Final Abstract

Final Report Approved on December 15, 2025

M.L. 2022 Project Abstract

For the Period Ending June 30, 2025

Project Title: Mitigating Cyanobacterial Blooms and Toxins Using Clay-Algae Flocculation

Project Manager: Judy Yang

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Funding Source:

Fiscal Year:

Legal Citation: M.L. 2022, Chp. 94, Sec. 2, Subd. 04c

Appropriation Amount: $326,000

Amount Spent: $326,000

Amount Remaining: -

Sound bite of Project Outcomes and Results

We identified a synthetic clay, laponite, that removes harmful algal bloom (HAB) cells and toxins using far less material, and we tested it with both laboratory cultures and field samples. These results provide a scalable, low-impact solution to protect Minnesota's lakes from HABs.

Overall Project Outcome and Results

Harmful algal blooms (HABs) are a growing threat to Minnesota's lakes, affecting water quality, fish, wildlife, recreation, and public health. Our project addressed the need for safe, effective, and practical tools that can quickly remove HAB-forming algae from freshwater systems.

We first identified a biocompatible synthetic clay, called laponite, that removes HAB-forming algae at doses ten times lower than common natural clays. Tests with water collected from Minnesota lakes confirmed its high efficiency. This work was published in Harmful Algae in 2024 and earned a national student research award.

Second, we discovered that short bursts of mixing greatly improve how well clay and algae come together and settle.

Using a custom-built experimental tower, we found that brief pulses of turbulence can increase algae removal by up to threefold. This work was published in Environmental Fluid Mechanics in 2025 and provides critical guidance for on-water applications, such as using boat motion or natural wind mixing to enhance treatment.

Third, we designed and field-tested a clay spray device in Minnesota streams, lakes, and ponds. The device successfully dispersed clay into the water and demonstrated that this approach is feasible for real-world HAB control.

To expand environmentally safe options, we also tested materials already approved by the U.S. Environmental Protection Agency. We found that combining two natural materials, chitosan and bentonite, can remove HAB cells efficiently without additional regulatory approval.

Our results directly led to a new $2 million award from the U.S. Army Corps of Engineers to test these technologies in the Great Lakes (2025–2028), showing the broader impact and promise of this work.
Overall, this project delivers practical, scalable tools that can help resource managers reduce HABs, protect lake ecosystems, and improve water quality across Minnesota.

Project Results Use and Dissemination

Project results were shared through two peer-reviewed publications in Harmful Algae and Environmental Fluid Mechanics, conference presentations, and a science outreach video available on YouTube. Our graduate student received a national Best Student Oral Presentation Award. We also engaged more than two hundred K12 students through Eureka! and Discover STEM programs, introducing them to HAB challenges and demonstrating our experimental setup. Manuscripts and the outreach video link are included in the Attachments. These materials support continued use of our findings by the public and by resource managers working to protect Minnesota's waters.

Environment and Natural Resources Trust Fund

M.L. 2022 Approved Final Report

General Information

Date: December 19, 2025

ID Number: 2022-099

Staff Lead: Tom Dietrich

Project Title: Mitigating Cyanobacterial Blooms and Toxins Using Clay-Algae Flocculation

Project Budget: $326,000

Project Manager Information

Name: Judy Yang

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Project Reporting

Final Report Approved: December 15, 2025

Reporting Status: Project Completed

Date of Last Action: December 15, 2025

Project Completion: June 30, 2025

Legal Information

Legal Citation: M.L. 2022, Chp. 94, Sec. 2, Subd. 04c

Appropriation Language: $326,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for St. Anthony Falls Laboratory to develop and test a clay-algae flocculation method to mitigate cyanobacterial blooms that can contaminate drinking water and cause mass fish mortality. This appropriation is subject to Minnesota Statutes, section 116P.10.

Appropriation End Date: June 30, 2025

Narrative

Project Summary: We plan to develop a clay-algae flocculation method to mitigate cyanobacterial blooms, which produce toxins that contaminate drinking water and cause mass mortalities in fishes and other animals in Minnesota.

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

Cyanobacterial blooms, widespread in Minnesota's lakes and rivers, produce toxins that contaminate drinking water and cause mass mortalities in fishes and other animals. Mitigating cyanobacterial blooms is critical to ensuring safe drinking water and reducing fishery and tourism losses, which are estimated to cost hundreds of millions of dollars per year in the Great Lakes. One of the most promising strategies to mitigate cyanobacterial blooms is rapid sedimentation of cyanobacteria through flocculation with clay, a natural material present in soils. When clay is sprayed to the contaminated water, it causes cyanobacterial cells to flocculate or aggregate and sink to the bottom. Once the cells are buried in the sediment, the majority of the toxins are removed from the water, and most of the cells die due to lack of oxygen and light. The clay-algae flocculation strategy has successfully controlled cyanobacterial blooms in Eastern Asian Countries for over 30 years. A modified clay was recently proved to be effective in removing cyanobacteria and toxins in Florida. However, this strategy has not been adopted in the state of Minnesota. The development of a clay-algae flocculation strategy is a promising way to mitigate cyanobacterial blooms in Minnesota's waters.

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.

The overarching goal of the proposed study is to develop a clay-algae flocculation strategy to mitigate cyanobacterial blooms in Minnesota's waters. While clay-cell flocculation strategies have been successfully implemented in East Asia and helped some Korean regions reduce annual fisheries losses by about 99%, we cannot directly apply their methods in Minnesota's lakes because the cyanobacterial species, water chemistry, and flow conditions are different. The objectives of this study are: (1) determine the optimum clay type and clay modifying chemicals that cause clay and cells to aggregate most effectively through microfluidic experiments, (2) determine the optimum dose of the selected clay that remove the cyanobacteria and toxins mostly efficiently, by conducting clay-cell flocculation experiments in a plankton tower that simulates Minnesota lake's environmental conditions, (3) design an effective clay application procedure based on clay-cell flocculation experiments in two representative ponds in Minnesota. The proposed study will guide on the dose of clay to apply and the application procedure to maximize cyanobacteria and toxin removal rate based on each lake's unique water chemistry, size, depth, and wind conditions. The results can also be used to improve designs of constructed ponds, including water depth and sediment texture, to reduce cyanobacterial blooms' occurrence.

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?

The results of this study include (1) selection of a natural or design of a modified clay that can most effectively remove harmful cyanobacterial cells and toxins; the modified clay can potentially result in a patent; (2) determination of the optimum dose of clay that can most effectively remove harmful cyanobacterial cells and toxins in Minnesota's water; (3) design of structures to mix and spray clay and clay application procedures which will enable future successful implementation of the clay-cell flocculation method in the field; the clay mixing and spraying structures will likely result in a second patent.

Project Location

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

Statewide

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

Statewide

When will the work impact occur?

During the Project and In the Future

Activities and Milestones

Activity 1: Microfluidic experiments to select optimum clay type, modifying chemicals, and clay dose

Activity Budget: $118,000

Activity Description:

We will determine the optimum clay type, modifying chemicals, and clay dose or concentration by imaging the formation rate of clay-cell aggregates in a microfluidic device using a confocal laser scanning microscope (CLSM). The microfluidic device consists of a micron-size channel and two inlets: one for injecting Microcystis culture solution and one for injecting clay suspension. The formation of the clay-cell aggregates will be visualized over time using a Nikon C2+ CLSM which has sub-micron spatial resolution. We will conduct experiments under the same condition using various types of clays, including kaolinite, bentonite, phosphatic clay, etc., as well as a range of modifying chemicals. By comparing the size of clay-cell aggregates generated using different clays and modifying chemicals, we will identify the optimum clay type and modifying chemical that can mostly effectively cause clay and cells to flocculate. At least four common modifying chemicals will be evaluated. In addition, we will repeat the experiments using six different clay concentrations to evaluate whether the results change with varying clay concentration. Each experiment will be repeated for at least three times to ensure the accuracy of our results.

Activity Milestones:

Description	Approximate Completion Date
Conduct microfluidic experiments and data analysis and select optimum clay type and modifying chemicals	June 30, 2023
Dissemination findings of Activity 1 via 1 open access journal publications	December 31, 2023

Activity 2: Plankton tower experiments to verify the optimum dose of clay and evaluate the efficiency of clay-algae flocculation method

Activity Budget: $108,000

Activity Description:

We will evaluate cell and toxin removal efficiency of the clay-algae flocculation method by conducting clay-cell flocculation experiments in a plankton tower that replicates Minnesota lake's chemical and hydrodynamic conditions. We will fill the plankton tower with water that represents the range of ionic strength, pH, and hardness in Minnesota lakes' water and use an oscillating grid to generate turbulence with a range of turbulent intensity typical in Minnesota's lakes. Afterwards, we will spray clay suspension into the plankton tower under systematically controlled conditions, including varying cell density, water salinity, pH, hardness, and turbulent kinetic energy. Then, we will use imaging and sampling-based methods to quantify the cell and toxin removal rates. We will repeat the experiments in a range of environmental conditions, including 3 turbulent intensities, 3 temperature conditions, 3 pH conditions, and 3 different cell densities. We will use the results to develop a semi-empirical formula for the optimum clay dose that leads to the maximum cell and toxin removal rate as a function of cell density, salinity, pH, hardness, and turbulent kinetic energy. The formula will lay a theoretical foundation for future application of the clay-cell flocculation methods in lakes with different chemistry and hydrodynamic conditions.

Activity Milestones:

Description	Approximate Completion Date
Repair and testing of the plankton tower and design of clay-spraying structures	December 31, 2022
Clay-cell flocculation experiments in a plankton tower and data analysis	September 30, 2023

Develop a formula to calculate optimum clay dose based on cell density, salinity, pH, hardness, and turbulent kinetic energy	June 30, 2024
Dissemination of Activity 2 findings via at least 1 open access journal publications	September 30, 2024

Activity 3: Field test in ponds to determine the optimum clay application procedure

Activity Budget: $100,000

Activity Description:

We will determine the optimum procedure to apply the clay-cell flocculation method in the field by conducting a clay-cell flocculation method in two ponds with different cell densities, water chemistry, and turbulent conditions in Minnesota. We will first calculate the optimum dose of clay using the empirical equation we developed based on the cell density, water salinity, pH, hardness, and turbulent conditions of each pond. Then, we will apply clay to a small region of the Microcystis-contaminated ponds and monitor the cell and toxin removal efficiency. We will test different clay spraying and mixing procedures and determine the optimum procedure that result in maximum cell and toxin removal efficiencies.

Activity Milestones:

Description	Approximate Completion Date
Field test and data analysis	December 31, 2023
Revisit the field sites and assess the results	December 31, 2024
Develop a guideline for future implementation of clay-cell flocculation methods in the field	April 30, 2025
Dissemination of Activity 2 findings via at least 1 open access journal publication	June 30, 2025
Dissemination of our results to local lake agencies and seeking their feedback	June 30, 2025

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Miki Hondzo	University of Minnesota	Co-Project Manager. Dr. Hondzo, a professor in the Department of Civil, Environmental, and Geo-Engineering, will guide the field experiments and be responsible for the development and guidance of the drone-based cyanobacteria and toxin detection technology.	Yes
Shahram Missaghi	Minneapolis Public Works - Surface Water & Sewers Division	Dr. Missaghi, Water Resources Regulatory Coordinator, will facilitate the field investigation and the outreach project.	No

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 results of this study will be published in reputable journals of the field and will be presented not only in national conferences but also local public seminars in Minnesota to increase awareness about harmful algal blooms in Minnesota. In particular, we will arrange annual public seminars at SAFL to inform the citizens of Minnesota about the danger of harmful algal blooms in Minnesota and update them about the research and actions we are taking at SAFL to understand and mitigate this important environmental problem. Furthermore, we will design a mini enclosed clay-algae flocculation device and bring it to the Minnesota State Fair to demonstrate the effectiveness of clay in removing cyanobacterial blooms and toxins. We will also design a calculator to provide guidance on the dose of clay and procedure to maximize cyanobacteria and toxin removal based on each lake's unique water chemistry, size, depth, and wind conditions. Lake associations can use the protocol and the calculator to calculate the optimum dose of selected clay and follow the steps in our document to successfully remove cyanobacteria and toxins in their specific sites. We are hopeful that our results will help mitigate cyanobacterial blooms in Minnesota's waters, which will likely help reduce fishery loss by millions of dollars per year and help improve the water quality and water-related tourism industry in the state. Finally, we will acknowledge the Environment and Natural Resources Trust Fund through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications and outreach.

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 results of this study include a protocol to apply the clay flocculation method to remove cyanobacteria and toxins in Minnesota's lakes. Lake associations can use the cyanobacteria-mitigation calculator to calculate the optimum dose of clay-lime mixture and follow the steps in our report to successfully remove cyanobacteria and toxins in their specific sites. We are hopeful that our results will help mitigate cyanobacterial blooms in Minnesota's waters, which will likely help reduce fishery loss by millions of dollars per year and help improve the water quality and water-related tourism industry in the state.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount	$ Amount Spent	$ Amount Remaining
Personnel										
Judy Yang (Project Manager)		Manage the whole project			27%	0.15		$39,531	-	-
Miki Hondzo (Co-project manager)		Manage field work			27%	0.06		$14,615	-	-
One graduate student researcher		Perform laboratory experiments and analyze data			45%	0.9		$48,200	-	-
SAFL Engineers		Fabrication of clay-spray structures			24%	0.1		$19,815	-	-
A postdoc scholar		Cultivate algae, conduct clay-flocculation experiments, and design field work			27%	2.1		$164,735	-	-
							Sub Total	**$286,896**	**$286,896**	**-**
Contracts and Services										
							Sub Total	**-**	**-**	**-**
Equipment, Tools, and Supplies										
	Tools and Supplies	(1) Cyanobacterial strains, Solutions (BG-11), culture flasks, pipettes, petri dishes, cell counting chip (deep haemocytometer); (2) Clay (bentonite and kaolinite), coagulants (to modify clay) and lime; (3) Mechanical components for clay-spray structures	To grow bacteria, modify clay, make the mechanical structures to spray clay					$38,670	$38,670	-
							Sub Total	**$38,670**	**$38,670**	**-**
Capital Expenditures										

							Sub Total	**-**	**-**	**-**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**
Travel In Minnesota										
	Miles/ Meals/ Lodging	Meals for field test; the cost is small because St. Anthony Falls Laboratory covered the gas and the vehicle charges	The field trips are needed to conduct in-situ clay-algae flocculation experiments in two ponds and to assess the effect of the project in the following year.					$21	$21	-
	Conference Registration Miles/ Meals/ Lodging	Registration fee for the Minnesota Teachers' Association Conference	Disseminate the results to Minnesota's teachers	X				$225	$225	-
							Sub Total	**$246**	**$246**	**-**
Travel Outside Minnesota										
	Conference Registration Miles/ Meals/ Lodging	Attend American Geophysical Union (AGU) fall conference (for the PI and the graduate student)	Disseminate the results to the academic society	X				$188	$188	-
							Sub Total	**$188**	**$188**	**-**
Printing and Publication										
	Publication	Page charges for publication	Our goal is to publish our results in leading-edge journals, such as Nature Communications which charges “open access” fee; “open access” allows our results to be available to everyone without charges.					-	-	-

							Sub Total	**-**	**-**	**-**
Other Expenses										
							Sub Total	**-**	**-**	**-**
							Grand Total	**$326,000**	**$326,000**	**-**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Travel Outside Minnesota	Conference Registration Miles/Meals/Lodging	Attend American Geophysical Union (AGU) fall conference (for the PI and the graduate student)	AGU Fall conference is the biggest geophysical conference in the U.S. Attending this conference will help us disseminate our results to the science community and receive their feedback to improve the design our project.
Travel In Minnesota	Conference Registration Miles/Meals/Lodging	Registration fee for the Minnesota Teachers' Association Conference	Attending the conference helped us disseminate the results of our projects to K12 students. There are several K12 teachers express interests to use the outreach projects we designed in their classrooms.

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount	$ Amount Spent	$ Amount Remaining
State						
In-Kind	Minneapolis Park and Recreation Board	Support to sample water from Minnesota's lakes	Secured	$6,000	$6,000	-
			State Sub Total	**$6,000**	**$6,000**	**-**
Non-State						
In-Kind	Unrecovered F&A	Support of SAFL facilities where research will be conducted.	Secured	$173,375	$173,000	$375
			Non State Sub Total	**$173,375**	**$173,000**	**$375**
			Funds Total	**$179,375**	**$179,000**	**$375**

Attachments

Required Attachments

Visual Component

File: efff3383-089.pdf

Alternate Text for Visual Component

Cyanobacterial blooms, which are widespread in Minnesota's waters, produce toxins that contaminate drinking water and cause mass mortalities in fishes and other animals. We plan to develop a clay-algae flocculation method to remove cyanobacterial blooms and toxins in Minnesota's water....

Supplemental Attachments

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

Title	File
Support Letter	54d6894e-182.pdf
Background check form	73e293fe-f47.pdf
UMN official cover letter	3d0b0b06-8fe.pdf
ResearchAddendum_Yang2022-099	b4386609-832.pdf
Graduate student Yuan's thesis proposal	06ad600d-22c.pdf
Journal publication - 2024	1161eddc-831.pdf
A $2 Million U.S. Army Corps of Engineers Award Secured, Year 1 Contract in Place (Thanks to LCCMR results)	51441cd6-6dd.pdf
Image of our field trial	faecc943-07e.pdf
Presentation at AGU conference in 2023	d353147f-d7d.pdf
Presentation in 12th U.S. Symposium on Harmful Algae	c019aa3a-90f.pdf
Clay-based HAB mitigation: the role turbulence in aggregate formation and settling	49b07d73-c4c.pdf

Media Links

Title	Link
Combatting Harmful Algal Blooms at the St. Anthony Falls Laboratory (SAFL)	https://www.youtube.com/watch?v=QjZ6I8N9OuI

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

The major change is the budget: (1) the request for two summer undergraduate students has been reduced to one, (2) the budget for co-investigator Miki Hondzo has been reduced by 30% and the budget for a research staff has been reduced by 30%

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?

N/A

Do you understand that travel expenses are only approved if they 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 understand the UMN Policy on travel applies.

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

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A

Work Plan Amendments

Amendment ID	Request Type	Changes made on the following pages	Explanation & justification for Amendment Request (word limit 75)	Date Submitted	Approved	Date of LCCMR Action
1	Amendment Request	• Budget - Professional / Technical Contracts • Budget - Capital, Equipment, Tools, and Supplies • Budget - Personnel • Budget - Non-ENRTF Funds Contributed	I am requesting budget change to reflect the fact that I hired a postdoc to do the work that was originally planned for an undergraduate and a technician. In addition, I modified the cost of Tools and Supplies to reflect the fact that we started to collaborate with City of Minneapolis to collect water samples so some of the supply costs were allocated to the postdoc salary. The total budget is the same. Thank you.	October 4, 2022	Yes	October 5, 2022
2	Amendment Request	• Budget - Travel and Conferences	I am requesting changes to the travel and conference budget, because we identified new conferences to disseminate our work. We think that it is important to share our work to Minnesota's teachers to teach future Minnesota's leaders the importance of Harmful Algal blooms related research in Minnesota, so we presented our work in the Minnesota Science Teacher Association Conference.	March 16, 2023	Yes	March 17, 2023
3	Amendment Request	• Other • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Budget - Printing and Publication • Attachments	I request a budget reallocation from domestic travel, publication, and conference funds to supplies. This is necessary as we need additional funds for fieldwork supplies. Our research center (Saint Anthony Falls Laboratory) covered gas expenses, and my student received an additional travel grant to attend AGU, leaving only $159 in costs. The remaining budget was reallocated to supplies. Additionally, our university's agreements with publishers eliminate the need for many publication fees.	October 1, 2024	Yes	October 2, 2024

4	Amendment Request	• Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Attachments	Total expenditures were within the $326,000 budget, with reallocations to meet project needs. A postdoctoral researcher contributed additional effort to maintain research progress while the graduate student fulfilled teaching assistant duties, resulting in higher postdoc salary/fringe and lower graduate salary costs. Lab supply expenses exceeded budget due to increased experimental work, offset by reduced travel, equipment, and operating expenses. These adjustments ensured resources were directed toward priority activities without exceeding the budget.	September 29, 2025	Yes	October 7, 2025

Status Update Reporting

Final Status Update August 14, 2025

Date Submitted: September 29, 2025

Date Approved: October 7, 2025

Overall Update
We successfully concluded the project with substantial progress toward our stated outcomes.

First, we identified a biocompatible synthetic clay, laponite, that removed harmful algal bloom (HAB)-forming cells at concentrations ten times lower than other clays, based on tests with natural lake samples from Minnesota. This work was published in Harmful Algae (Li et al., 2024) and presented by graduate student Yuan Li, who received an award.

Second, we demonstrated that impulse mixing enhanced clay–algae flocculation efficiency. Using a custom-designed plankton tower, we found that short bursts of turbulence increased algae removal efficiency by up to threefold. We have submitted a manuscript to the journal Environmental Fluid Mechanics, received major revision, and submitted the revision.

Third, we designed and tested a clay spray device in Minnesota streams, lakes, and ponds, confirming feasibility for field application. Our results have led to a $2.04 million award from the U.S. Army Corps of Engineers to demonstrate the effectiveness of clay technology in the Great Lakes.

In addition, we conducted research on EPA-approved materials for HAB remediation and discovered that combining two EPA-approved natural materials, chitosan and bentonite, can efficiently remove HABs. We have prepared a manuscript for this discovery.

Activity 1
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2
We demonstrated that turbulent mixing enhances clay–algae flocculation efficiency. Using a custom-designed plankton tower with an oscillating grid and in-situ imaging, we examined turbulence intensities ($\varepsilon = 8\times10^{-9}$ to 9×10^{-5} m^2/s^3) and their effects on algal cell removal, aggregate properties, and settling velocity.

Our results show that short bursts of turbulence can increase harmful algal cell removal efficiency by up to threefold. Higher turbulence produces denser aggregates with faster settling, while residual mixing sustains aggregation for up to 60 minutes after turbulence ceases. These findings demonstrate the importance of controlled turbulence in optimizing clay-based HAB mitigation and provide practical insights for field applications, such as leveraging boat-generated hydraulic shear or natural wind-driven mixing.

We have submitted the manuscript describing these results to the journal Environmental Fluid Mechanics. Our manuscript was recommended for major revision, and the revised version has been submitted. The manuscript is attached for reference.
(This activity marked as complete as of this status update)

Activity 3
We have designed and tested a clay spray device in two outdoor lakes at St. Anthony Falls Laboratory (SAFL) and East

Twin Pond, demonstrating the feasibility of our approach for freshwater harmful algal bloom (HAB) management. Photos of the field trials and device design are attached.

In parallel, we consulted with the EPA regarding the potential use of our synthetic clay in natural lakes. The EPA indicated a special approval process is required. To explore alternatives, we tested EPA-approved materials and found that combining chitosan and bentonite efficiently removes HABs. A manuscript detailing these results is attached.

To disseminate our findings to local stakeholders, we presented a poster at the SAFL Research Showcase mini-symposium on June 13, 2025, led by the City of Minneapolis (MPLS) and in collaboration with MPRB and SAFL, highlighting five years of partnership.

Our work has led to a $2.04M award from the U.S. Army Corps of Engineers to demonstrate clay technology in the Great Lakes, led by PI Miki Hondzo and Co-PI Judy Yang (Dec 2025–Nov 2028). The Year 1 contract letter is attached.
(This activity marked as complete as of this status update)

Dissemination
We have published our results in Harmful Algae (Y. Li, M. Hondzo, and J. Yang, 2024, https://doi.org/10.1016/j.hal.2024.102667). Two additional manuscripts are in progress: one recommended for publication pending major revision, and another to be submitted within a month (both attached).

Our work was presented at both the American Geophysical Union (AGU) Fall Meeting and the 12th U.S. Symposium on Harmful Algae (presentations attached). At the symposium, graduate student Yuan Li received the Best Oral Presentation by a Student Award. I covered nearly all conference costs using my startup funds; ENRTF support was only used to pay meals and local transportation for Yuan to attend AGU.

We also disseminated our findings locally by presenting a poster at the SAFL Research Showcase on June 13, 2025, a mini-symposium led by the City of Minneapolis (MPLS) in collaboration with the Minneapolis Park and Recreation Board (MPRB) and SAFL.

Additional outreach included a short YouTube science video (https://www.youtube.com/watch?v=QjZ6I8N9OuI) and engagement with over 100 K–12 students through the Eureka! summer camp and Discover STEM program, where we introduced harmful algal bloom issues and demonstrated our experimental setup.

Status Update Reporting

Status Update March 1, 2025

Date Submitted: March 6, 2025

Date Approved: March 18, 2025

Overall Update

We have made significant progress toward our project outcomes.

1. We discovered a biocompatible synthetic clay, laponite, that effectively removes harmful algal bloom (HAB)-forming cells. Our findings show that laponite removes algae at a concentration 10 times lower than other clays, based on tests with natural lake samples from Minnesota. This work was published in Harmful Algae (Li et al., 2024) and presented by graduate student Yuan Li, who received an award.
2. We demonstrated that impulse mixing enhances clay-algae flocculation efficiency. Using a custom-designed plankton tower, we found that short bursts of turbulence can improve algae removal efficiency up to threefold. A manuscript detailing this work is finalized and will be submitted soon.
3. We designed and tested a clay spray device in Minnesota stream lakes and ponds, confirming its feasibility for field applications.
4. Our findings contributed to securing a $2 million grant from the U.S. Army Corps of Engineers to demonstrate these methods in the Great Lakes (2025–2028, PI: Miki Hondzo, Co-PI: Judy Yang).

Activity 1

This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2

Activity 2 is nearly complete. Since the last update, we have demonstrated how impulse mixing enhances the efficiency of clay-algae flocculation. Using a custom-designed plankton tower with an oscillating grid and in-situ imaging, we examined turbulence intensities ($\varepsilon = 8\times10^{-9}$ to 9×10^{-5} m^2/s^3) and their effects on algal cell removal, settling velocity, and aggregate properties.

Our findings show that short bursts of turbulence can increase harmful algal cell removal efficiency by up to threefold. Higher turbulence produces denser aggregates with faster settling, while residual mixing sustains aggregation for up to 60 minutes post-turbulence cessation. These results highlight the role of controlled turbulence in optimizing clay-based HAB mitigation and offer practical insights for field applications, such as leveraging boat-generated hydraulic shear or natural wind-driven mixing.

We have completed a manuscript detailing these findings and plan to submit it within the next month. The manuscript is attached for reference. The final step is submission, followed by revisions upon receiving reviewer feedback.

Activity 3

We have designed and tested a clay spray device in two outdoor stream lakes at the Saint Anthony Falls Laboratory and East Twin Pond, a site about three miles south of downtown Minneapolis. These field trials demonstrated the feasibility of our approach for freshwater harmful algal bloom (HAB) management. Photos of our field trials and device design are attached.

Our results have led to a $2.04 million award from the U.S. Army Corps of Engineers to demonstrate the effectiveness of clay technology in the Great Lakes. This project, led by PI Miki Hondzo and Co-PI Judy Yang, will run from December 2025 to November 2028. The contract letter for Year 1 is attached.

Dissemination

1. We have published our results in Harmful Algae: Y. Li, M. Hondzo, and J. Yang, "A synthetic clay removes Microcystis aeruginosa efficiently," Harmful Algae, 2024. https://doi.org/10.1016/j.hal.2024.102667

2. Graduate student Yuan Li presented our work at the 12th U.S. Symposium on Harmful Algae, where he received the Best Oral Presentation by a Student Award.

3. We also engaged in outreach activities, reaching over 60 K-12 students through the Eureka! summer camp and Discover STEM program. Eureka! is a five-year STEM program for girls in the Twin Cities, many of whom will be first-generation college students. We introduced them to harmful algal bloom issues and demonstrated our experimental setup. Discover STEM is a week-long on-campus program for 11th and 12th graders, where we also shared our research.

Status Update Reporting

Status Update September 1, 2024

Date Submitted: October 1, 2024

Date Approved: October 2, 2024

Overall Update

First, we have discovered a transparent and biocompatible clay, laponite, that can effectively remove harmful algal blooms (HABs)-forming cells. We found that this synthetic clay can remove harmful algal cells at a concentration 10 times lower than that required for other clays. We tested the results using natural samples from a Minnesota's lake. This result was recently published in the journal Harmful Algae.

- Y. Li, M.Hondzo, and J. Yang, "A synthetic clay removes Microcystis Aeruginosa efficiently," Harmful Algae, 2024. (https://doi.org/10.1016/j.hal.2024.102667)

Second, we have set up experiments in a plankton tower to study how turbulence impact clay-algae flocculation. We discovered an optimum shear rate, or mixing condition, that optimizes the clay-algae flocculation efficiency. We are currently preparing a manuscript and plan to submit it to an academic journal in the next two to three months.
Third, we have identified two lakes for conducting field research in collaboration with City of Minneapolis and Minneapolis Park and Recreation Board. We also shared our plans with Environmental Protection Agency. We have designed mechanical systems to mix and spray clay and are currently testing them in two ponds in Minneapolis.

Activity 1

We have found the optimum clay, laponite, and dosage to remove harmful agal cells. Since our last report, we have written a manuscript about our results. We have submitted this manuscript to the journal Harmful Algae, which is currently under review. In our manuscript, we demonstrated that the synthetic clay, laponite, has the optimum efficiency in removing harmful Microcystis aeruginosa (a harmful algal bloom forming cyanobacterium) cells. The optimum concentration required to remove the cells is 0.1 g/L, much smaller than the concentration of over 1 g/L required for other natural clays, such as bentonite. Laponite is a synthetic clay weathered in the lab from natural rocks, it has similar structures as natural bentonite and has been used in cosmetic and biotech industries. The major different between laponite and bentonite is its smaller sizes, which makes it more efficient in removing harmful algal cells.
(This activity marked as complete as of this status update)

Activity 2

Since our last report, we have conducted series of experiments in a plankton tower. We have identified the optimum mixing condition, or turbulent kinetic energy, that will make the clay-algae flocculation occurs most efficiently. We are currently working on developing a theory to explain our results and are expected to have a manuscript draft by the next three months.

Activity 3

Since our last report, we have identified two ponds to conduct the field work with help from the City of Minneapolis and Minneapolis Park and Recreation Board. We also communicated with Environmental Protection Agency to make sure our plan meets the federal requirements. We have designed mechanical systems to mix and spray clay and are currently testing them in two ponds in Minneapolis. We plan to have the field results ready in the next two to three months.

Dissemination

Since our last report, we have conducted another outreach event to over 50 under-represented K12 girls through the Eureka! summer camp. Eureka! is a five-year summer and school year program for girls focused on science, technology, engineering, and mathematics. Eureka! builds sisterhood with girls from all over the Twin Cities, exploring their career interests and dreams while supporting them through high school graduation and preparing them for the next step in

their post-secondary education. Many of these girls will be the first-generation college students. We demonstrated the harmful algal blooms issues to them and showed them our experimental setup.

Status Update Reporting

Status Update March 1, 2024

Date Submitted: March 1, 2024

Date Approved: March 8, 2024

Overall Update

We have identified a transparent and biocompatible clay, laponite, that can effectively remove harmful algal blooms (HABS)-forming cells. We discovered that this clay can remove 80% of harmful algal cells at 0.1 g/L concentration. In comparison, the required dosage of other natural clays such as bentonite is about 2 g/L. We also found that laponite can effectively remove harmful algal cells sampled from a lake in Minnesota. We have submitted a manuscript to the journal Harmful Algae, which is currently under review. In addition, we have repaired a plankton tower that can generate different turbulent intensity to mimic a lake. We have measured the turbulent kinetic energy and found that low turbulent intensity facilitates algae-clay aggregation, while high turbulent kinetic breaks up aggregate. We are currently conduct systematic experiments under a range of turbulent levels to identify the relationship between clay-algae flocculation efficiency and shear rate. Furthermore, we have started planning the field work with City of Minneapolis and Minneapolis Park and Recreation Board to plan the field work. We are in the process of getting a permit to test the method we developed in a couple of ponds in Minnesota.

Activity 1

We have found the optimum clay, laponite, and dosage to remove harmful agal cells. Since our last report, we have written a manuscript about our results. We have submitted this manuscript to the journal Harmful Algae, which is currently under review. In our manuscript, we demonstrated that the synthetic clay, laponite, has the optimum efficiency in removing harmful Microcystis aeruginosa (a harmful algal bloom forming cyanobacterium) cells. The optimum concentration required to remove the cells is 0.1 g/L, much smaller than the concentration of over 1 g/L required for other natural clays, such as bentonite. Laponite is a synthetic clay weathered in the lab from natural rocks, it has similar structures as natural bentonite and has been used in cosmetic and biotech industries. The major different between laponite and bentonite is its smaller sizes, which makes it more efficient in removing harmful algal cells.

Activity 2

Since our last report, we have repaired a plankton tower that can generate different turbulent intensity to mimic a lake. We have measured the turbulent kinetic energy and found that low turbulent intensity facilitates algae-clay aggregation, while high turbulent kinetic breaks up aggregate. We are currently conduct systematic experiments under a range of turbulent levels to identify the relationship between clay-algae flocculation efficiency and shear rate.

Activity 3

Since our last report, we have started planning the field work with City of Minneapolis and Minneapolis Park and Recreation Board to plan the field work. We are in the process of getting a permit to test the method we developed in a couple of ponds in Minnesota. In the last report, we have demostrated that laponite can effectively remove Harmful Algal Blooms-forming cells from the water sampled from lake Cedar, Powderhorn and Nokomis in Minnesota last summer.

Dissemination

Since our last report, we have conducted outreach event to over 50 under-represented K12 girls through the Eureka! summer camp. Eureka! is a five-year summer and school year program for girls focused on science, technology, engineering, and mathematics. Eureka! builds sisterhood with girls from all over the Twin Cities, exploring their career interests and dreams while supporting them through high school graduation and preparing them for the next step in

their post-secondary education. Many of these girls will be the first-generation college students. We demonstrated the harmful algal blooms issues to them and showed them our experimental setup.

Status Update Reporting

Status Update September 1, 2023

Date Submitted: October 13, 2023

Date Approved: October 17, 2023

Overall Update

We have identified an environmentally-friendly synthetic clay, laponite, that can effectively remove Harmful algal cells. From laboratory experiments, we found that 0.1g/L laponite can remove Microcystis aeruginosa (a harmful algal bloom forming cyanobacterium) cells at over 80% efficiency, while other clays such as bentonite needs over 1g/L to remove the cells with a similar efficiency. We also collected Harmful Algal Blooms-contaminated water from lake Cedar, Powderhorn and Nokomis in Minnesota. We tested the cell removal efficiency using the collected water and found that laponite clay has the optimum efficiency in removal Harmful Algal Cells. We further found that turbulent mixing can significantly improve the cell removal efficiency, so our next step is to develop a method to mix the clay and cells to further improve its efficiency, design a clay mixing structure, test the method in the field.

Activity 1

We have discovered that the synthetic clay, laponite, has the optimum efficiency in removing harmful Microcystis aeruginosa (a harmful algal bloom forming cyanobacterium) cells. The optimum concentration required to remove the cells is 0.1 g/L, much smaller than the concentration of over 1 g/L required for other natural clays, such as bentonite. Laponite is a synthetic clay weathered in the lab from natural rocks, it has similar structures as natural bentonite and has been used in cosmetic and biotech industries. The major different between laponite and bentonite is its smaller sizes, which makes it more efficient in removing harmful algal cells. Graduate student Yuan Li has summarized these results in her PhD theses proposal (attached as "Graduate student Yuan's thesis proposal"). We are currently writing a journal article and plan to submit it in the next two months.

Activity 2

We have designed an algal flocculation visualization system, consisting of a 1-meter-long tube, a vertical moving system, a laser, and a camera. We are currently using this system to quantify the setting velocity of clay-algae flocculates in still water.

We plan to start using this system to study the impacts of turbulence and mixing on clay-algae flocculation after we finished our current measurements in still water, likely in April.

Activity 3

We also collected Harmful Algal Blooms-contaminated water from lake Cedar, Powderhorn and Nokomis in Minnesota. We tested the cell removal efficiency using the collected water and found that laponite clay has the optimum efficiency in removal Harmful Algal Cells. We plan to directly bring clay to the field in the summer of 2024.

Dissemination

1. We have made a science video about our project and shared it on social media: https://www.youtube.com/watch?v=QjZ6I8N9OuI

We acknowledged Minnesota Environmental and Natural Resources Trust Fund in the video and also tagged MN ENRTF in the social media post.

2. We presented our work to over 60 K12 girls, many of who will be first-generation college graduates, through the Eureka! Summer camp. We represented our Harmful Algal Bloom research and showed them the video we made in July 2023.

Status Update Reporting

Status Update March 1, 2023

Date Submitted: March 15, 2023

Date Approved: March 17, 2023

Overall Update

We have sampled Harmful agal bloom-contaminated water in Minnesota's lakes in collaboration with the City of Minneapolis. From these samples, we identified key toxic algal cells in Minnesota's water, which include the species Microcystis aeruginosa and Planktotrix. We have started cultivated these two species and developed an imaging system to test the efficiency of the clay-algae flocculation using different clays. Our study shows that swelling clay, bentonite, is more efficient in causing cells to flocculate and sediment. In addition, we found that a synthetic smectite clay, laponite, can hinder the growth of Microcystis aeruginosa cells. We have written a manuscript, which is currently under review. The preprint has been published online: https://www.authorea.com/doi/full/10.1002/essoar.10511130.1
We have finished testing clay-algae flocculation in still water. We are currently developing a system to test how the algae cells and clay flocculate in the presence of turbulence and flows, because flows and turbulence are widely present in natural water. In addition, we have repaired two outdoor bioreactors that simulate lakes and started growing algal cells there.

Activity 1

We have made the following progress:
1. We have shown that a synthetic smectite clay, laponite, can hinder the growth of Microcystis aeruginosa cells. We have written a manuscript, which is currently under review. The manuscript is submitted to an academic journal and its preprint has been published online: https://www.authorea.com/doi/full/10.1002/essoar.10511130.1
4. We have finished testing clay-algae flocculation in still water, so Activity 1 is almost complete.
Our next goal is to develop a system to test how the algae cells and clay flocculate in the presence of turbulence and flows, because flows and turbulence are widely present in natural water.

Activity 2

(1) Instead of repairing the plankton tower, we are currently building an imaging system with turbulence generator, which will have similar functions as the plankton tower. In the new system, we use a meter-long tube to study algal-clay flocculation. We mounted a camera on a moving translational system that can move with the sinking clay-algae flocculates. In this new system, we will be able to observe how cell and clay stick together over time.
(2) In addition, we have repaired two outdoor bioreactors that simulate lakes and started growing algal cells there. However, due the cold temperature, the cells were not growing in these outdoor artificial lakes. We expect to have more progress in the summer when the weather is warm.

Activity 3

This activity will be conducted in year 3.

Dissemination

(1) We have designed outreach activities, including two lectures and hands-on activities, related to microbe in aquatic ecosystems and conducted outreach activities).
(2) We have made a science video about harmful algal blooms and clay-algae flocculation. The video will be published in a couple of months.
(3) The PI Yang has presented the work and the outreach events to K12 teachers in Minnesota during the Minnesota Science Teacher Association Conference in late 2022. There are several teachers expressed interest in conducting the outreach activities we designed in their classroom.

Additional Status Update Reporting

Additional Status Update September 29, 2022

Date Submitted: October 4, 2022

Date Approved: October 5, 2022

Overall Update
Since the start of the project (07/01/2022), we have hired a graduate student and a postdoc to work on the project. We have started inoculating algal cells in the lab and conduct table-top flocculation experiments in beakers to identify clays. We also started designing microfluidic channels using our new 3D printer. In addition, we collected some bottles of algal cells from two lakes in collaboration with the City of Minneapolis. These cells are used in our clay flocculation experiments. We plan to collect 50 gallons of water from Powderhorn Lake next week and start growing the cells in the two artificial lakes at Saint Anthony Falls Laboratory. We tested three types of natural clays and have started selected clay modifying chemicals.

Regarding the budget, the personnel and material costs haven't been charged to the account yet, because I got my LCCMR chart-string relatively late (in Early September). Our accountant will reconcile related charges soon.

Activity 1
We have made the following progress:
1. We sampled cells from a couple of lakes and conducted some small scale flocculation experiments using these natural algal cells.
2. We designed two microfluidic channels, tested them, and identified ways to improve the design.
3. We tested three types of clay (Kaolinite, bentonite, and phosphatic clay), our preliminary experiments show that bentonite works better than the other two clays. We plan to continue testing these clays.
4. We start looking into clay modifying chemicals that can help improve the flocculation efficiency of clay.

Activity 2
This activity will be conducted in year 2.

Activity 3
This activity will be conducted in year 3.

Dissemination
(1) My group and I have led three 1-hour outreach activities (lecture + hands-on activity) in the “Eureka!” summer camp in June 30, July 7, July 14 (2022). The “Eureka!” summer camp aims to engage K12 girls, most of whom will be first-generation college graduates, in science and engineering. We talked about harmful algal blooms in lakes and how clay can help remove these cells. We asked students to simulate and study algal-clay interactions using slime mold to simulate microbial biofilms and plastic balls to simulate clay.
(2) We led the same outreach activity about clay-algae flocculation and harmful algal blooms in two 1.5-hour outreach sessions at the Geoscience Alliance Conference (July 28-30). The goal of the conference is to engage Native American students in geosciences, and most of the conference participants are from under-represented groups.