Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-037

Proposal Title: Hyperspectral Characterization of Toxic Harmful Algal Blooms

Project Manager Information

Name: Ardeshir Ebtehaj

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Project Basic Information

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.

Funds Requested: $399,000

Proposed Project Completion: July 31, 2027

LCCMR Funding Category: Water Resources (B)

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

Narrative

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.

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
Data compilation and development of machine learning detection tools	November 30, 2026
Examine and validate the 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	Senior Personel	Yes

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

Project Manager and Organization Qualifications

Project Manager Name: Ardeshir Ebtehaj

Job Title: Associate Professor at the UMN Twin Cities

Provide description of the project manager's qualifications to manage the proposed project.

Dr. Ebtehaj will be responsible for overall project coordination and supervision of the study, design of the experiments, and development of the analytical models to quantify spectral signatures of HABs before and after the release of toxins. He has been studying remote sensing of environment and water systems for 15 years. He has conducted peer-reviewed research in satellite remote sensing of precipitation, soil moisture, vegetation, snow as well as plastic pollution in freshwater ecosystems. He has been the PI for numerous NASA projects and one LCCMR project. He has published more than 45 peer-reviewed papers and co-authored a book chapter on remote sensing of the environment in the handbook of environmental engineering in 2019. Dr. Ebtehaj is an associate editor of the Journal of Hydrometeorology, an affiliate member of the University of Minnesota Institute on the Environment, and a member representative of the University of Minnesota in the University Centers for Atmospheric Research (UCAR). He is the recipient of an editor award from the American Meteorological Society and a recipient of NASA's Earth and Space Science Fellowship in 2014, and NASA's new investigator (Early Career) award in 2018 for his contribution to Earth's remote sensing sciences.

Drs. M. Hondzo, and J. Yang, are experts in the biological aspects of HABs growth and manage the Eco-Lab and bio-

reactors at SAFL. They have numerous projects on HABs' toxicity and treatment with LCCMR and other projects and have published dozens of papers in peer-reviewed journals of the field on the topic. Dr. Olmanson is a world expert in remote sensing of Cholorphyll and HABs and has published numerous publications on the topic. The hope is that the collaboration between the team would lead to groundbreaking results in remote sensing of HABs toxicity and the development of modern early warning systems in Minnesota.

Organization: U of MN - St. Anthony Falls Laboratory

Organization Description:
The University of Minnesota is one of the largest, most comprehensive, and most prestigious public universities in the United States (http://twin-cities.umn.edu/about-us). The laboratories and offices of the PI contain the necessary fixed and moveable equipment and facilities needed for the proposed studies. The PI will conduct the research in the Saint Anthony Falls Laboratory. The St. Anthony Falls Laboratory (SAFL) is an interdisciplinary hydraulic research lab and educational facility under the College of Science and Engineering at the University of Minnesota. There are engineers and scientists who collaborate across disciplines to solve water and pollution problems. The vision encompasses both science and practice, beginning with basic research and moving through application, decision-making, and management. Located on Hennepin Island in the Mississippi River in the heart of Minneapolis, SAFL serves as a resource for departments across the Twin Cities campus, the statewide University system, and the broader research community. We partner with local, state, and federal agencies; private consulting firms; businesses of many kinds; technical associations; and other educational institutions to expand knowledge and solve problems.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Ardeshir Ebtehaj		PI			36.8%	0.15		$23,593
Miki Hondzo		Co-PI			36.8%	0.15		$32,900
Judy Yang		Co-I			36.8%	0.15		$21,759
Leif Olmanson		Co-I			36.8%	0.24		$27,223
Dick Christopher		Design and construction of equipment			36.8%	0.24		$26,742
Graduate Student		Research Assistant			24.1%	3		$163,544
							Sub Total	**$295,761**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Equipment	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.					$77,106
	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	**$83,239**
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-

Travel In Minnesota								
							Sub Total	**-**
Travel Outside Minnesota								
	Miles/ Meals/ Lodging	Two travels per year are considered for the PhD student and Co-PIs 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: $2,000 = $500 (airfare) + 5 × $250 (hotel) + 5 × $49 (Per Diem).	Presentation of the research results in annual conferences of the field.	X				$12,000
							Sub Total	**$12,000**
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
Travel Outside Minnesota	Miles/Meals/Lodging	Two travels per year are considered for the PhD student and Co-PIs 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: $2,000 = $500 (airfare) + 5 × $250 (hotel) + 5 × $49 (Per Diem).	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...

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
quote of the camera	50da7886-090.pdf
LOC	ddc2ff50-9d3.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

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 design, construction, or renovation of a building, trail, campground, or other capital asset costing $10,000 or more?

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?

No