



Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-174

Proposal Title: Innovative Sensing and Modeling for Improving Water Quality

Project Manager Information

Name: Zhenong Jin

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

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Project Basic Information

Project Summary: Integrated soil nutrient management for improving Minnesotan water quality through a novel sensing and hybrid model data assimilation system

Funds Requested: \$841,000

Proposed Project Completion: June 30, 2026

LCCMR Funding Category: Methods to Protect, Restore, and Enhance Land, Water, and Habitat (F)

Project Location

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

Region(s): SE

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.

Minnesota is a state with over 10,000 lakes, but about 40 percent of its waters are polluted. The largest fraction of pollutants come from over 26 million acres of agricultural land due to flawed soil nutrient management practices that load nitrogen (N) and phosphorus (P) to water bodies.

To improve the water quality in Minnesota, we need to mitigate the reactive N and P losses from agricultural land. However, we can't manage what we can't measure. Measuring those pollutants needs local observations in the soil and water flux. Sending people to collect samples on-site is the most widely adopted approach but can be labor-intensive and discontinuous. Using sensors for real-time nutrient monitoring has emerged recently but existing sensors can be expensive, single-functional, and hard to maintain. In contrast, the multifunctional graphene nanosensor has the potential for low-cost and real-time measurements.

In addition, even with the novel nanosensor, deploying it state-wide to measure all over Minnesota's land is still not practical due to sensor maintenance demands. A smarter way is deploying sensors strategically and then using model approaches constrained with observations (mostly by the novel sensors) to predict nutrient losses and reveal underlying causes to further mitigate the water pollution.

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.

First, we will develop a low-cost and high-sensitive nanosensor, and develop a power-autonomous sensor network to provide real-time nitrate and phosphate measurements together in agricultural soil and water. This sensor network will be validated extensively in the lab, and in a tile-drained field. Such a sensor network allows us to form a reliable wireless sensing system for soil nutrient monitoring.

Second, we will develop a hybrid model framework to combine the power of mechanics-driven and data-driven approaches to explicitly estimate the nutrient losses and reveal the underlying relationships between management practices and nutrient losses. The model will be trained/validated using both synthetic data and nanosensor measurements.

Combining the above two efforts, we will deploy the newly-developed sensor in representative fields over a pilot demonstration watershed, and measurements from each subregion (with a 10-digit hydrologic unit code (HUC10)) of the watershed will be aggregated as one study sample. The sensor measurements will help train the hybrid model to predict reliable predictions matching observations. The well-optimized model will be extrapolated to all watersheds in Minnesota to generate a reliable soil/water nutrient database and provide a comprehensive understanding of processes for further management practice optimization and water pollution mitigation.

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 outcomes of this project include:

A newly developed low-cost, high-sensitive, multifunctional nanosensor and a power-autonomous, wireless-communicating sensor network for monitoring nitrate and phosphate loads from agricultural soil to the water;

A hybrid model framework combining the mechanics-driven and data-driven approaches constrained by nanosensor observations capable of estimating the soil nutrient losses, and revealing the drivers and patterns for optimizing the agricultural management practices;

A set of detailed measurements of soil nitrate and phosphate concentration and flux over the Cannon River watershed, and a continuously updating database of model predicted soil nutrient losses together with corresponding soil states across Minnesota

Activities and Milestones

Activity 1: Develop and validate real-time on-site soil nanosensors with multiple functions to monitor nutrients for agricultural production systems

Activity Budget: \$453,271

Activity Description:

We will develop a low-cost and high-sensitive nanosensor and a power-autonomous sensor network for agricultural nutrient measurement. The nanosensor will comprise both electrochemical and optical sensing elements to monitor soil/water nitrate and phosphate together and corresponding environmental factors with good precision. The sensor network integrating the nanosensor, a data-acquisition electronic, a wireless antenna, a suction cup, and a solar panel will be power-autonomous and have wireless communication capability that would allow transmission of the recorded data to a base station enabling distributed site-specific real-time management.

The validation for the sensor network will initially involve a controlled lab-scale simulated soil system in which sensor data can easily be compared to data from laboratory analysis using a spectrophotometer to obtain nutrient concentrations and absorption spectrometry for heavy metals. Then we will develop and install a field sampling plan in-situ simultaneously collecting samples for nanosensor analysis and laboratory analysis for validation. A corresponding system will be developed utilizing the same sampling technique, but with samples stored for later collection and laboratory analysis. These corresponding systems would be installed in close proximity to the nanosensors and the data collected from each pair of two systems will be compared and validated against each other.

Activity Milestones:

Description	Completion Date
Sensor network development	June 30, 2024
Sensor network validation	December 31, 2024
Sensor field test and improvement	December 31, 2025

Activity 2: Develop and validate an effective and efficient hybrid modeling framework for predicting agricultural soil nutrient losses and understanding controlling processes

Activity Budget: \$181,800

Activity Description:

To predict the nitrate and phosphate in the soil profile and water flux, and reveal the causal relations of controlling factors such as soil thermal, hydrology, crop type, and management practices (e.g. fertilizer, tile drainage), We will develop a new hybrid framework for agroecosystem combining the power of mechanics-driven and data-driven approaches and assimilating data from different sources. The deep learning model gated recurrent unit (GRU) will be the basis for modeling the time dependence of the previous soil states. An advanced mechanics-driven agroecosystem model will be used to provide the causal relations between nutrient dynamics and controlling factors for model hierarchical structure development and generate millions of “free” synthetic data for model pretraining.

Measurements from the nanosensors located sites can be used to finetune/validate the developed hybrid model framework. Specifically, these measurements provide observations of nitrate and phosphate fluxes through leaching and tile drainage for constraining nutrient loss predictions. More importantly, the nanosensor provides intermediate variables (nitrate and phosphate concentrations in soil profiles) that may serve as critical checkpoints to constrain the controlling causal relations such as how fertilizer rate influences the soil nitrate and then drainage nitrate.

Activity Milestones:

Description	Completion Date
Hybrid model development	December 31, 2023

External observed data collection	June 30, 2024
Hybrid model training/validation	December 31, 2024

Activity 3: Integrate the newly developed sensor and model into a framework for measuring water pollution from agricultural soil nitrate and phosphate

Activity Budget: \$205,929

Activity Description:

We will deploy the new nanosensor network over the Cannon River watershed (huc-07040002) as a test. The sensors would be installed in representative fields of the watershed and the fields in each subregion with HUC10 of the watershed would be aggregated as one study sample. After the deployments, the soil/water nitrate and phosphate concentration and water flux rate data will be collected during a long period (>1 year) automatically with a daily frequency, to cover at least a whole crop-producing year.

Measurements from different HUC10s will be independent samples to support optimizing the new hybrid model. The objective is to finetune the hybrid model framework to generate predictions matching observations and provide reliable relationships between management practices and soil nutrient losses.

The hybrid model framework constrained by nanosensor measurements will eventually be extrapolated to other watersheds with limited or no on-site measurements to generate a database of estimations of nutrient losses and corresponding intermediate variables at high spatial and temporal resolutions, by assimilating the blooming remote sensing data. The database is expected to be cost-effective, accurate, scalable, and down-to-field, with great potential to be used directly by farmer communities to optimize management practices to reduce water pollution.

Activity Milestones:

Description	Completion Date
Sensor network deployment over one watershed	April 30, 2024
Hybrid model finetuning/adjusting over one watershed	June 30, 2025
Sensor data collection and analysis	June 30, 2026
Hybrid model extrapolation and nutrient database generating	June 30, 2026

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?

his project proposes are expected to enable new methods of managing soil N and P cycles for more efficient agricultural production and improved water quality. The tools to be developed are expected to be cost-effective, accurate, scalable, and down-to-field, with great potential to be used directly by farmer communities to optimize field-scale N and P fertilizer uses. There are multiple channels to support the tools derived from this project including national programs such as the Great Lakes Restoration Initiative, state funding sources like the Agricultural Fertilizer Research and Education Council (AFREC), and other market mechanisms aiming at clean water.

Project Manager and Organization Qualifications

Project Manager Name: Zhenong Jin

Job Title: Assistant Professor

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

Zhenong Jin is a broadly trained agroecologist whose research pushes the frontier of data analytics for sustainable agriculture by integrating remote sensing, computational modeling and machine learning, such that we can monitor and manage every cropland, track pollutants, forecast agricultural risks, provide farmers best solutions to minimize negative environmental impacts, and ultimately help the world to achieve a sustainable food future. Since joining the UMN in 2019, Dr. Jin has served as PI and Co-PI for multiple federal grants of more than \$10 million budget. His current projects mainly focus on crop mapping and yield forecast, nitrogen (N) and phosphorus (P) cycle modeling, high-resolution quantification for agricultural greenhouse gas (GHG) emissions, and climate change adaptations. Dr. Jin received a Ph.D. degree in Earth & Atmospheric science from Purdue University, had his Postdoctoral training at Stanford University, and was the Lead Crop Scientist at AtlasAI.

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

Organization Description:

The University of Minnesota is a federal land grant public institution of higher learning. The above referenced proposal is hereby endorsed, and submitted, on behalf of the Board of Regents of the University of Minnesota. The proposed research will mainly conducted In the College of Food, Agricultural and Natural Resources Sciences (CFANS). CFANS is dedicated to advancing Minnesota as a global leader in food, agriculture, and natural resources through extraordinary education, science-based solutions, and dynamic public engagement that nourishes people and enhances the environment in which we live.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	\$ Amount
Personnel								
Researcher		Zhenong Jin - Assistant Professor - Will lead the project and coordinate the field work; Jin will also surprise the modeling component of this project			25%	0.18		\$20,477
Researcher		Tianhong Cui - Professor - will lead the nanosensor development, fabrication and lab test			25%	0.24		\$76,544
Researcher		Roger Ruan - Professor - will work closely with Dr. Cui and lead sensor testing, benchmarking, calibration, field deployment			25%	0.12		\$31,880
Senior Personnel		Licheng Liu - Research Scientist - will lead the model-data integration objective, including tasks to calibrate and validate the mechanistic model, develop a hybrid AI-based model to assimilate nanosensor measurements, generate high-resolution regional maps			25%	0.75		\$67,413
Technician		TBD (with Jin) - Electrical Engineer - Packaging sensor for field deployment, tasks including integrating interface, datalogger, field unit hardware engineering, field deployment experiment and regular maintainence			25%	1.5		\$122,569
Postdoc Researcher		TBD (with Cui) - Postdoc - Will work under Prof. Cui's supervision to develop, fabricate and test the nanosensor			17.3%	3		\$179,311
Graduate Research Assistant		TBD (with Ruan) - this 50% RA will work with Prof. Ruan to benchmark, test, calibrate and deploy the nanosensor			19.1%	1.5		\$160,138
Graduate Research Assistant		TBD (with Jin) this 25% RA will work under Prof. Jin's supervise to develop and calibrate the modeling of water fluxes and runoff using ecosys; generating large ensemble of synthetic data for training hybrid models			19.1%	0.75		\$80,070
							Sub Total	\$738,402
Contracts and Services								
TBD	Professional or Technical	external service fee to reimburse fieldwork by local watershed partners, including sensor maintenance,				2		\$20,000

	Service Contract	nitrate and phosphate solute sampling and measurement in for at least 5 locations and 3 times per year						
							Sub Total	\$20,000
Equipment, Tools, and Supplies								
	Tools and Supplies	Consumable materials sensor development shared by Cui, Ruan and Jin such as graphene sensor toolkit, nitrate/phosphate-selective membranes, Interfaces/support electronics, Datalogger electronics, Field unit hardware, standard solutions, and other consumables per year	for nanosensor development, testing, and fabrication					\$36,598
	Tools and Supplies	Facility charge for using MN Nano Center for sensor manufacturing, with annual charge budgeted at \$14000, \$12000 and \$4000	facility charge					\$30,000
							Sub Total	\$66,598
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
	Miles/ Meals/ Lodging	Weekly travel for regular checkups on field plots in UMN Southern Research and Outreach Center. Expense will be expensed in accordance of the University of MN reimbursement rates and guidelines in Year 1, and multiple sampling sites in a local watershed (likely the Cannon River Watershed). Expense will be expensed in accordance of the University of MN reimbursement rates and guidelines.	travel for field sensor test and deployment					\$7,500
							Sub Total	\$7,500

Travel Outside Minnesota								
	Conference Registration Miles/ Meals/ Lodging	Cui or the Postdoc travel to national conference to present research findings and seeking feedbacks. Budgeted for one trip per year with average registration fee of \$500, and an average stay of 3 days	travel to academic conference					\$4,500
							Sub Total	\$4,500
Printing and Publication								
	Publication	publication fee for two open access journal articles	to cover the publication cost					\$4,000
							Sub Total	\$4,000
Other Expenses								
							Sub Total	-
							Grand Total	\$841,000

Classified Staff or Generally Ineligible Expenses

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

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	-
Non-State				
			Non State Sub Total	-
			Funds Total	-

Attachments

Required Attachments

Visual Component

File: [144a45e4-63f.pdf](#)

Alternate Text for Visual Component

The project workflow overview. Including a) study region; b) developing nanosensor network; c) developing hybrid model framework; d) assimilating remote sensing data; and e) generating databases for on-site observations and model predictions....

Optional Attachments

Support Letter or Other

Title	File
Institutional Approval to Submit	19c0e310-f41.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?

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?

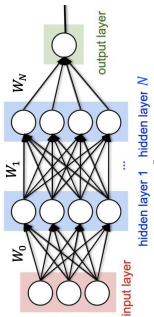
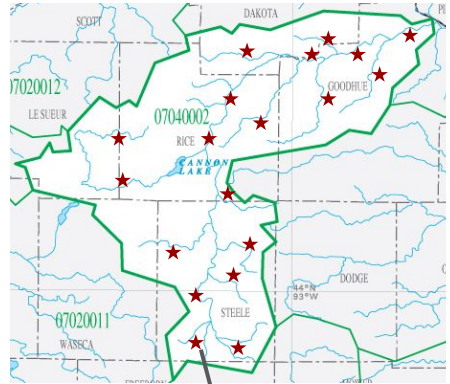
Yes

Does the organization have a fiscal agent for this project?

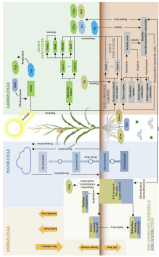
No

(a)

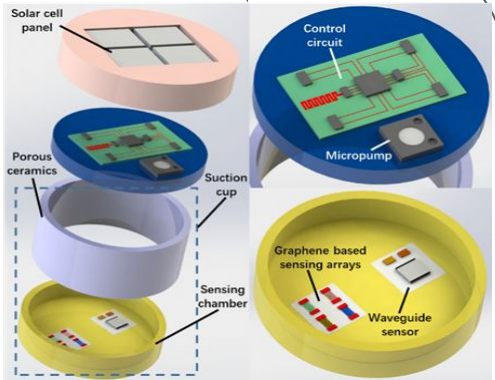
Soil nutrient losses detecting region and demonstration watershed to be on-site observed



Develop a **hybrid model framework** combining mechanics-driven and data-driven approaches constrained with nanosensor measurements

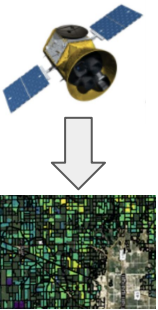


(b)



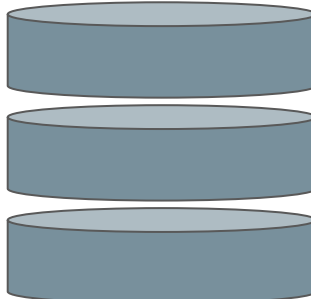
Develop a low-cost, high-sensitive, multifunctional **nanosensor** and a power-autonomous, wireless-communicating **sensor network** for monitoring reactive N and P in soil and water

(c)

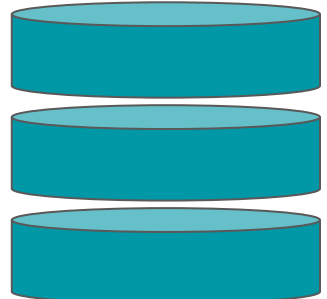


Assimilating the remote sensing data for on-site observation sparse areas for generating reactive N and P loss map

(d)



Database of **model predictions** over the whole Minnesota state for nutrient losses and corresponding intermediate variables



Database of **on-site measurements** over selected representative fields, drainage outlets and channels for nitrate and phosphate in soil and water flux

(e)