Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-210

Proposal Title: Sulfate Sensors for Monitoring Water Pollution in Minnesota

Project Manager Information

Name: Tianhong Cui

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: We propose to develop a small, cheap, and accurate sensor using a graphene transistor to monitor sulfate concentrations for protection of wild rice waters and the environment in Minnesota.

Funds Requested: $460,000

Proposed Project Completion: June 30, 2027

LCCMR Funding Category: Water Resources (B)

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

Narrative

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

Sulfate concentration is a key challenge across the state due to sulfate drainage from industries (mining industry, power plants, etc.) and a restrictive water quality standard of 10 mg/L in wild rice waters. Wild rice plays an important role in the ecosystem in Minnesota and is primarily found in water bodies with low sulfate levels. Until 2022, EPA and MPCA added 35 water bodies to the list of Minnesota's impaired water due to high sulfate levels. Immediate actions are needed to monitor sulfate in Minnesota waters for protection of wild rice species and for control of sulfate discharge from industry. Current detection methods for sulfate are flow injection analyses and ion chromatography (IC), which require collecting samples and measuring in laboratory. This limits the number of samples that can be tested. Moreover, sulfate levels in wastewater and treatment processes fluctuate, thus off-line measurements lead to delays in the results and are not capable of capturing variations in the data. The advanced manufacturing techniques at the University of Minnesota allow us to develop the sulfate sensors in a very high quantity at a super low cost, while surmounting the performance of sulfate detection using large equipment or devices.

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.

We propose to develop a sulfate sensor based on a graphene field effect transistor (FET) to achieve (1) a wide detection range, (2) point-of-location and remote detection, (3) small size and low cost, and (4) smart, on-sensor data processing. The proposed sensor will help to guide policy and law-making to better protect wild rice waters in Minnesota. By using and optimizing graphene and sulfate ion sensitive membranes (ISM), a large detectable range from 1 part per billion to 1000 parts per million will be achieved. Graphene is a material with one layer of carbon atoms. It enables high sensitivity of sulfate testing. ISM is a polymer film that allows only ion exchange of sulfate in the water to achieve specific detection of sulfate ions. Point-of-location detection will be achieved by using a field effect transistor as the sensor platform. FET sensors can be fabricated into portable sensing systems at very small size. Moreover, real-time sulfate sensing signals can be produced and transmitted. The sensor will be powered by a small battery. Sulfate sensors can be deployed in wastewater discharge locations for real-time and on-site measurement of sulfate. Advanced micromanufacturing technology will be used to greatly reduce the sensor cost.

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 project aims to solve the challenges of real-time sulfate detection, to reduce sulfate discharge, and to protect wild rice species in water bodies of Minnesota. Sulfate levels in water significantly affect the growth of wild rice. By accurately monitoring sulfate levels in wastewater and natural water, the control of sulfate in water can be much more effective. With guidance from the improved sulfate monitoring system, protection of the water bodies can be achieved. Therefore, the proposed sensor makes it possible to maintain a healthier natural water ecological environment and to enhance the state's unique wild rice resource.

Activities and Milestones

Activity 1: Development of a small, cheap, and accurate graphene field effect transistor for sulfate detection in laboratory

Activity Budget: $230,000

Activity Description:
A graphene field effect transistor (FET) for detection of sulfate concentrations in water will be designed, fabricated, and tested. The sensors in a rice grain size can achieve accurate and stable measurement of sulfate from low to high concentrations. We propose to develop a comb-structured FET array, including sulfate and pH sensors together. A single layer graphene will be transferred to the FET array to serve as sensing channels. Ion sensitive membranes for sulfate will be synthesized and coated on the sulfate sensor. A hydrogen sensitive membrane will be coated on the pH sensor. The real-time pH value will be used to correct sulfate sensor outputs. Sensor packaging and protection will be optimized to achieve long-term stability. The developed sensors will be tested in the laboratory with solutions at different sulfate concentrations from the sulfate treatment pilot systems with the process water from NRRI, Duluth. Real water samples will be collected by Fond du Lac Environmental Program, Western Lake Superior Sanitary District, and Aurora Wastewater Treatment Facility under the guideline and support of MPCA (see attached supporting letters) and will be tested with the sensors. The measured sulfate concentrations will be compared with readings in laboratory with ion chromatography analyses.

Activity Milestones:

Description	Approximate Completion Date
Design and fabricate the graphene field effect transistor sensors	December 31, 2024
Characterize, evaluate, improve, and optimize the designed graphene transistor sensors	June 30, 2025
Test the graphene sensors in the two sulfate treatment pilot systems from NRRI at Duluth	August 31, 2025
Package and protect the graphene transistor sensors for long-term stability and usage	December 31, 2025

Activity 2: Development and integration of graphene field effect transistor sulfate sensors with wireless and on-site testing modules

Activity Budget: $230,000

Activity Description:
A wireless communication module will be designed and fabricated in laboratory. The built-in transmitter will transfer the sulfate concentration data to a cloud data logger. Onboard sensor control will be implemented with the wireless communication system. The control system will measure electrical signals from the sulfate sensor and process the signal into real sulfate concentration output. The output will be transferred to the cloud by the wireless communication module. After optimization of the sulfate sensor system, sensors will be deployed to wild rice water bodies to periodically gather sulfate data without the need for water sample collection. Sensors will also be deployed to wastewater discharge sites to evaluate actual sulfate levels. Long-term continued monitoring by the sensors will be conducted in two sulfate treatment pilot systems (a chemical treatment system and a biological treatment system) while field pilot trials are performed. Drs. Cui and Simon will work with Dr. Cai closely on the field tests. We will work with Fond du Lac Environmental Program, Western Lake Superior Sanitary District, and Aurora Wastewater Treatment Facility on field tests of sulfate sensors. The sulfate sensors will help MPCA to implement a new sulfate quality standard in waters used to produce wild rice.

Activity Milestones:

Description	Approximate Completion Date
Design and fabricate the wireless communication module	June 30, 2026
Deploy the sensor with the wireless communication module in two sulfate treatment systems	July 31, 2026
Design and implement the smart data acquisition and processing system	December 31, 2026
Field test sulfate sensors with wireless communication and smart data processing modules	June 30, 2027

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Terrence Simon	University of Minnesota, Twin Cities	Dr. Simon will work with Dr. Cui on the design of sulfate sensors using his expertise of mass transport to enhance the sensing performance. He will also help to work on the experiments of sulfate sensors in laboratory. Drs. Cui and Simon will co-advise the postdoc on his daily work.	Yes
Meijun Cai	Natural Resources Research Institute (NRRI), University of Minnesota at Duluth	Dr. Cai will collaborate with Drs. Cui and Simon on the implementation of water sampling from lakes, wastewater treatment facilities, and power plants for laboratory tests of sulfate sensors. She will also facilitate and collaborate with Dr. Cui on field tests of sulfate sensors in the above fields.	Yes

Long-Term Implementation and Funding

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

An integrated sulfate sensing system will be developed in Minnesota. This will help MPCA to develop standards and strategies to prevent, control, and abate sulfate discharges that cause water pollution. Patents based on the developed prototypes will be applied for commercialization. The systems will be deployed in water bodies in Minnesota. Further work will focus on integration and intelligence of the sensing system, such as the implantation of wireless communication and closed-loop control systems for sulfate treatment. Federal funding from NSF and EPA, and private funds, will be applied to further develop the sulfate sensors and sensor networks.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Develop Small and Inexpensive Purification System for Community Drinking Water	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 04e	$425,000
Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 07c	$300,000

Project Manager and Organization Qualifications

Project Manager Name: Tianhong Cui

Job Title: Distinguished McKnight University Professor

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

Dr. Tianhong Cui is a Distinguished McKnight University Professor at the University of Minnesota. He is a Professor in Mechanical Engineering and an Affiliate Senior Member of the graduate faculty in Electrical and Computer Engineering. He joined the faculty of the University of Minnesota in 2003. He is a Fellow of the American Society of Mechanical Engineering. He is also a member of European Academy of Sciences and Arts. Dr. Cui is an international leading expert on micro sensors and advanced manufacturing. He has 368 archived publications in scientific journals and prestigious conferences. He is the founding Executive Editor-in-Chief for a Nature journal, Microsystems & Nanoengineering. He has received awards including the STA & NEDO Fellowships in Japan, the Alexander von Humboldt Fellowship in Germany, the Richard & Barbara Endowed Chair and the Distinguished McKnight University Professorship from the University of

Minnesota, the Blaise Pascal Chair Visiting Professorship in France (named after famous French scientist Blaise Pascal), the Distinguished Visiting Fellowship from the Royal Academy of Engineering and the Global Chair at the University of Bath in UK, a recent JSPS faculty fellowship at the University of Tokyo, and numerous best paper awards.

Dr. Cui will serve as the PI and project manager, responsible for overseeing the project, all reports, and deliverables. He will supervise one postdoc to work on the design, fabrication, and characterization of the sulfate sensors for water pollutant detection. He will hold weekly meetings and daily technical discussions with his advisee to ensure good progress of this proposed work. Dr. Cui will work with Dr. Terrence Simon who will assist in design aspects associated with species transport and experiments in laboratory. He will collaborate with Dr. Meijun Cai on field tests of the sulfate sensors in lakes where wild rice is cultured, wastewater treatment facilities, and power plants.

Organization: U of MN - College of Science and Engineering

Organization Description:
Organization Description:
The College of Science and Engineering at the University of Minnesota was recently named among the top 10 programs in the nation by Research.com. This work will be performed at the University of Minnesota in the Technology Integration & Advanced Nano/Microsystems Laboratory (TIAN Lab), located in the Mechanical Engineering Building. Professor Cui is the director of TIAN Lab equipped with the state-of-the-art instrument and facility to conduct the proposed research, with a variety of fabrication and characterization equipment and tools, sufficient for Professor Cui and his postdoc to design, fabricate, characterize, and analyze the proposed sulfate sensors. Some fabrication work will be done in Minnesota Nano Center, a state-of-the-art facility in nanoscience and applied nanotechnology.

The Natural Resources Research Institute (NRRI) is an applied research and economic development engine for the University of Minnesota research enterprise. NRRI employs over 130 scientists, engineers, and technicians to deliver on its mission to integrate research solutions that value our resources, environment, and economy for a sustainable and resilient future. NRRI collaborates broadly across the University system, the state, and the region to address the challenges of a natural resource-based economy. NRRI researchers have extensive experience in managing large interdisciplinary projects.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Tianhong Cui		Principal Investigator			26.9%	0.15		$42,211
Terry Simon		Co-Principal Investigator			26.9%	0.15		$45,937
Post Doctoral Associate		Research assistant of PI's to design, fabricate, and test the sulfate sensors			21.9%	3		$217,661
Mei Cai		Co-Principal Investigator			26.39%	0.24		$29,936
Shashi Rao		Collaborator on field tests using the two pilot sulfate treatment systems			26.9%	0.09		$15,044
Chan Lan Chun		Collaborator on water sampling from power plants at Duluth			26.9%	0.24		$11,203
Post Doctoral Associate		Ion Chramatography measurement in laboratory			21.9%	0.06		$4,284
Technician		Assistance on set-up of field tests			26.9%	0.03		$2,594
Researcher 2		Two pilot system operation for field tests			26.9%	0.09		$8,017
Graduate Student		Assistance on some field tests			19.4%	0.03		$1,536
Undergraduate Student		Summer intern on training of sulfate sensors			0%	0.45		$16,380
Temp/Casual		Technical support on filed tests			7.6%	0.03		$1,350
							Sub Total	**$396,153**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Materials & supplies for fabrication and testing of sulfate sensors	These are materials and supplies needed for the development of sulfate sensors					$21,847
	Tools and Supplies	Supplies for ion chramatography machine, sample collection/processing, and other general supplies	These are tools and supplies for laboratory and field tests					$9,000
							Sub Total	**$30,847**

Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Other	In-state travels	This budget is for in-state travels from Minneapolis to Duluth for field tests					$9,000
	Other	Sample collections	This is a budget for in-state travel from NRRI to fields for on-site tests					$1,800
							Sub Total	**$10,800**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
		Scientific Services	Cost of fabrication and characterization equipment usage at Minnesota Nano Center and Characterization Facility at the University of Minnesota					$18,000
		Shipping	Sample shipping to UMN, or to external labs					$1,200
		Lab services	External lab measurement					$3,000
							Sub Total	**$22,200**
							Grand Total	**$460,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	F&A	Support facility at both laboratories at Twin Cities and Duluth at the University of Minnesota	Secured	$252,721
			Non State Sub Total	**$252,721**
			Funds Total	**$252,721**

Attachments

Required Attachments

Visual Component

File: 0f4324ae-760.pdf

Alternate Text for Visual Component

Comparison of old and new technologies of sulfate detection...

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
MPCA Letter of Support	b2845467-e07.pdf
Fond Du Lac Letter of Support	f5c47c65-f4e.pdf
WLSSD Letter of Support	41f58298-036.pdf
UMN SPA Support Letter	4635efcc-a67.pdf
Aurora Wastewater Treatment Facility Supporting Letter	2e56ac2a-2dd.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

Yes

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

Yes

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

No

Does your project include original, hypothesis-driven research?

No

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Does your project include the design, construction, or renovation of a building, trail, campground, or other capital asset costing $10,000 or more?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services, as defined in Minnesota Statutes section 299C.61 Subd.7?

No