Environment and Natural Resources Trust Fund

M.L. 2024 Approved Work Plan

General Information

ID Number: 2024-037

Staff Lead: Tom Dietrich

Date this document submitted to LCCMR: June 5, 2024

Project Title: Hyperspectral Characterization of Toxic Harmful Algal Blooms

Project Budget: $399,000

Project Manager Information

Name: Ardeshir Ebtehaj

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Project Reporting

Date Work Plan Approved by LCCMR: June 20, 2024

Reporting Schedule: June 1 / December 1 of each year.

Project Completion: July 31, 2027

Final Report Due Date: September 14, 2027

Legal Information

Legal Citation: M.L. 2024, Chp. 83, Sec. 2, Subd. 04a

Appropriation Language: $399,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota, St. Anthony Falls Laboratory, to investigate the use of hyperspectral microscopic imaging to detect harmful algal bloom (HAB) species and toxicity levels in Minnesota lakes that will support the development of HAB early-warning remote sensing tools. This appropriation is subject to Minnesota Statutes, section 116P.10, and is available until June 30, 2028, by which time the project must be completed and final products delivered.

Appropriation End Date: June 30, 2028

Narrative

Project Summary: The project will investigate why, when, and where different species of harmful algal blooms release toxins into the water using hyperspectral microscopic imaging towards developing early warning remote sensing tools.

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Harmful algal blooms (HAB) are a matter of concern in Minnesota and will likely worsen in future climate scenarios as temperature, precipitation, air carbon dioxide, and thus nutrient runoff increase. Some HAB strains in Minnesota (i.e., Planktothrix agardhii, Raphidiopsis raciborskii, and Microcystis aeruginosa) can produce potent hepatotoxins and cause illness and death in exposed animals and humans. The toxin is generally maintained inside viable cells. By adding chemicals and clays, the cell-clay-bound algae can be removed by settling in the water column. However, under some environmental conditions, which are not yet well understood, the cell can rupture, and the intracellular toxin pool can be dissolved into the water, rendering the bloom more harmful and difficult to clean up. For several years, satellite and airborne remote sensing have been used to map the blooms for early warning systems. The traditional methods rely on the mapping of chlorophyll-a and cannot directly identify the bloom species and toxicity. The main reason is that previous studies have relied on multi-spectral large-scale satellite images (20-by-20 meters) that are limited to a few wavebands (e.g., Sentinel-2 has 13 wavebands) and cannot be accurately referenced against in situ measurements of bloom characteristics.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

Recently, there has been an increase in the availability of hyperspectral imaging instruments that can measure hundreds of narrow wavebands to produce a complete high-resolution optical spectrum of the blooms. We hypothesize that hyperspectral imaging under controlled laboratory conditions can reveal microscopic details that were previously invisible to large-scale satellite data with a few bands, opening a path to the development of novel early warning remote sensing tools for the determination of species, timing, extent, and toxicity levels of algal blooms. To test the hypothesis, the activities of the project are as follows:

- To collect hyperspectral microscopic images at a micrometer resolution of the three common species of toxic HABs in Minnesota under controlled conditions before and after the release of toxins.
- To collect bulk hyperspectral measurements of a mixture of blue-green and green algal species at a meter-scale resolution over the outdoor SAFL bioreactors to scale up the outcomes of the previous activity for remote sensing applications.
- To compile the collected data and apply the obtained knowledge to verify the extent to which current and upcoming satellite observations (e.g., Seintenel-2, LandsatNext) can be used to detect and estimate HABs species and toxicity levels in Minnesota.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

For the first time, the project will collect a unique hyperspectral microscopic dataset, under controlled laboratory conditions, that will advance our understanding of how different species of toxic HABs in Minnesota absorb or reflect light (i.e., spectral signatures) before and after the release of toxins. The outcomes will pave the way for developing remote sensing technologies for satellites, drones, and smart swimming robots that can identify different species of HABs and map the timing and extent of the toxins released into the water. The dataset will be shared with the public through GitHub to foster future research and developments.

Project Location

What is the best scale for describing where your work will take place?

Region(s): Metro, NW,

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

In the Future

Activities and Milestones

Activity 1: Hyperspectral Microscopy of HABs Species before and after Toxin Release

Activity Budget: $181,794

Activity Description:
To obtain relevant strains of the three cyanobacteria, we will sample Madison Lake, MN, where the presence of Microcystis is studied by the team previously. We will also obtain the three most problematic HAB strains from the Department of Fisheries and Allied Aquacultures in Alabama that maintain different species of cyanobacteria. The strains will be cultivated in the Eco-Lab at SAFL for a few weeks to reconstruct the growth cycle, cell rupture, and toxin release. We will build a new hyperspectral microscopy system by pairing the available Nikon E400 microscope at SAFL with a hyperspectral imaging component (e.g., surface optics SOC-710) that we will be purchased as a part of the project. The system will enable us to identify the location and concentration of different species in the culture and to characterize the effects of strain type and toxin release on the spectral properties of the HABs with an unprecedented resolution. To the best of our knowledge, such an experimental setup and data collection strategy have not yet been investigated and implemented in the world.

Activity Milestones:

Description	Approximate Completion Date
Culturing the HABs strains to create the growth cycle and toxin release in the lab	November 30, 2024
Microscopic Spectral data collection and analysis before and after toxin release.	March 31, 2025
Dissemination of the results through one publication.	August 31, 2025

Activity 2: Outdoor Spectroradiometery of the Mixture of Green Algae and HABs

Activity Budget: $107,564

Activity Description:
The three strains of HABs will be cultured using Mississippi water and a mixture of naturally growing green algae in the outdoor bio-reactors at SAFL to scale up the experiments for remote sensing applications and further validate the results of the indoor experiments in a more natural environmental setting. To that end, we will measure the bulk spectral properties of the mixed bloom, over a field of view of 30 cm to 2 meters, using a hyperspectral ASD FieldSpec 4 Hi-Res spectroradiometer that was acquired by a previously supported LCCMR project. By comparing these measurements with those obtained from Activity 1, we will quantify how spatial variability of the type and toxicity of HABs in the microscale will be translated into bulk light absorption properties of the bloom observed by drones or satellites. The measurements in both activities will enable us to develop modern mathematical tools to estimate fractional abundance and toxicity levels of the blooms from the coarse-resolution drone or satellite observations.

Activity Milestones:

Description	Approximate Completion Date
Culture a mixture of green algae and HABs using Mississippi water in SAFL's outdoor bioreactors	September 30, 2025
Collect and analyze data on spectral properties of the mixture of the algal community	December 31, 2025
Study the connections between the coarse-scale outdoor and the indoor microscopic data	March 31, 2026
Dissemination of the findings via one journal publication	September 30, 2026

Activity 3: Compile the Data and Develop Detection Tools in the Field

Activity Budget: $109,642

Activity Description:

Based on the data collected in activities 1 and 2, we will develop modern machine learning and artificial intelligence tools that can learn from the data and provide, for the first time, predictive skills for detecting the blooms' species, timing, extent, and toxicity levels. Recently, NASA posed a scientific challenge to the community, with a $30k prize, to use Sentinle-2 satellite imagery for detecting and classifying the severity and toxicity of cyanobacteria blooms in small, inland water bodies at https://www.drivendata.org/competitions/143/tick-tick-bloom/. In this competition, NASA released coincident satellite imageries and in situ observations over lakes in the Midwest United States. We aim to test and validate the results of the proposed research using that independent field dataset. Moreover, we will validate the results using Sentinel-2 satellite data over Madison Lake MN, and compare them with the in situ observations that we have collected using the SAFL's buoy for many years to study the characteristics of Microcystis HABs in that lake.

Activity Milestones:

Description	Approximate Completion Date
Establishing correlation between hyperspectral data and the levels of toxins released	September 30, 2026
Data compilation and development of machine learning detection tools	November 30, 2026
Examine and validate the AI predictive tools with the field data sets	February 28, 2027
Disseminate the results via 1 to 2 journal publications and workshops	June 30, 2027

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Miki Hondzo	University of Minnesota	Co-I	Yes
Judy Yang	University of Minnesota	Co-I	Yes
Leif Olmanson	University of Minnesota	Co-I	Yes
Dick Christopher	University of Minnesota	Senior Personnel to construct the required equipment for obtaining the required measurments of the spectral reflectance.	Yes

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
The research will produce new data sets and papers published in reputable journals in the field. As explained below, the data sets will be shared with the research community and the public.

Reflectance Data: We will collect reflectance images in the lab and a time series of bulk reflectance values over the OSL and Lake Madison or Nokomis. The lab measurements will consist of raster images of the hyperspectral reflectance values (400-1100 nm) of cyanobacteria reflectance during the growth and lysis processes. The outdoor measurements will consist time series of ASD (350-2500 nm) data with a few range of selected sizes of field of view ranging from 30 to 200 cm.

Physical variables: A range of physical variables such as air and water temperatures, PAR, Chl-a, and phycocyanin concentrations will be measured both in the lab and in the field. All the physical data along with reflectance measurements will be released to the public on GitHub (https://github.com/aebtehaj).

Data Type and Size: The data will be stored either in HDF5 or NetCDF along with the metadata. Currently, the file size of drone scans is not clear to us. However, we will split the data set and will provide data blocks of the size of no more than 10 GB. Simple codes for merging the data blocks will be provided to the potential users. The total file sizes in a single format will be less than 50 GB and can fit into GitHub.

Expected Software Types: The software tools will be a set of codes, encoding machine learning and explainable AI tools for detecting toxicity of algal blooms from their hyperspectral reflectance data. All software tools and algorithm theoretical basis documents (ATBD) will be shared with the community.

Publication Sharing: The project will hire one graduate research assistant. The results of the work under the supervision of the PI and Co-Is will lead to at least three publications in reputable journals of the field.

All presentations and publications associated with the research will acknowledge the ENTRF support by using the ENTRF logo or referring to the project funding identifier as instructed by the ENTRF acknowledgment guidelines. As explained above the spectral data sets will be published on GitHub for public access.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?

The four PIs have a wide range of experience in growing HABs and remote sensing. A research assistant will be hired to help the PIs. The project aims to build a unique hyperspectral microscope by purchasing a new camera that will provide the required measurements. The project will benefit from the existing facilities at SAFL that have been partly supported by LCCMR grants. We plan to continue this research by submitting future proposals to NOAA (https://www.noaa.gov/news-release/noaa-awards-189m-for-harmful-algal-bloom-research-monitoring), NASA Remote Sensing of Water Quality, and NSF environmental engineering program (https://beta.nsf.gov/funding/opportunities/environmental-engineering-1).

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Remote Sensing And Super-Resolution Imaging Of Microplastics	M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 08j	$309,000

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Ardeshir Ebtehaj		PI: Oversees the implementation of all objectives and activities of the project and provide expertise in data collection and analysis of the HABs reflectance data.			36.8%	0.21		$32,593
Miki Hondzo		Co-PI: Provides expertise in culturing and sampling of HABs before and after toxin release.			36.8%	0.15		$32,900
Judy Yang		Co-I: Provide expertise in culturing HABs in the lab and help the PI to connect the hyperspectral camera to the existing microscope in the SAFL EcoLab.			36.8%	0.15		$21,759
Leif Olmanson		Co-I: Provide expertise to connect the information content of the collected data in the laboratory to develop methodology for satellite applications.			36.8%	0.24		$27,223
Dick Christopher		Design and construction of equipment			36.8%	0.24		$26,742
Graduate Student		Research Assistant to conduct the project tasks under the supervision of the PIs.			24.1%	3		$163,544
							Sub Total	**$304,761**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	algal specimens, mounting of cameras, connections with the data logger systems, contains for culturing	Supporting the data collection experiments					$6,133
							Sub Total	**$6,133**
Capital Expenditures								
		Internal Scanning VNIR Hyperspectral Imaging System (400-1000nm)	To measure hyperspectral properies of different species of HABs in microscopic scale before and after the toxin release.	X				$77,106

							Sub Total	**$77,106**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
							Sub Total	**-**
Travel Outside Minnesota								
	Conference Registration Miles/ Meals/ Lodging	One travel is considered for the PhD student to present the research results in the annual meetings of the American Geophysical Union or other relevant workshops and conferences. A rough cost breakdown for each travel is: $430 ticket + 7*288+7*79 ~$3000	Presentation of the research results in annual conferences of the field.	X				$3,000
							Sub Total	**$3,000**
Printing and Publication								
	Publication	We envision at least 4 publications as a result of the proposed project and consider roughly $2000 for each publication cost.	Dissemination of the results to the scientific community					$8,000
							Sub Total	**$8,000**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$399,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Expenditures		Internal Scanning VNIR Hyperspectral Imaging System (400-1000nm)	The equipment is needed to quantify the impacts of toxin release on diffused special reflectance of HABs. **Additional Explanation :** The equipment will be used to image the spectral reflectance of different genera of HABs before and after toxin release.
Travel Outside Minnesota	Conference Registration Miles/Meals/Lodging	One travel is considered for the PhD student to present the research results in the annual meetings of the American Geophysical Union or other relevant workshops and conferences. A rough cost breakdown for each travel is: $430 ticket + 7*288+7*79 ~$3000	We need to present the outcome of the research to the scientific community and receive feedback and interact with the community to foster collaborations and further advances in the research.

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount
State				
In-Kind	The University of Minnesota does not charge the State of Minnesota its typical overhead rate of 55% of the total modified direct costs.	Supporting execution of the project at SAFL.	Secured	$97,870
			State Sub Total	**$97,870**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**$97,870**

Attachments

Required Attachments

Visual Component

File: da744029-100.pdf

Alternate Text for Visual Component

A visual representation of the activities are provided...

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
quote of the camera	50da7886-090.pdf
LOC	ddc2ff50-9d3.pdf
Accepted Revised Research Addendum	32f89ef1-9dc.pdf

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

Hi Mike,
Thanks for your patience with me.

I addressed comments from 07/20/2023 to 09/29/2023. I addressed all the comments concerning the budget (Items 1--2), dissemination (items 4--5), and project collaborator (item 6) as instructed. Once again, I highly appreciate your effort and provided feedback. I hope I could have addressed the comments properly. Please let me know if I need to do anything else.

Cheers, Ardeshir

Hi Mike,

Thanks for the feedback. I have made the following changes.

Comment on April 10, 2024

1- I edited milestone 2 under activity 3: “Examine and validate the AI predictive tools with the field data sets”
2- I added the following milestone: Establishing a correlation between hyperspectral data directly and the levels of toxins released (9/30/2026) to the third activity.
3- Task 8 of the addendum namely “Validation of the Results and predictive tools” already exists as milestone 2 in the third activity under the name of “Examine and validate the AI predictive tools with the field data sets” (2/28/2027).

Comment on May 24, 2024

Done.

Many thanks. I hope the new changes meet your expectations. Please let me know if I need to do anything else.

Regards, Ardeshir

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

Yes

Do you agree travel expenses must follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I agree to the UMN Policy.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

No

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing $10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care, treatment, education, training, instruction, or recreation to children")?

No