Final Abstract

Final Report Approved on December 4, 2025

M.L. 2021 Project Abstract

For the Period Ending June 30, 2025

Project Title: Remote Sensing and Super-Resolution Imaging of Microplastics

Project Manager: Ardeshir Ebtehaj

Affiliation: U of MN - St. Anthony Falls Laboratory

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Website: https://www.safl.umn.edu/

Funding Source:

Fiscal Year:

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 08j

Appropriation Amount: $309,000

Amount Spent: $302,489

Amount Remaining: $6,511

Sound bite of Project Outcomes and Results

This study investigated the optical properties of weathered and virgin macroplastic debris in freshwater through controlled flume experiments using Mississippi River water. The resulting open-access database characterizes spectral signatures of various plastic types, supporting the advancement of remote sensing techniques for detecting and monitoring floating plastics in riverine environments.

Overall Project Outcome and Results

Plastic pollution has become one of the major environmental challenges of our time. Every year, large amounts of plastic debris travel through rivers before reaching lakes and oceans, where they harm aquatic life, disrupt food webs, and can even affect human health. To effectively manage and reduce this pollution, scientists need better ways to detect and monitor plastics in water systems.

One promising approach is remote sensing — using instruments that observe light reflected from surfaces to identify materials from a distance. However, while scientists have learned a lot about how plastics reflect light in ocean environments, much less is known about their behavior in freshwater systems like rivers and lakes.

This study fills that gap by creating a new open-access database of how different types of plastic — both weathered (aged) and virgin (new) — reflect light under realistic river conditions. Using real water collected from the Mississippi River, the researchers conducted controlled experiments in a laboratory flume (a small artificial river channel). They measured how plastics reflect light across a wide range of wavelengths, from ultraviolet (350 nanometers) to shortwave infrared (2500 nanometers), under different flow and sediment conditions. While we originally intended to investigate remote sensing of microplastics, initial experiments showed that the spectral signatures of floating microplastics are not detectable by the spectroradiometer, and we pivoted the research to larger plastic debris.

The resulting database, available in widely used formats (NetCDF and CSV), captures detailed “spectral fingerprints” of floating plastics in freshwater. These data will help scientists and environmental agencies develop and test remote sensing tools — such as drones, satellites, and airborne sensors — to more accurately detect and track plastic pollution.

By improving our ability to identify plastic debris from space or the air, this research supports cleaner rivers, healthier ecosystems, and better-informed efforts to protect water resources.

Project Results Use and Dissemination

The project produced three peer-reviewed papers and two open-access datasets, advancing remote sensing of plastic debris in aquatic environments. The final paper, published in Nature Scientific Data, marks a major milestone. The research attracted significant media attention, including coverage by CBS News, the Minnesota Daily, and the University of Minnesota’s College of Science and Engineering.

Environment and Natural Resources Trust Fund

M.L. 2021 Approved Final Report

General Information

Date: December 5, 2025

ID Number: 2021-223

Staff Lead: Tom Dietrich

Project Title: Remote Sensing and Super-Resolution Imaging of Microplastics

Project Budget: $309,000

Project Manager Information

Name: Ardeshir Ebtehaj

Organization: U of MN - St. Anthony Falls Laboratory

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Project Reporting

Final Report Approved: December 4, 2025

Reporting Status: Project Completed

Date of Last Action: December 4, 2025

Project Completion: June 30, 2025

Legal Information

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 08j

Appropriation Language: $309,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, St. Anthony Falls Laboratory, to develop and test remote sensing techniques for cost-effective monitoring of microplastics in lakes, rivers, and streams as well as in wastewater treatment plants. This appropriation is available until June 30, 2025, by which time the project must be completed and final products delivered.

Appropriation End Date: June 30, 2025

Narrative

Project Summary: The research will collect samples of microplastics to establish relationships between physical and remote sensing characteristics of microplastics for cost effective monitoring of microplastics in Minnesota natural and engineered waters.

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

Plastic pollution of water resources is a growing worldwide problem and Minnesota is no exception. Global production of plastics has increased to more than 350 million metric tons per year. Plastics break down to smaller pieces called "microplastics". Humans and wildlife consume microplastics via water and food. Ingestion of microplastics by humans results in uptake and bioaccumulation of harmful chemicals, including known carcinogens (e.g., polychlorinated biphenyls [PCBs] and polycyclic aromatic hydrocarbons [PAHs]) as well as emerging contaminants such as pesticides, pharmaceuticals, and endocrine disrupting compounds. In addition, ingested microplastics cause digestive and reproductive problems, as well as death in fish, birds, and other animals. Microplastics may even harbor pathogenic bacteria. Recent research by the US Geological Survey and U of MN indicates that high concentrations of microplastics are potentially present in Minnesota waters. Little is known; however, about the spatial distribution and heterogeneity of microplastics in Minnesota waters.

To better understand and mitigate the effects of microplastics on public health and wildlife we first need to measure them in a regional scale. Modern techniques for cost effective detection and mapping of microplastics in surface waters are critically needed.

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 this proposed study is to advance our understanding of remote sensing properties of microplastics in surface waters. The objectives of the project are to:

- Characterize physical properties of microplastics in Minnesota natural and engineered waters.
- Conduct laboratory experiments to quantify remote sensing properties of microplastics in surface water.
- Develop/validate drone-based and in-situ remote sensing techniques for cost effective monitoring of microplastics in rivers and lakes.
- Disseminate the findings to stakeholders, legislators, and the public for strategic planning and awareness.

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?

This study will advance science to pave the ways for drone-based and satellite remote sensing and super-resolution in-situ imaging of microplastic particles. The results will lead to cost effective tools for mapping of microplastics in Minnesota waters and real-time monitoring of their concentration in inlets/outlets of wastewater treatment plants. The developed technology will inform decision makers for timely mitigation strategies and policy making to limit environmental and human health effects of related contamination in Minnesota.

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: Sample and characterize physical properties of microplastics in Minnesota waters

Activity Budget: $180,000

Activity Description:
Microplastics of various types and concentration will be introduced into the outdoor reactors and experimental stream facilities at the Saint Anthony Falls Laboratory (SAFL) to resemble the boundary conditions and flow regimes of lakes and rivers, respectively. A new hyperspectral spectroradiometer will be purchased and installed over the reactors and the outdoor stream facilities to measure the far field remote sensing signals of microplastics from visible to near infrared wavelengths. The results will reveal connections between the remote sensing signals and concentration, size distribution and types of microplastics. In parallel an RGB camera (available at SAFL) with zoom-in lens in the near field will be deployed for super-resolution imaging of individual microplastic particles.

The former experiment will identify a few key wavelengths that can be used by commercial lightweight cameras on drones (e.g. MicaSens Altum, available with SAFL drone) to quantify and map microplastic type and abundance in the field. The latter experiment will serve as the ground truth for interpreting remote sensing signals, validation and in-situ measurements of microplastics with high degree of accuracy.

Activity Milestones:

Description	Approximate Completion Date
Water samples collected, analyzed for microplastic types and abundance	September 30, 2021
Data analyzed and physical characteristics are determined based on the sampled groups	January 31, 2022
Dissemination findings of Activity 1 via 1 open access journal publications	May 31, 2022

Activity 2: Laboratory experiments to determine remote sensing properties of microplastics in water

Activity Budget: $50,000

Activity Description:
Remote sensing and physical properties of microplastics are tightly connected. Groups of samples from streams, rivers and lakes (30), storm water (10), and treated wastewater effluents (10) will be collected throughout Minnesota. The goal is collect a baseline dataset that enables us to study remote sensing properties of microplastics in laboratory (activity 2) based on the type and concentration of microplastics in different water bodies (i.e., rivers vs lakes). The sampling will be conducted during low and high runoff conditions over the first year to make sure that all potential types of microplastics are properly sampled as we hypothesis that their concentration and types vary seasonally based on changes in water transport mechanism and land use. Water samples will be analyzed to determine the type of microplastics as fragments, pellets/beads, lines/fibers or foams.

Activity Milestones:

Description	Approximate Completion Date
Collect samples of spectral properties of microplastic in the SAFL reactors and stream lab	August 31, 2022
Develop high-resolution techniques for microplastic particle imaging	March 31, 2023
Data analysis to inference spectral bandwidth for sensing of microplastics using drones	April 30, 2023
Dissemination of Activity 2 findings via at least 1 open access journal publications	September 30, 2023

Activity 3: Design, deploy and validate the developed remote sensing techniques in the field

Activity Budget: $79,000

Activity Description:

Based on activities 1-2, we will design the remote and in-situ sensing platforms including both the hardware and data processing software to detect the type and estimate the concentration of microplastics. We test and validate the platforms in two stages. First, we conduct controlled experiments in the laboratory, knowing the concentration of microplastics released. Second, based on the data in Activity 1, we will identify a watershed and key areas with high concentrations of microplastics as well as a wastewater treatment plant to deploy the remote sensing platforms for data collection and validation in the field.

Activity Milestones:

Description	Approximate Completion Date
Hardware and software developments for the remote sensing platforms	September 30, 2023
Deploying the platforms in the field	May 31, 2024
Dissemination of Activity 3 findings via at least 1 open access journal publications	July 31, 2024
Validation and analysis of the field data	July 31, 2024

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Jiarong Hong	University of Minnesota	Dr Hong is an associate Professor of Mechanical Engineering. Dr. Hong will be responsible for developing in-situ imaging of microplastics in water.	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 findings of the project 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 public awareness about the pollution problem of microplastics. To that end. we will arrange annual public seminars at SAFL to inform the public about the plastic pollution and update citizens of Minnesota about the research and actions we are taking at SAFL to understand and mitigate this important health problem. All the seminars will be recorded and will be broadcast online. The collected data will be shared publicly using the Data Repository for University of Minnesota (DRUM) to foster research advancement in the field.

At the same time, the team will reach out to the Minnesota Pollution Control Agency and update the division of microplastic pollution about the findings and explore future opportunities for advancing the project into large-scale cost effective monitoring of microplastics in Minnesota waters. The support from the Natural Resources Trust Fund will be acknowledged through use of the Trust Fund logo in the presentations and will be directly acknowledged in publications per the ENTRF Acknowledgment Guidelines.

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?
This project will provide a new and easily deployable tool for statewide remote sensing of microplastics in rivers and lakes and also pave the ways for future commercial technology developments for satellite remote sensing. The results provide capabilities to the state agencies to establish technology and guidelines to control and reduce microplastics at the sources, advance our storm water management systems and treatment plants to protect public from this emerging treat.
The project also pave the ways to target federally funded projects in near future such the one (https://nsf.gov/pubs/2020/nsf20050/nsf20050.jsp?org=NSF).

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount	$ Amount Spent	$ Amount Remaining
Personnel										
Undergraduate Student		Undergraduate Student			0%	0.06		$10,000	-	-
Graduate Student		Graduate Student			44%	1.5		$152,410	-	-
Research Scientist		Research Scientist			24%	0.18		$7,266	-	-
Jiarong Hong		Co PI			27%	0.12		$21,737	-	-
Ardeshir Ebtehaj		PI			27%	0.12		$17,632	-	-
Post-doc		Post-doc			27.1%	1		$60,000	-	-
							Sub Total	**$269,045**	**$269,045**	**-**
Contracts and Services										
Dr. Chris Ellis	Professional or Technical Service Contract	Designing a new data collection system for mounting the ASD spectroradiometer on the carriage of the titled flume to measure spectral signatures of floating plastic debris under natural environmental conditions such as waves, suspended sediments and bed load. Chris designed the carriage and have access to the drawing.				0.07		$8,000	$3,330	$4,670
Nick Neary https://www.nickneary.design/	Professional or Technical Service Contract	Nick is a graphic designer. We would like to sketch our data acquisition system for high-profile publications and dissemination to better communicate our research with the public.				0.01		$1,000	$488	$512
							Sub Total	**$9,000**	**$3,818**	**$5,182**
Equipment, Tools, and Supplies										

	Tools and Supplies	Nylon mesh sieves and mixed cellulose ester membrane filters.	conducting the field sampling					$7,500	$7,500	-
							Sub Total	**$7,500**	**$7,500**	**-**
Capital Expenditures										
		A Spectroradiometer with spectral range 350-2500 nmwith resolution 2 to 8 nano-meter.	To determine key wavelengths in the reflectance spectrum responding to the presence of floating plastics in water.	X				$16,078	$14,749	$1,329
							Sub Total	**$16,078**	**$14,749**	**$1,329**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**
Travel In Minnesota										
	Miles/ Meals/ Lodging	Travel to sites for sampling of microplastics in rivers, lakes and wastewater treatment outlets. The cost covers using SAFL trucks and deploying the SAFL boats.	Sample microplastics in Minnesota waters and use them for laboratory experiments to determine their remote sensing properties.					$3,627	$3,627	-
							Sub Total	**$3,627**	**$3,627**	**-**
Travel Outside Minnesota										
							Sub Total	**-**	**-**	**-**
Printing and Publication										
	Publication	Activities 1 will lead to 1 publications in reputable open access journals of the field.	Dissemination of knowledge to the community					$1,250	$1,250	-
	Publication	Activities 2 will lead to 1 to 2 publications in reputable open access journals of the field	Dissemination of knowledge to the community					$1,250	$1,250	-

	Publication	Activities 3 will lead to 1 to 2 publications in reputable open access journals of the field	Dissemination of knowledge to the community					$1,250	$1,250	-
							Sub Total	**$3,750**	**$3,750**	**-**
Other Expenses										
							Sub Total	**-**	**-**	**-**
							Grand Total	**$309,000**	**$302,489**	**$6,511**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Expenditures		A Spectroradiometer with spectral range 350-2500 nmwith resolution 2 to 8 nano-meter.	The equipment was needed to measure the spectral reflectance of water and floating plastic debris at different hyperspectral wavebands from 350 to 2500 nm. This equipment helped us to measure how light is reflected from the surface of water depending on the material and concentration of plastic debris. **Additional Explanation :** This equipment has been used to measure the spectral reflectance of plastic debris in the tilting flume at Saint Anthony Falls Lab as reported before. The collected data are being processed now for publication and public release. This equipment will be further use for remote sensing of HABs through future projects with LCCMR.

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount	$ Amount Spent	$ Amount Remaining
State						
Cash	grants-in-aid	The original requested budget for the project was 360k and 309k was approved. The PI applied for grant-in-aid to be able to properly manage the project and purchase the equipment.	Secured	$36,578	-	$36,578
			State Sub Total	**$36,578**	**-**	**$36,578**
Non-State						
In-Kind	Unrecovered F&A	Support of SAFL facilities where research will be conducted.	Secured	$139,062	-	$139,062
			Non State Sub Total	**$139,062**	**-**	**$139,062**
			Funds Total	**$175,640**	**-**	**$175,640**

Attachments

Required Attachments

Visual Component

File: 60966c00-84d.pdf

Alternate Text for Visual Component

The graphics show samples of different types of micro and macro plastics in water, spectroradiometric experiments in outdoor stream facility at SAFL and drone-based remote sensing of microplastics over river and lakes....

Supplemental Attachments

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

Title	File
The new quote for the spectroradiometer	bc79eb5f-a4d.pdf
Research Addendum	d290665c-60d.docx
background checks	fe111bbd-681.pdf
Optical detection of plastic debris	1ea27aa5-480.pdf
built data acquisition system	0488b044-c22.jpe
A paper under revision	853ec613-07d.pdf
images of the experiments	082b64dc-a66.pdf
Uncovering Plastic Litter Spectral Signatures: A Comparative Study of Hyperspectral Band Selection Algorithms	4bf78bb0-e6b.pdf
experimental setup and collected samples	065f808d-99f.png
A Hyperspectral Reflectance Database of Plastic1 Debris for River Ecosystems	73f10a2d-b20.pdf
A Hyperspectral Reflectance Database of Plastic Debris with Different Fractional Abundance in River Systems	3f8ef6cf-f5c.pdf
Project Visual Presentaiton	0acb0c52-2d0.pdf

Media Links

Title	Link
First-of-its-kind study uses remote sensing to monitor plastic debris in rivers and lakes	https://cse.umn.edu/college/news/first-its-kind-study-uses-remote-sensing-monitor-plastic-debris-rivers-and-lakes
A Hyperspectral Reflectance Database of Plastic Debris for River Ecosystems	https://github.com/aebtehaj/Hyperspectral_reflectance_library

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

We have not changed the content of the proposal and will strive to deliver the promised goal and objectives of the proposal. We mainly reduced the requested summer salaries for the PI and Co-PI and removed 25% of the requested graduate assistant. This might reduce the number of promised publications to 3 to 4 papers in the reputable journals of the field instead of 5 to 6.

We have primarily budgeted for an ASD spectroradiometer that is not longer in production. The new product is way more expansive but will provide a much better measurement quality and will benefit the quality of research significantly and foster other remote sensing research activities at the Saint Anthony Falls Laboratory. We attached the new quote. We appreciate the opportunity.

We have carefully incorporated all the feedback received from all reviewers and the LCCMR staffs in the revised

addendum.

Sincerely, 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 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?

No

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

N/A

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

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

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 - Personnel • Budget - Professional / Technical Contracts	I need to hire Dr. Chis Ellis who is a retried senior research associate at SAFL. He has the right expertise to conduct the project and has already helped us on the design of a new data collection system. We incorrectly budgeted him as research scientist while he is retried and has to be listed as a contractor.	October 21, 2022	Yes	October 21, 2022
2	Amendment Request	• Budget • Budget - Personnel • Budget - Professional / Technical Contracts • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Attachments	I need a graphic artist to help us sketch our experimental setup for high-profile publications and better communication of the research with the public. I talked to Nick Nearing (https://www.nickneary.design/) who has designed a number of graphics for the civil engineering department at the U. He mentioned that the total cost would be around $500 to $750.	December 6, 2023	Yes	December 6, 2023
3	Amendment Request	• Other • Activities and Milestones • Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Non-ENRTF Funds Contributed • Attachments	The graduate assistant on the project notified me that he plans to graduate by the end of summer and I need to hire a postdoc to continue the project. Currently, the balance is 101,704.48. The PI applied for grants-in-aid at the UMN and supplied the project with more than $36,000 for the capital equipment and thus we have extra money in that budget line and already purchased the project equipment.	February 15, 2024	Yes	February 16, 2024

Status Update Reporting

Final Status Update August 14, 2025

Date Submitted: October 8, 2025

Date Approved: October 14, 2025

Overall Update
The original project aimed to characterize the optical properties of microplastics in natural waters, with the hypothesis that microplastics exhibit distinct reflectance signatures. This was to be tested through spectroradiometry of floating microplastic debris. Due to budget cuts, the PI secured an additional ~$40k in external funding through a grant-in-aid to acquire a high-quality spectroradiometer. Initial experiments confirmed that dry microplastics show unique reflectance features, but these signals were obscured in wet conditions because of water's strong light absorption. Consequently, the project shifted to focus on larger macroplastic debris, which serve as sources of microplastics and are detectable with the purchased equipment. Plastic debris was collected from Minnesota waters, and a custom data acquisition system was developed to replicate the natural boundary conditions of rivers and lakes in a controlled laboratory setting.

The revised achieved objectives are as follows: (1) Characterize the physical properties of macroplastics in Minnesota's waters. (2) Conduct controlled experiments to quantify the remote sensing properties of macroplastics. (3) Develop and validate machine learning approaches for cost-effective detection of plastic debris extendible to different remote sensing platforms. (4) Disseminate results to stakeholders, legislators, and the public to support strategic planning and technology developments.

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

Activity 2
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 3
As reported on June 1, we published the results of our laboratory experiments and validations, which reconstruct real-case outdoor scenarios under controlled conditions, in a reputable Nature Journal. Since then, we completed the project, assembled the data, and published it in the Zenodo repository, accessible at https://zenodo.org/records/13377060.
(This activity marked as complete as of this status update)

Dissemination
The project resulted in three peer-reviewed papers (items 1-3) and two publicly available datasets (items 4 and 5). The work has also received notable media coverage, both previously and as highlighted in this final report. The last paper was published in a Nature Journal, which is among the most prestigious journals in the field.

1- M. Olyaei*, A. Ebtehaj, and J. Hong (2022), Optical Detection of Marine Debris using Deep Knock-off, IEEE Trans. on Geosci. and Remote Sens. DOI: 10.1109/TGRS.2022.3228638
2- M. Olyaei*, A. Ebtehaj (2023), Uncovering Plastic Litter Spectral Signatures: A Comparative Study of Hyperspectral Band Selection Algorithms, Remote Sens. 2024, 16(1), 172; https://doi.org/10.3390/rs16010172.
3- M. Olyaei*, A. Ebtehaj, and C. Ellis (2024), A Hyperspectral Reflectance Database of Plastic Debris with Different Fractional Abundance in River Systems, Nature, Scientific Data, 11, 1253.

4- https://github.com/aebtehaj/Hyperspectral_reflectance_library
5- https://zenodo.org/records/13377060

Media Coverage:
1- https://cse.umn.edu/college/news/first-its-kind-study-uses-remote-sensing-monitor-plastic-debris-rivers-and-lakes
2- https://mndaily.com/292393/campus/umn-study-strives-to-tackle-mississippis-plastic-debris/
3- https://www.cbsnews.com/minnesota/news/university-of-minnesota-plastic-monitoring-mississippi-river/

Status Update Reporting

Status Update June 1, 2025

Date Submitted: October 8, 2025

Date Approved: October 14, 2025

Overall Update
Aligned with objectives 3 and 4 for macroplastics, the published Nature paper expanded our knowledge of the optical properties of floating macroplastics in aquatic ecosystems and developed machine learning models that can learn from the data, which can be leveraged for remote sensing of plastic debris using airborne and spaceborne platforms. We made the data publicly available to foster future research that benefits the health and well-being of Minnesotans.

In particular, we learned how different types of plastic debris reflect light from the invisible to the short-wave infrared range under varying concentrations of sediments in both foamy and clear waters, under sub-critical flow conditions commonly found in most rivers and streams. We identified specific absorption and reflection lines in response to plastic materials and demonstrated how different water turbidities can alter them. We showed that machine learning tools (i.e., extreme gradient boosted decision trees) can extract information from the collected dataset to detect and classify different types of macroplastics (e.g., Polyethylene Terephthalate, High-Density Polyethylene, Low-Density Polyethylene, Polypropylene, and Expanded Polystyrene Foam) in freshwater ecosystems.

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

Activity 2
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 3
We published the results of our laboratory experiments and validations, which reconstruct real-world outdoor scenarios under controlled conditions, in a reputable Nature Journal. Over the past few months, we completed the project, assembled the data, and published it in the Zenodo repository, accessible at https://zenodo.org/records/13377060. In the publication, we provided an open-access hyperspectral reflectance database of floating weathered and virgin plastic debris found in Minnesota river systems under controlled laboratory experiments. Utilizing natural waters from the Mississippi River, the database was assembled using a remote sensing data acquisition system deployed over a hydraulic flume operating under subcritical flow conditions and varying suspended sediment concentrations. The measurements encompass hyperspectral diffused light reflectance from ultraviolet (UV, 350 nm) to shortwave infrared (SWIR, 2500 nm) wavelengths. We studied the effects of varying concentrations of suspended sediment and white caps (i.e., water foams resulting from turbulence) on the spectral reflectance of different types of (e.g., Polyethylene terephthalate) plastic debris. We demonstrated that these signatures can be utilized through modern machine learning algorithms for the detection and classification of floating plastic debris in natural freshwater using airborne and spaceborne platforms.
(This activity marked as complete as of this status update)

Dissemination
The project resulted in three peer-reviewed papers (items 1-3) and two publicly available datasets (items 4 and 5). The work has also received notable media coverage, both previously and as highlighted in this final report.
1- M. Olyaei*, A. Ebtehaj, and J. Hong (2022), Optical Detection of Marine Debris using Deep Knock-off, IEEE Trans. on Geosci. and Remote Sens. DOI: 10.1109/TGRS.2022.3228638

2- M. Olyaei*, A. Ebtehaj (2023), Uncovering Plastic Litter Spectral Signatures: A Comparative Study of Hyperspectral Band Selection Algorithms, Remote Sens. 2024, 16(1), 172; https://doi.org/10.3390/rs16010172.
3- M. Olyaei*, A. Ebtehaj, and C. Ellis (2024), A Hyperspectral Reflectance Database of Plastic Debris with Different Fractional Abundance in River Systems, Nature, Scientific Data, 11, 1253.
4- https://github.com/aebtehaj/Hyperspectral_reflectance_library
5- https://zenodo.org/records/13377060

Media Coverage:
1- https://cse.umn.edu/college/news/first-its-kind-study-uses-remote-sensing-monitor-plastic-debris-rivers-and-lakes
2- https://mndaily.com/292393/campus/umn-study-strives-to-tackle-mississippis-plastic-debris/
3- https://www.cbsnews.com/minnesota/news/university-of-minnesota-plastic-monitoring-mississippi-river/

Additional Status Update Reporting

Additional Status Update January 11, 2025

Date Submitted: January 11, 2025

Date Approved: January 21, 2025

Overall Update
We are close to wrapping up the project. We have published three research papers and a valuable data set of plastic debris remote sensing characteristics for future technology developments. We are working on the final stage of data quality control and release. We will finish the project on time.

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

Activity 2
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 3
In the past six months, we successfully published the research results in Nature Scientific Data, perhaps the most prestigious journal in the field. The paper is entitled M. Olyaei*, A. Ebtehaj, and C. Ellis (2024), A Hyperspectral Reflectance Database of Plastic Debris with Different Fractional Abundance in River Systems, Nature, Scientific Data, 11, 1253. Under controlled laboratory experiments, the study provided an open-access hyperspectral reflectance database of floating weathered and virgin plastic debris found in river systems. Utilizing natural waters from the Mississippi River, the database was assembled using a remote sensing data acquisition system deployed over a hydraulic flume operating under subcritical flow conditions and varying suspended sediment concentrations. The measurements encompass hyperspectral diffused light reflectance from ultraviolet (UV, 350 nm) to shortwave infrared (SWIR, 2500 nm) wavelengths. The data offers valuable insights for better understanding key spectral signatures indicative of floating plastic debris with different fractional abundance in freshwater ecosystems. All field validation efforts were conducted under controlled laboratory conditions. We are in the final stage of data quality control to ensure accuracy.

Dissemination
M. Olyaei*, A. Ebtehaj, and C. Ellis (2024), A Hyperspectral Reflectance Database of Plastic Debris with Different Fractional Abundance in River Systems, Nature, Scientific Data, 11, 1253. We are working to finalize the software tools and data released at https://github.com/aebtehaj/Hyperspectral_reflectance_library for further dissemination. The paper is featured at https://cse.umn.edu/college/news/first-its-kind-study-uses-remote-sensing-monitor-plastic-debris-rivers-and-lakes. The LCCMR grant is acknowledged in all publications and media coverages.

Status Update Reporting

Status Update December 1, 2024

Date Submitted: January 11, 2025

Date Approved: January 21, 2025

Overall Update
We are close to wrapping up the project. We have published three research papers and a valuable data set of plastic debris remote sensing characteristics for future technology developments. We are working on the final stage of data quality control and release. We will finish the project on time.

Activity 1
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Activity 2
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Activity 3
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Status Update Reporting

Status Update June 1, 2024

Date Submitted: July 18, 2024

Date Approved: July 23, 2024

Overall Update
Hi Tom,
Here is the update on 07/02.
I checked with our accounting office. They confirmed that the budget was correct by June 01. I attached the paper under review. Please also see my updates for activity 3 as requested.
Best, Ardeshir

In the past year, our laboratory data collection was finished. A data set entitled "A Hyperspectral Reflectance Database of Plastic Debris for River Ecosystems" was released to the public. The NETCDF files are available at https://doi.org/10.5281/zenodo.10723548. The software codes for working with the database in MATLAB and Python are accessible on GitHub at https://github.com/olyae001/Hyperspectral_reflectance_library. So far we have published two peer reviewer papers as follows:

1- M. Olyaei*, A. Ebtehaj, and J. Hong (2022), Optical Detection of Marine Debris using Deep Knock-off, IEEE Trans. on Geosci. and Remote Sens. DOI: 10.1109/TGRS.2022.3228638
2- M. Olyaei*, A. Ebtehaj (2023), Uncovering Plastic Litter Spectral Signatures: A Comparative Study of Hyperspectral Band Selection Algorithms, Remote Sens. 2024, 16(1), 172; https://doi.org/10.3390/rs16010172.
3- M. Olyaei, A. Ebtehaj and C. Ellis (2024), A Hyperspectral Reflectance Database of Plastic Debris...

Activity 1
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Activity 2
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Activity 3
The third paper of the project was prepared and submitted with the following abstract. I attached the submitted draft. We previously conducted a series of field-scale and laboratory measurements at SAFL. While the spectral signatures of plastic debris remained consistent, the impacts of the background environment varied. Controlling the concentration of plastic debris outdoors proved challenging, compromising data accuracy. To mitigate background noise, we designed controlled experiments in SAFL flumes, allowing us to manage the background concentration of suspended sediments and their spectral reflectance, as well as the concentration of sub-grid scale plastic debris within the spectroradiometer's field of view. Based on our scientific judgment, these controlled laboratory experiments effectively emulate and surpass field-scale measurements, enabling us to fully control background environmental effects and ensure measurement accuracy by eliminating background noise. Consequently, the ongoing controlled laboratory measurements exceed the initial vision for field-scale spectral reflectance collection. We received a sample of microplastics from the University of Memphis by Prof. FrahadJazaei. The current spectroradiometer is unable to see the signature of microplastics. We aim to use a new camera we are going to buy through a new LCCMR project to expand the project to micro and nanoplastics.

Dissemination

We had an oral presentation at the American Geophysical Union in 2023 with the title available at https://agu.confex.com/agu/fm23/meetingapp.cgi/Paper/1344712. In all publications and presentations of the project outcomes, we added the following acknowledgment statement: "The funding support from the Legislative-Citizen Commission on Minnesota Resources (LCCMR, M.L.2021 E812RSM) is greatly acknowledged".

Additional Status Update Reporting

Additional Status Update February 1, 2024

Date Submitted: February 15, 2024

Date Approved: February 16, 2024

Overall Update

The second publication of the project is available in an open-access remote sensing journal.
M. Olyaei*, A. Ebtehaj (2023), Uncovering Plastic Litter Spectral Signatures: A Comparative Study of Hyperspectral Band Selection Algorithms, Remote Sens. 2024, 16(1), 172; https://doi.org/10.3390/rs16010172. The current research assistant is working on the third paper to release the newly collected data of plastic spectral signature and the third paper is under preparation. The data will be submitted to GitHub and we plan to publish the outcome of experimental research in the Nature Scientific Report, hopefully.

Activity 1

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Activity 2

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Activity 3

The laboratory data of spectral signatures of plastic debris are collected and organized for public release. The graphics of the paper are done and the PI and the graduate assistant are preparing the third paper that explains the signatures of plastic debris in optically complex freshwater ecosystems. The paper's first draft became ready for the PI's comments on Feb 15, 2024. The PI plans to hire a new postdoc based on the remaining budget of the project to complete the last activity of the project. The PI aims to extend research by collecting plastic debris's spectral signatures in the field. The assessment is that less than 30% of the third activity remains to be finished.

Dissemination

The second publication of the project is available in an open-access remote sensing journal.
M. Olyaei*, A. Ebtehaj (2023), Uncovering Plastic Litter Spectral Signatures: A Comparative Study of Hyperspectral Band Selection Algorithms, Remote Sens. 2024, 16(1), 172; https://doi.org/10.3390/rs16010172.

Status Update Reporting

Status Update December 1, 2023

Date Submitted: December 6, 2023

Date Approved: December 6, 2023

Overall Update
Following our previous progress report in June 2023, I am pleased to update you on our recent developments. We have completed our laboratory experiments and are currently in the data analysis phase.
Moreover, I am excited to share that our paper titled "Optical Signatures of Plastic Litter: A Probabilistic Approach Using Sparse Representation" has been accepted for oral presentation at the upcoming AGU (American Geophysical Union) 2023 conference in San Francisco.

In addition, we have submitted another journal paper, titled "Uncovering Plastic Litter Spectral Signatures: A Comparative Study of Hyperspectral Band Selection Algorithms," to the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing.

Currently, our focus is on publishing the results of our experimental work. We are diligently working on a draft for a journal paper entitled "Spectral Signatures of Plastic Debris in Optically Complex Freshwater Aquatic Systems," with plans to submit it to the Journal of Nature Scientific Data.

Activity 1
This activity was previously marked complete.
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Activity 2
A remote sensing data acquisition system was built over the tilted flume (14.6*0.9*0.6 m) at Saint Anthony Fall Laboratory (SAFL) to measure the spectral reflectance of plastic debris. Data collection employed an Analytical Spectral Devices (ASD) spectroradiometer covering the range of 350 to 2500 nm, with a resolution of 3 nm in the visible and near-infrared (VINR) and 8 nm in the short-wave infrared (SWIR). The spectroradiometer was mounted on a carriage system where the distance to the water surface can be set to the desired level. Additionally, a digital single-lens reflex (DSLR) camera was synchronized with the spectroradiometer to capture images of the Field of View (FOV), recording sub-grid scale fractions and types of floating plastics.
The figure attached shows different views of the data acquisition system.

So far, we have learned how plastic debris with different materials alters the reflection of light at different wavelengths depending on the concentration of the suspended sediments. We developed methodologies that can identify important regions of the electromagnetic spectrum that need to be observed for developing remote sensing platforms.
(This activity marked as complete as of this status update)

Activity 3
We are working on the preparation of the third paper to publish the collected data. For future work after analyzing the dataset of laboratory experiments and publication, we plan to design the experiments in the field to validate our findings.

Dissemination
Right now, my student is preparing his paper entitled "Spectral Signatures of Plastic Debris in Optically Complex Freshwater Aquatic Systems".

We are planning to release our data set in NetCDF (Network Common Data Form), which is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented heterogeneous scientific data. Each NetCDF file will include the measured reflectance at wavelengths between 350 and 2500 nm, a description of sample characteristics and experimental settings, as well as an RGB image and a pixel-wise mask for calculating the plastic fraction within the field of view of the spectroradiometer.

Status Update Reporting

Status Update June 1, 2023

Date Submitted: June 1, 2023

Date Approved: June 9, 2023

Overall Update
We are making progress in the second objective and hopefully will finish it by publishing two papers from the collected data. The second activity will hopefully begin this summer and will continue through out the 3rd year of the project.

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

Activity 2
To advance the second activity, we made partial progress on two fronts. First, we designed a data acquisition platform over the tilting flume in the Saint Anthony Falls Laboratory. The purchased ASD hyperspectral spectroradiometer, which was purchased for the project, was mounted over a carriage (see the uploaded pictures). The ASD collects spectral reflectance data of the debris. A DSLR camera was mounted on the carriage too to take visible images of the field of view of the radiometer and sub-grid fraction of the debris. Different amounts of suspended sediments were released and waves were generated in the flume to simulate the impacts of the background reflection of natural waters on spectral signatures of plastic debris. We collected more than 1000 samples of spectral signatures of plastic debris under controlled environmental conditions and are working on a paper to make the data available to the public. At the same time, a publicly available data set (https://data.4tu.nl/articles/_/12896312) was obtained. We developed modern AI and machine learning methods to isolate the best wavelengths for remote detection of plastic debris. Please see https://drive.google.com/file/d/14U4-qGoAOs1oqufRhivOt12uDSYtqx77/view?usp=sharing.

Activity 3
The third activity will begin hopefully in August 2023. We aim to make measurements in a more natural entremets of the plastic debris spectral signatures in the Outdoor Stream Laboratory (OSL). We aim to release plastic debris of different sizes ranging from micro to macro plastic on the outdoor stream in OSL and study their spectral signatures considering the effects of bedforms and natural sediment and colored dissolved organic matter. This field study will identify under which size and type of plastic debris and flow conditions, we would be able to detect the presence in freshwater aquatic systems in the field.

Dissemination
One paper is already published (https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9982459). One paper is under revision and one paper is under preparation. The under-revision paper is attached.

Status Update Reporting

Status Update December 1, 2022

Date Submitted: January 7, 2023

Date Approved: January 10, 2023

Overall Update
We have collected our samples, purchased the required equipment and ready to run experiments and collect the required data for developing remote sensing technologies for monitoring of plastic debris in natural waters.

Activity 1
We have collected samples of plastic debris from a few sites, including Lake Hiawatha. We are trying to collect more samples and bring them to the lab for further experiments. These samples will be based on weathered and virgin plastic debris to understand the impacts of weathering on the spectral signatures. Initial results conducting hyperspectral measurements indicate that we need to focus on plastic debris with various sizes to understand the minimum detectable size and type of the plastics. We have purchased a high-resolution ASD spectroradiometer high-resolution-spectroradiometer for the project. Due to the budget cut and price increase, the PI had to write a grant-in-aid proposal to the UMN office of the vice president for research to be able to complete the project. The proposal got funded and UMN contributed around $36k to the project. The PI also contributed $22.5k from his start-up funds to be able to purchase the equipment. The equipment arrival was delayed for months due to COVID and supply chain backlogs. The equipment has arrived in August 2022. Results from the work conducted under this activity were published in the journal, IEEE Transactions on Geoscience and Remote Sensing.
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Activity 2
The second activity is ongoing. We built a hyperspectral data acquisition system over the SAFL tilted flume to obtain hyperspectral reflectance data in a controlled laboratory setting over radiometrically complex waters. This system involved the installation of the spectroradiometer on a carriage on top of the tilted flume at SAFL to collect spectral signatures of floating plastic debris under natural environmental conditions and examine the effects of waves, and sediment loads on the signatures. We hired Dr. Chris Ellis and he made the design and built the new data collection system. We realized that the intensity of light sources is not adequate for the collection of spectral signatures. We are purchasing more supplies to add to the light sources of the experimental setups. We will collect data in the weeks to come.

Activity 3
The work for algorithm development just got started on early December 2022. A paper is under preparation using some initial data collected in the lab and some supplemented data sets from recently published data in the literature. We aim to make progress to make the algorithms available to the new data sets that will be collected in the lab. In the final stage of the project, we aim to expand the data acquisition system to the SAFL outdoor stream laboratory.

Dissemination
Publications:
1- M. Olyaei*, A. Ebtehaj, and J. Hong (2022), Optical Detection of Marine Debris using Deep Knock-off, IEEE Trans. on Geosci. and Remote Sens. https://ieeexplore.ieee.org/document/9982459

Additional Status Update Reporting

Additional Status Update March 26, 2022

Date Submitted: April 1, 2022

Date Approved: August 16, 2022

Overall Update

A student (Mohammadali Olyaei) has been hired to conduct the research objective of the project since Fall 2021. The project has undergone a budget cut of $60k, while the cost of the main requested instrument (i.e., ASD hyperspectral spectroradiometer) of the project has increased from $22k to $75k. The PI wrote supplementary proposal to the office of vice president for research at UMN and awarded $36k to supplement the project funds. The instrument was ordered in January 2022. Due to the supply change challenges because of the pandemic the production of the instrument has a backlog. The latest update from representative of the Malvern Panalytical company is that the instrument will bs shipped to UMN on June 17, 2022. Along with the instrument, through the supplemental funds, we ordered a light supply that will allow us to conduct remote sensing experiments indoor. Th goal is to expedite the experimental part of the research during the winter inside of the laboratory. To make progress in the knowledge development we are currently advancing our knowledge to understand and develop new methodologies for detection of marine debris (including microplastic) using satellite data through modern machine learning methodologies using a publicly available Macroplastic.

Activity 1

The instrument, ASD FieldSpec 4 spectroradiometer, was ordered and will be delivered by July 2022. The delay is due to supply chain disruption caused by COVID-19 situation. The experiments would be quickly initiated afterwards.
We plan to analyze the samples based on the type of microplastics as fragments, pellets/beads, lines/fibers or foams. Moreover, some samples will be synthesized based on various polymers such as polyethylene (PE), polypropylene (PP) and polystyrene (PS) to examine how the reflectance is affected by the polymer types.

Activity 2

This activity will be started after arrival of the spectroradiometer in July 2022. The great feature about the instrument is the illuminator reflectance lamp which is a light source designed specifically for accurate indoor diffuse reflectance measurements. By this perfect lighting accessory, we could easily conduct our experiments even when there is no sunlight inside of the laboratory and expedite the research. The results will reveal connections between the remote sensing signals and concentration, size distribution and types of microplastics

Activity 3

This activity would be expected to start in July 2023. Based on the activities 1-2, we will design the remote and in-situ sensing platforms including both the hardware and data processing software to detect the type and estimate the concentration of microplastics. We test and validate the platforms in two stages. First, we conduct controlled experiments in the laboratory, knowing the concentration of microplastics released. Second, based on the data in activity 1, we will identify a watershed and key areas with high concentration of microplastics as well as a wastewater treatment plant to deploy the remote sensing platforms for data collection and validation in the field.

Dissemination

Currently, we are preparing a paper entitled “Application of Deep knockoff in optical Satellite data for Marine Macroplastic detection”, which is aligned with the over objective of the project. In this paper a deep neural network called deep knockoffs is applied to the visible, near infrared, and short-wave infrared part of the spectrum using Sentinel-2 satellites data. By utilizing various statistical techniques, we ranked various spectral bands in terms of importance in microplastic detection. Considering the fact that our instrument has 2151 channels which covers the

spectral range of 350-2500 nm, the result of this research could substantially advance our knowledge in understating spectral signature of the microplastics. We plan to send the paper for review by June to a reputable scientific journal such as IEEE Transactions on Geoscience and Remote Sensing.