in 2 field seasons ($2850). Boat maintenance & transport or rental at larger lakes (e.g. lower St. Louis River estuary). Boat maintenance, storage fees, fuel and repair to trailer used for transport ($1150).	$ 4,000
Additional Budget Items: none	$ -
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 207,000

V. OTHER FUNDS

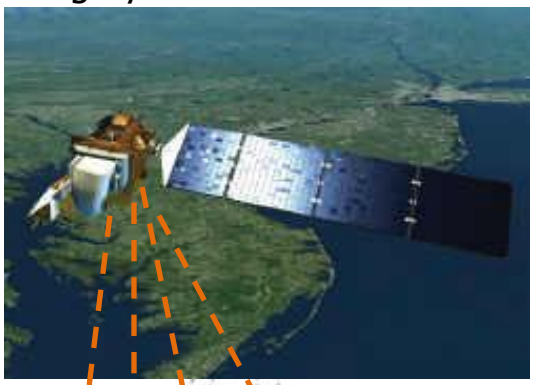
SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ Being Applied to Project During Project Period: none	$ -	
Other State $ Being Applied to Project During Project Period: none	$ -	
In-kind Services During Project Period: Data generated from PI Finlay's MN Sea Grant Project on biogeochemistry in the St. Louis River estuary will be made available to the proposed project. The Seagrant project is developing models of river and lake water movement, and impacts, in the estuary and offshore waters of Lake Superior. Satellite images of the site are being collected, and data can be used for model development and validation in our proposed work	$ -	*ongoing through 2014*
Professors Brezonik and Bauer have committed 1 month per year uncompensated time to the project.		
Remaining $ from Current ENRTF Appropriation (if applicable): not applicable	$ -	
Funding History: MN Sea Grant (2012-2014) Project explores how hydrologic variability influences ecosystem functioning in the St. Louis River Estuary.	$189,000	*ongoing*
Professional development grant for retired faculty (2011-2013): Project explores nature of colored dissolved organic matter and interactions with methylmercury	$4,000	*ongoing*

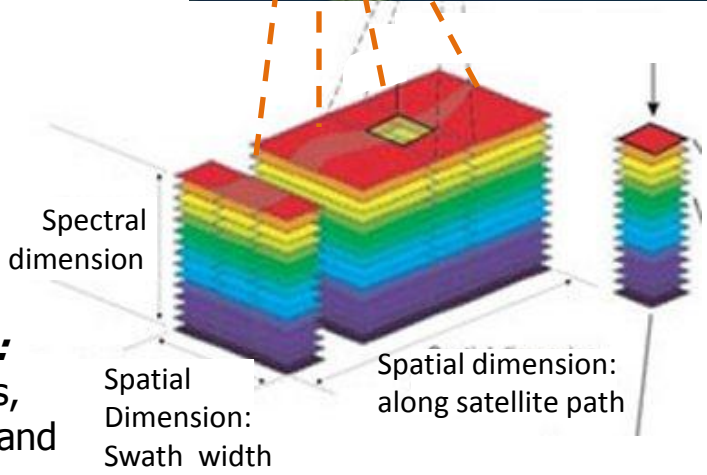
Water quality monitoring based on satellite imagery

1. Collect samples from set of calibration lakes to measure water quality variables that affect light reflectance from water bodies and thus are amenable to measure-ment by satellite imagery.

Such variables include: turbidity, suspended solids, Secchi depth, chlorophyll and other algal pigments, and colored dissolved organic matter (CDOM), also known as aquatic humic matter.

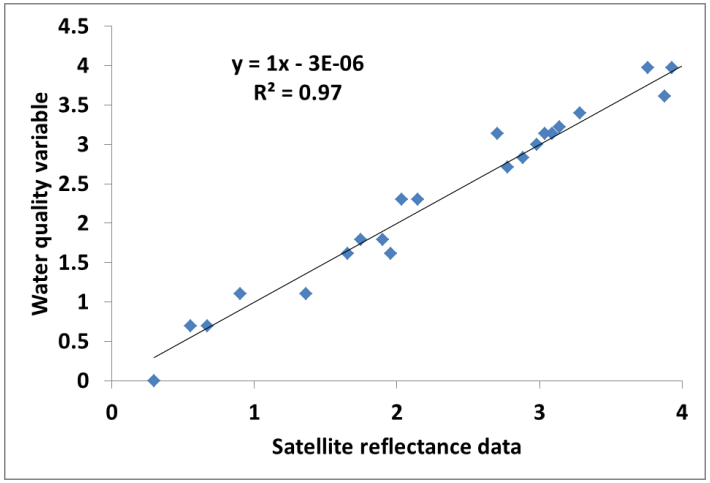
2. Near the same time, satellite imagery is collected.



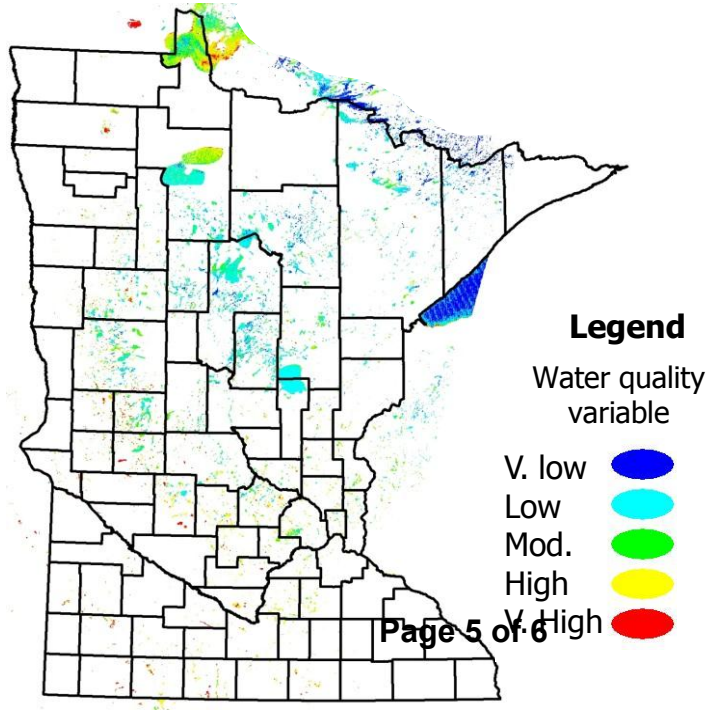


Each pixel has spectral information that can be used to estimate water quality characteristics.

3. Build predictive models using the calibration data.



4. Apply models to lakes across Minnesota using satellite imagery.



Project Manager Qualifications for *"Remote sensing characterization to improve water quality monitoring"*. The project brings together interdisciplinary expertise to expand and strengthen water quality monitoring in Minnesota. Project manager Jacques Finlay is an associate professor (since 2003) in the Department of Ecology, Evolution and Behavior (EEB) and the Saint Anthony Falls Laboratory at the University of Minnesota. Finlay is an ecosystem ecologist broadly interested in the ecology of aquatic ecosystems, and their interaction with surrounding natural and human altered landscapes (www.cbs.umn.edu/lab/finlay). Finlay has conducted basic and applied research in systems ranging from boreal watersheds and streams, the Laurentian Great Lakes, human-dominated floodplains, agricultural and urban ecosystems, alpine lakes, and pristine streams. A central goal of Finlay's research is to understand how transport of terrestrial organic matter, especially dissolved materials, and nutrients influences the functioning of recipient freshwater ecosystems. Finlay has advised two masters and seven PhD students, mentored eight postdocs, and published over 60 peer reviewed scientific articles and book chapters. Finlay is collaborating with Professors Brezonik and Bauer, and research associate Olmanson in ongoing water quality research projects in Minnesota.

Organization Description All investigators are based at the St. Paul campus of the University of Minnesota, which houses the necessary facilities and expertise for the proposed research. Professor Marv Bauer and colleagues maintain the Remote Sensing and Geospatial Analysis Laboratory at the University of Minnesota (http://rsl.gis.umn.edu/). This lab has laboratory space with state-of-the-art computing and software resources with a suite of data analysis, image processing, and GIS software, including ERDAS IMAGINE, Trimble eCognition, ESRI ArcGIS, R, and Rulequest.

As a collaborator to the experimental Hyperspectral Imager for the Coastal Ocean (HICO) sensor onboard the International Space Station we have access to HICO imagery and the ability to request new targets. We will also have access to imagery from the European Space Agency "state of the art" Sentinel satellites to be launched beginning later this year. Data policies allow free access to the recently launched "state of the art" Landsat 8 and MODIS imagery. These new imagery resources available at no cost with improved spectral, spatial and temporal characteristics will greatly enhance the ability for comprehensive water quality monitoring in Minnesota, potentially on a biweekly basis.

Project manager Finlay has a fully equipped lab for analysis of gaseous, dissolved, and particulate nitrogen, phosphorus and carbon, and basic limnological variables. Finlay has a Shimadzu TC-VCPN analyzer for dissolved nitrogen and carbon analysis, and Lachat QuickChem autoanalyzer for analyses of phosphorus forms, and inorganic nitrogen. His lab is equipped with drying ovens, fume hoods, a freeze drier, balances, deionized water, spectrophotometers and grinding mills. Finlay has Hukseflux LP02 thermopile pyranometers for global and diffuse radiation, two terrestrial Hobo Micro Station data loggers with photosynthetically active radiation (PAR) sensors and underwater quantum sensors to measure PAR in water. Two handheld fluorometers are available for dissolved organic carbon analyses. Small boats with outboard motors are available for use, as are canoes and kayaks. Professor Emeritus Brezonik has access to facilities in the laboratories of the Department of Civil Engineering for various water quality analyses, including scanning spectrophotometers, dissolved carbon analyzers, ion chromatograph, atomic absorption spectrophotometer, turbidimeters, fluorometers, and field equipment to measure water quality variables.