Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2018 ENRTF Work Plan (Main Document)

Today's Date: February 15, 2018

Date of Next Status Update Report: January 31, 2019

Date of Work Plan Approval:

Project Completion Date: June 30, 2021

Does this submission include an amendment request? No

PROJECT TITLE: Providing Critical Water Quality Information for Lake Management

Project Manager: Jeffrey Peterson

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College/Department/Division: Water Resources Center

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Location: Statewide

Total Project Budget: $250,000

Amount Spent: $0

Balance: $250,000

Legal Citation: M.L. 2018, Chp. xx, Sec. xx, Subd. xx

Appropriation Language:

I. PROJECT STATEMENT:

This project will create an automated system delivering near real-time data and maps of key water quality measures for all Minnesota Lakes. In a current LCCMR-supported project (Assessment of Surface Water Quality with Satellite Sensors, Finlay et al. 2016) we have developed methods to expand remote sensing capabilities beyond water clarity to include chlorophyll and color. This project will apply those methods in a fully automated system that acquires, processes, and delivers new satellite-derived water quality data as it becomes available (approximately biweekly). Citizens, government agencies, and researchers will have routine access to the data via an interactive web interface linked to a spatial database that will operate at minimal cost for years to come. This unique data source will dramatically improve data-driven resource management decisions and will help inform agencies and the public about water quality conditions statewide.

The project is a compelling opportunity that takes advantage of new data streams from recently operational satellites and the high performance computing resources at the University of Minnesota. The Water Resources Center (WRC) will coordinate the project and disseminate its products within a larger WRC "digital water" initiative to expand water quality information and strengthen understanding of our changing water resources. This proposal was developed in cooperation with staff from state water management agencies and is designed to support their information and management needs.

The project goals are to:

1. Develop automated methods to process satellite images to retrieve near real-time data on chlorophyll, water clarity and color based on conventional methods developed with previous R&D;
2. Create a database of satellite-based water quality during the open-water season in Minnesota's lakes using high performance computing;
3. Work with key government agencies to deliver data products useful for their monitoring and management needs;
4. Provide robust datasets to drive advances in understanding fish habitat dynamics, harmful algal blooms (HABs), and effects of land use changes on water quality;

The remotely sensed components of water quality (water clarity, chlorophyll, color) generated by this project will be useful for many applications. One example would be for MPCA and MDNR managers to account for differences among lakes across a range of spatial scales and follow changes through time. By being able to see regional anomalies and changes over time, managers will be able to target field monitoring where needed, leading to more effective decision making and improved water quality and habitat conservation outcomes. Another example is to enhance existing fish habitat models by accounting for key components that affect dissolved oxygen and temperature, the primary determinants of fish habitat quality. The MDNR is very interested in using these products to assess the impacts of changing land cover and atmospheric conditions on fish habitat and prioritize funding decisions for protection vs. restoration and other management activities.

II. OVERALL PROJECT STATUS UPDATES:

First Update January 31, 2019

Second Update June 30, 2019

Third Update January 31, 2020

Final Update June 30, 2020

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: *Build advanced near real-time methods for measuring water quality in surface waters of Minnesota using remote sensing.*

Description: We will develop computer code to automate methods for acquisition and processing of satellite imagery for water quality monitoring using high performance computing techniques. Water quality data resulting from the computerized system will be validated with field data to provide confidence in the results.

Satellite imagery *Landsat-8 and Sentinel-2 Imagery*
This project will use optical imagery from the Landsat-8 (http://landsat.usgs.gov) and Sentinel-2 (https://sentinel.esa.int/web/sentinel/missions/sentinel-2) satellites to map water quality variables. Landsat-8 Top-of-atmosphere (TOA) and surface reflectance (SR) products (referred to hereafter as level-1 and level-2, respectively) will be obtained from the USGS Earth Resources Observation Science (EROS) Center. Sentinel-2 Level-1 TOA products will be obtained from either the European Space Agency (ESA) *Sentinels Scientific Data Hub* (https://scihub.copernicus.eu/) or the USGS EROS Center depending on evolving international data transfer and archiving agreements. Both Landsat and Sentinel-2 data are available at no cost. We will derive level-2 SR products using the Sentinel-2 Toolbox full source code distributed under the GNU General Public License (GPL), and available through GitHub or best available method as determined in our current LCCMR (Finlay et al. 2016) and NSF (Hozalski et al. 2015) projects.

Level-2 SR imagery from Landsat-8 and Sentinel-2 will be clipped using an open water mask (OWM). This product will be constructed using clear-sky warm season Landsat-8 or Sentinel-2 TOA imagery using methods used to map water clarity in Minnesota (Olmanson et al. 2008).

Water Quality (in situ) *Calibration/Validation Measurements*
This project will rely on well-established water quality monitoring programs of agencies in Minnesota, along with existing/ongoing in situ spectroscopic measurements of lake optical properties and targeted sampling for on water clarity, chlorophyll, , and color being collected by related ongoing projects (Finlay et al. 2016, Hozalski et al. 2015). These datasets will be used as calibration and validation (Cal/Val) measurements to establish confidence in the use of remote sensing data for water quality management, an important component of this project, which will require documentation of data quality and associated uncertainties. Operational use of remote sensing water quality products necessitates long-term quality-assured match-up data for continued validation of retrieval algorithms.

We will inventory existing water quality sampling activities for continued Cal/Val of remote sensing algorithms. To use these data appropriately, we will collect information on their efficacy by inventorying federal, state and tribal databases. Metadata will be compiled on sample locations, collection methods and equipment, and analytical methods for the parameters of interest, and the continuity of the programs will be confirmed. We also will establish staff contacts and secure data-use agreements for future data retrievals. An easily accessible database structure will be designed and populated with existing water quality data that will be updated annually following each field season.

Remote Sensing Methodology and Supercomputing
We will use digital image data from the Landsat-8/Sentinel-2 constellation to retrieve water clarity, chlorophyll, and color water quality variables during the warm season (May-October). Using in situ measurements, we will be able to constrain uncertainties between ground and satellite-derived water properties caused by varying atmospheric conditions and calibrate/validate water quality retrieval algorithms to yield verifiable water products for Minnesota lakes.

Our approach to develop water quality products (hereafter referred to as level-3 data) for Minnesota will consist of two steps. First, we will develop image pre-processing routines, prototype retrieval algorithms, and prototype level-3 data products for sub-regions in Minnesota. Prototype source code will be developed using Python and Matlab programming languages, and the project team will vet prototypes iteratively during project year 1 to ensure that level-3 data products match end-user decision-making needs. Second, we will translate the prototype source codes into the Minnesota Supercomputing Institute's (MSI) HPC infrastructure.

Image Pre-Processing. Level-3 water quality data products will be derived from Landsat-8 and Sentinel-2 level-1 TOA and level-2 SR imagery at each sensor's nominal acquisition scale. Using the Sen2cor source code (i.e., ESA's atmospheric correction module), we will derive level-2 SR products for Sentinel-2. Cloud masks for Landsat-8 and Sentinel-2 will be constructed using the level-1 TOA products. Imagery having cloud cover percentages > 50% will be excluded from further processing. Cloud masks and level-2 SR images will be clipped with the Minnesota OWM product. Water quality retrieval algorithms will be applied to level-2 SR images containing only open water areas of lakes.

Cloud Masking Algorithm. We will generate cloud masks for Landsat-8 and Sentinel-2 by methods similar to Crawford et al. (2013), whose algorithm combines the accumulated cloud cover assessment (ACCA) algorithm (Irish et al. 2006) and includes the solar geometry cloud shadow algorithm for Landsat (Huang et al. 2010). The cloud algorithm includes a dynamic dimension that accounts for seasonality in land surface and cloud brightness temperatures and a pass-3 screen for optically thin clouds using the water vapor cirrus spectral band. Because Sentinel-2 does not acquire thermal infrared measurements, we will modify the Landsat-8 cloud algorithm by removing the pass-2 thermal screen, and use only pass-1 and pass-3 screens.

Optical Water Quality Algorithms. Water quality mapping using visible-near infrared imagery has primarily relied on Landsat satellites, which have spatial resolution suitable for lakes > 10 acres. Their few spectral bands, however, have limited measurements primarily to water clarity and CDOM. The increased frequency and additional spectral bands of Sentinel-2 satellites will enable estimation of chlorophyll (Olmanson et al. 2011, 2013 & 2015, Matthews 2011). We will build on these advances to develop procedures to assess > 10,000 Minnesota lakes multiple times per year using semi-automated processing methods and lay the groundwork for operational programs based on remote sensing to provide ongoing data on water quality and fish habitat variables.

Remote sensing assessments of lakes at regional scales typically have used regression models that relate spectral reflectance data to concurrent field data. The resulting models then predict water quality variables for lakes in the image where field data are lacking (Olmanson et al. 2015, Matthews 2011). A more useful approach would correct the radiance measured by a sensor to a standard surface reflectance, which then would allow development of "universal algorithms" for water quality variables, i.e., algorithms not requiring concurrent calibration data. Correction of radiance to reflectance – i.e., removal of effects caused by atmospheric moisture, haze, sun angle, and other factors not related to the optical properties of the water body has improved significantly recently with the new Landsat 8 and Sentinel 2 sensors. In current LCCMR (Finlay et al. 2016) and NSF (Hozalski et al. 2015) projects, we are evaluating, with in situ water quality data, several methods for atmospheric correction: MAIN, ACOLITE, SeaDAS/l2gen, FLAASH, along with Landsat surface reflectance products provided by EROS.

With these products, we are developing water quality models that can be used on similarly corrected imagery. To date we have obtained reliable results for CDOM in optically complex waters using a two-term model (Olmanson et al. 2016a) and have applied that model to radiometrically corrected imagery in Minnesota to create the first state-wide CDOM map (Olmanson et al. 2016b). The method that provides the most consistent reliable results, if different from the level-2 product mentioned above, will be used for the water quality variables. We also have found that by using in situ CDOM data we have been able to improve the model we have been using (Olmanson et al. 2008) for water clarity (R^2 = 0.58 without vs. 0.79 with CDOM) to account for reduced transparency from CDOM. We anticipate similar results with satellite derived CDOM (These results were obtained with in situ spectra to simulate Landsat 8 data and included many high CDOM waters). In a related project (Finlay et al. 2016), we are developing models for chlorophyll using Sentinel-2 imagery. We expect that these models will be similar those reported in the literature (e.g., Matthews et al. 2011, Olmanson et al. 2011, 2013 & 2015).

Supercomputing using MSI HPC Resources. Translation of prototyped source code for image pre-processing, retrieval algorithms, and level-3 data products will require efficient, timely, and automated scripting to disseminate diverse, complex, voluminous, geographically distributed, and growing Earth observation assets. The HPC component will support both standard scripting and customizable scripting workflows that can be dynamically modified as new level-1/2 Earth observation data pipelines and formats become available. We anticipate that both background (batch) and interactive processing will be needed as the project evolves. Background automated processing is needed periodically for ongoing ingestion of level-1/2 satellite imagery as they are collected and made available in the form of level-3 data products.

Water quality remote sensing investigators will provide prototype source code for image pre-processing, retrieval algorithms, and level-3 data products. MSI personnel will translate this prototype source code into efficient and automated processes within a flexible workflow framework that can be extended by the project team. To achieve this, we will: (1) identify and maintain a working list of level-1/2 Earth observation data archives; (2) establish methods for automatically downloading level-1/2 data as it becomes available from both the USGS EROS Center and ESA Sentinels Scientific Data Hub; (3) implement automated workflows for processing level-1/2 data into level 3 products (including pixel level, basin averages); (4) automatically post these level-3 water quality products, as they are generated, to MSI's tier-2 (CEPH) storage; and (5) make level 3 products on CEPH accessible to web based services.

ENRTF BUDGET: $132,231

Outcome	Completion Date
1. System to automatically acquire and prepare satellite images for further processing	June 2019
2. Automated method to apply water quality algorithms from previous R&D to open water pixels for comprehensive and frequent water quality monitoring of Minnesota lakes	December 2019
3. Validation of satellite results with routine water quality data collected by citizens, local and state agencies	June 2020

First Update January 31, 2019

Second Update June 30, 2019

Third Update January 31, 2020

Final Update June 30, 2020

ACTIVITY 2: ***Build water quality geospatial database and provide it to the government agencies, the research community, and citizens.***

Description: We will develop a spatial database to store continually updated water quality maps at the pixel level to visualize seasonal and annual changes in water quality. The data will also be summarized by time (e.g., seasonal averages) in collaboration with agency staff who will advise us on data needs to improve management and better meet their missions. An upgraded version of the Lake Browser (http://lakes.rs.umn.edu/) will provide access to lake water quality data. Interactive processing will allow HPC experts and the water quality investigators to view results with the capability of filtering by location, time period, or product. This environment will allow the project team and users to discover what data products are most relevant to decision-making as the project evolves, thus enabling dynamic modification of existing scripting workflows to improve synergy in terms of ingested level-1/2 satellite data, level-3 water quality data products, and evolving end-user needs.

As described in activity 1, pixel level and basin averaged lake water quality data will be automatically stored on the Minnesota Supercomputing Institute's (MSI's) tier-2 (CEPH) storage as it is generated. An advantage of this

CEPH storage is that it can share data as web addresses over the wide area network. To provide a flexible, standard, and user friendly access to this data, a geographic information system (GIS) database and web server will be available for this project. One virtual machine (VM) will host the geospatial database, and a second VM will host the web server that will present a user facing web page to the public. Both VMs, and software to run the database and web server, are freely available for this project through the Office of Information Technology (OIT) at the University of Minnesota (UM). The GIS database will be adapted from working examples from the UM's U-Spatial Institute. Scripts running the first VM will periodically pole MSI's CEPH storage for new data and post it to the database. The second MV will run an ArcGIS server which is configured to read data from the GIS database on the first VM. The user facing website, presented by the ArcGIS server, will be curated by staff at the UM's Water Resources Center (WRC) using the ArcGIS desktop.

ENRTF BUDGET: $117,769

Outcome	**Completion Date**
1. Near real-time water quality data integrated into a continually updated, publically accessible web database and mapping tool.	December 2019
2. Seasonal summaries of water quality data needed for research needs.	December 2019
3. A web interface maintained by the University of Minnesota's Water Resources Center that provides access to lake water quality data.	June 2020
4. At least a two year database with ~bi-weekly water clarity, chlorophyll and color.	June 2020

IV. DISSEMINATION:

Description: Project results will be communicated using a range of outlets. The primary mode of dissemination is the update and expansion of the Lake Browser. This website provides content for diverse users including citizen scientists, homeowners, classrooms, natural resource managers, researchers at agencies and academic institutions. Results will also be disseminated in the peer reviewed literature, and in presentations made at conferences and at state agencies.

First Update January 31, 2019

Second Update June 30, 2019

Third Update January 31, 2020

Final Update June 30, 2020

V. PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview: See attached budget spreadsheet

Explanation of Capital Expenditures Greater Than $5,000: N/A

Explanation of Use of Classified Staff: N/A

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours: 3,446	Divide by 2,080 = TOTAL FTE: 1.66

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours: N/A	Divide by 2,080 = TOTAL FTE: N/A

B. Other Funds:

SOURCE OF AND USE OF OTHER FUNDS	Amount Proposed	Amount Spent	Status and Timeframe
Other Non-State $ To Be Applied To Project During Project Period:	$ N/A	$ N/A	
Other State $ To Be Applied To Project During Project Period:	$ N/A	$ N/A	
In-kind Services To Be Applied To Project During Project Period: *unrecovered Indirect costs (54% MTDC)*	$135,000	$ N/A	Secured
In-kind Services To Be Applied To Project During Project Period: *Value of Landsat* ***satellite imagery*** *from EROS Data Center The estimated net value of Landsat imagery over the project period is* ***$326,400*** *(~544 images X $600/per image).* ***Minnesota Supercomputing Institute*** *is providing 300,000 core hours of compute time MSI's Linux cluster, 5 TB of primary (POSIX compliant) data storage and 10 TB of tier 2 (object oriented CEPH) data storage at a value of* ***$24,900****.The* ***Minnesota Department of Natural Resources*** *will provide 100 hours per year for 2 years in-kind support to this project, for a value of* ***$21,450****. The* ***Minnesota Pollution Control Agency*** *and The* ***Metropolitan Council Environmental Services*** *will provide their lake and river water quality data in support of calibration and validation of remote sensing results. Estimate value $150 per sample x 400 samples* ***$60,000****.*			
See description above.	$432,750	$N/A	Secured
Past and Current ENRTF Appropriation: *ENRTF: 2016 PI Jacques Finlay - Assessment of Surface Water Quality with Satellite Sensors - Activity 1 unspent funds available.*	$	$ 205,000	Secured
Other Funding History: *The National Science Foundation Award # 1510332 PI Raymond Hozalski "Spatial and Temporal Variability in CDOM at Large Regional Scales by Optical Remote Sensing: Effects on Water Quality, Water Treatment, and Aquatic Ecosystem Properties". Funds will all be expended before July 1, 2018.*	$	$ 230,000	Secured

VI. PROJECT PARTNERS:

A. Partners receiving ENRTF funding

Name	Title	Affiliation	Role
Jeffery Peterson	Director WRC	UMN WRC	PI
Leif Olmanson	Research Associate	UMN FR & WRC	Co-PI Technical PI

David Porter	Scientific Computing Cons	UMN MSI	Co-PI

B. Partners NOT receiving ENRTF funding

Name	Title	Affiliation	Role
Marvin Bauer	Professor emeritus	UMN FR	Co-I

VII. LONG-TERM- IMPLEMENTATION AND FUNDING: This project directly addresses LCCMR funding priorities in Water Resources and Foundational Natural Resource Data and Information. Our project brings together expertise in remote sensing, high performance computing, aquatic ecology and water quality analysis to advance the capability to monitor and understand spatial and temporal patterns in water quality. Our past development of remote sensing methods for monitoring water clarity, funded in part by LCCMR, has allowed routine monitoring of >10,000 Minnesota lakes. Expansion of these capabilities through the use of new satellite capabilities and automated image processing using supercomputing to include chlorophyll and organic color will be a major step in the development of more cost-effective and spatially comprehensive methods to monitor, understand and manage Minnesota's freshwater resources. Because water quality affects fisheries, drinking water, ecosystem integrity, and human enjoyment of water bodies, results from our project will be of immediate use to the Minnesota Pollution Control Agency, Department of Natural Resources, and local agencies in decision making and prioritization of resources. At the end of this project, we will be able to provide data through the new water quality portal (updated Lake Browser) to these and other relevant agencies with the basic tools needed to initiate their own use of remote sensing water quality data as operational tools for frequent, statewide assessments of surface water quality throughout the state.

This automated image processing system using supercomputing and basic geospatial database of remotely sensed water quality data maintained by the WRC will make a strong foundation for ongoing research and addition of more advanced capabilities as resources become available:

1. Advanced exploration of the water quality data (e.g. visualization and customized infomatics).
2. More water quality variables (e.g. non-algal turbidity, harmful algal blooms).
3. Integration of other data sources (e.g. land use, BMPs).
4. Targeted field monitoring of optically complex waters underrepresented in routine monitoring efforts.

VIII. REPORTING REQUIREMENTS:

- **The project is for two years, will begin on July/1/2018, and end on June/30/2020.**
- **Periodic project status update reports will be submitted January/30 and July/31 of each year.**
- **A final report and associated products will be submitted between June 30 and August 15, 2020.**

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

A. Budget Spreadsheet
B. Visual Component or Map
C. Parcel List Spreadsheet
D. Acquisition, Easements, and Restoration Requirements
E. Research Addendum

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2018 Budget Spreadsheet

Project Title: Providing Critical Water Quality Information for Lake Management
Legal Citation:
Project Manager: Jeff Peterson
Organization: University of Minnesota
College/Department/Division: CFANS / Water Resources Center
M.L. 2018 ENRTF Appropriation: $250,000
Project Length and Completion Date: 2 years, June 30, 2020
Date of Report: 2/27/2018

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	TOTAL BUDGET	AMOUNT SPENT	TOTAL BALANCE
BUDGET ITEM			
Personnel (Wages and Benefits)	$247,000	$0	$247,000
Jeff Peterson, PI, (75% Salary, 25% benefits) 1% per year, will coordinate project ($4,400)			
Leif Olmanson, Co-PI, (75% Salary, 25% benefits) 41% per year, will oversee technical aspects of project/RS coding/database/Lake Browser ($68,400)			
David Porter, Co-PI, (75% Salary, 25% benefits) 20% year1, 10% year 2, will oversee and conduct supercomputing and database aspects of the project ($44,500)			
Database Specialist, TBN,(75% Salary, 25% benefits) 17% per year, Build Spatial database ($21,700)			
Research Fellow, TBN , (75% Salary, 25% benefits) 80% per year, RS coding/database/Lake Browser ($108,000)			
Travel expenses in Minnesota			
Travel to meetings with collaborators and state agencies. Expenses will be charged in accordance with University of Minnesota travel reimbursement rates and guidelines	$1,000	$0	$1,000
Other			
Remote sensing and geospatial analysis laboratory fees	$2,000	$0	$2,000
COLUMN TOTAL	**$250,000**	**$0**	**$250,000**

Providing Critical Water Quality Information for Lake Management

Goals: This project develops an operational, near real-time **automated** system to process new **satellite** data for key **water quality** characteristics of Minnesota's 10,000+ lakes. It will provide easy-to-use, strategic information to **improve lake monitoring, management and fish habitat**.

Background: Water clarity of lakes and rivers is controlled by:

Algae

Suspended solids (turbidity)

Dissolved organic color

These key water quality characteristics have **different causes** and **distinct consequences** for aquatic habitat management and are measurable by satellite imagery.

Approach:

Recently launched satellites:
Landsat 8
Sentinel-2
Sentinel-3

EROS Data Center

Automated satellite imagery pipeline

UMN high performance computing systems

Normalize images

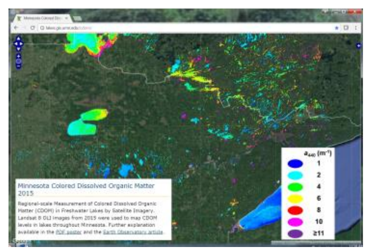
Remove land, clouds, shadows, haze...

Prepare images using new automated methods.

- Chlorophyll
- Water clarity
- Color

Apply water quality models from previous LCCMR-funded R&D

Maps, data, statistical summaries



Improved Lake Browser

Provide information to agencies, researchers, and citizens.

Applications:

Results of this project will improve **monitoring** of 10,000+ lakes to assist agency decision-making for **lake protection** vs. **restoration**, provide better data to assess **fish habitat**, evaluate **recreational suitability**, and help citizens evaluate and protect **property values**.