



Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-162

Proposal Title: Intelligent Drainage Systems Embedded with Miniature Nutrient Sensors

Project Manager Information

Name: Jeffrey Strock

Organization: U of MN - Southwest Research and Outreach Center

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Project Basic Information

Project Summary: We propose to develop an intelligent drainage system with embedded miniature sensors for precise monitoring and managing agricultural drainage water to reduce nitrogen and phosphorus pollution of surface waters.

Funds Requested: \$951,000

Proposed Project Completion: June 30, 2026

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

Narrative

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

In Minnesota, and across the Midwest, land use is dominated by row crop agriculture with extensive use of artificial subsurface drainage and ditches to manage field soil water conditions. Drainage is essential to agricultural production, but drainage also discharges nutrients from agricultural lands into sensitive waters, including lakes and rivers. Variations in the water cycle marked by increased precipitation, runoff, and nutrient and sediment transfers to rivers and lakes reflect climate change and increasing degradation of soil and water resources. Eutrophication arising from agricultural nitrogen and phosphorus inputs to surface waters accelerates growth of nuisance and harmful algae, reduces water transparency, negatively impacts aquatic life, degrades water quality, and can significantly impair or prohibit the use of rivers and lakes for aquatic recreation. Existing monitoring methods rely on bulky laboratory test equipment with expensive sensors that cannot perform on-site testing over real-time within farmland drainage systems. Therefore, new drainage system management coupled with miniature embedded sensors for monitoring nitrate and phosphate in agricultural drainage will be of great value in agricultural production and environmental protection.

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 proposed research will result in a convergence of two technologies into one integrated system for managing drainage water and improving water quality. We propose a collaborative research effort to design miniature, low-cost, robust, and nutrient selective sensors for stability in harsh environments (e.g., cold temperatures). These sensors will be embedded within intelligent drainage water management systems to aid in mitigating water and nutrient loss from agricultural drainage through minimally invasive ditch management. New electrochemical sensors for nitrate and phosphate detection will be designed, fabricated, and deployed in a test intelligent drainage water management system. Sensors will be fabricated by advanced micro-manufacturing. Mass fabrication processes will reduce the cost of doing reliable nutrient measurement in water from the present cost of greater than \$10,000 per sensor to less than \$1. This project will lead to fundamental changes in agricultural drainage water management from the existing paradigm that focuses on rapid water conveyance through ditches, which drastically limits water storage and nutrient cycling, to a new paradigm where intelligent drainage water management with embedded nutrient sensors are seen as a valuable resource for improving water quality, enhancing groundwater recharge, and reducing peak flows.

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 addresses the grand challenge of water pollution from agricultural drainage systems by mitigating nitrogen and phosphorus in water. Agricultural drainage is the main source of nutrients entering surface waters from farmed landscapes. Reducing nutrient content in drainage is of great value toward controlling eutrophication. It improves water quality and diminishes the development of harmful algal blooms. It also reduces drinking water treatment costs and supports ditch-side riparian vegetation with its many attendant habitat, wildlife, and aesthetic values.

Activities and Milestones

Activity 1: Co-Development of miniature, inexpensive, sensitive sensors to detect real-time nitrate and phosphate concentrations and intelligent drainage water management systems.

Activity Budget: \$325,274

Activity Description:

We propose to evaluate a low-cost, miniature sensor array for nutrient detection in water. The sensor array will be designed, fabricated, and evaluated by Profs. Cui and Simon. There are three key features of the sensor array to ensure high performance. Sensor material must be stable under a range of environmental conditions. The sensor array must be selective for the priority nutrients, nitrate and phosphate. The sensor array must have a high level sensitivity over a wide range of nutrient concentrations. The sensor will be tested and evaluated in the lab with water mimicking drainage water containing nitrate and phosphate.

We propose a water management practice to mitigate the negative impacts of agricultural drainage while minimizing undesirable consequences on crops and farm management. Our approach conceptualizes networks of coordinated sensing and actuation devices to dynamically manage flows in drainage ditches using intelligent drainage water management systems. These systems can be managed to provide the necessary drainage capacity for agricultural production, build storage capacity prior to large storm events or periods of peak runoff, and increase water retention time to enhance nutrient retention and nutrient reduction through natural and enhanced biological processes. This work will be overseen by Prof. Strock.

Activity Milestones:

| Description | Completion Date |
|---|-----------------|
| Design and fabrication of a new sensor array as a testing prototype in the laboratory. | June 30, 2024 |
| Evaluation of sensor performance under complex environments in the lab and with real environmental water. | June 30, 2024 |
| Deployment and testing of an intelligent drainage water management system in the field. | June 30, 2024 |

Activity 2: Integration of sensor arrays with the intelligent drainage water management system; evaluation of the integrated system by lab scale testing.

Activity Budget: \$306,866

Activity Description:

The focus of this activity is to merge two technologies into one integrated system for managing drainage water and improving water quality. We propose to integrate the sensor array within a bench-top scale intelligent drainage water management system in the laboratory to measure nitrate and phosphate concentrations throughout. A wireless communication unit will be added to transmit results from the sensors to smartphones or computers, and the data will be analyzed to optimize drainage system management by control of water levels by weirs distributed throughout.

Activity Milestones:

| Description | Completion Date |
|---|-----------------|
| Improved design, fabrication, and evaluation of a sensor array for real environment water measurements. | June 30, 2025 |
| Integrated intelligent water management system and embedded sensors; Evaluation of the system in the lab. | June 30, 2025 |

Activity 3: Optimization into a full-scale integrated intelligent drainage water management system with embedded sensors and evaluation of performance in the field.

Activity Budget: \$318,860

Activity Description:

The focus of this activity will be field testing of sensor arrays in the intelligent drainage water management system under natural conditions at the University of Minnesota experimental drainage research facility located at the Southwest Research and Outreach Center, near Lamberton, MN. Our methods will integrate embedded sensor arrays in an intelligent drainage water management system within a small watershed (300 acres) designed to measure the impact of crop production and ditch water management on water quantity and water quality.

Activity Milestones:

| Description | Completion Date |
|---|-----------------|
| Optimize long-term stability, under natural conditions, synergy between sensor array and intelligent drainage management system. | June 30, 2026 |
| Optimization, under natural conditions, operation and management of intelligent drainage management system with embedded sensors. | June 30, 2026 |

Project Partners and Collaborators

| Name | Organization | Role | Receiving Funds |
|----------------|-------------------------|---|-----------------|
| Tianhong Cui | University of Minnesota | Dr. Tianhong Cui is a co-PI, Distinguished McKnight Professor, and Fellow of the American Society of Mechanical Engineering. Dr. Cui is an expert on micro-devices and advanced manufacturing. He will co-supervise staff working on design, fabrication, and characterization of miniature nutrient sensors. | Yes |
| Terrence Simon | University of Minnesota | Dr. Terrence Simon is a Professor in the Department of Mechanical Engineering. He will serve as a co-PI and will co-supervise staff with Prof. Cui. His contributions to the project will include computation, visualization, and characterization of mass transfer of nutrients to enhance sensor performance. | 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?

This project will result in performance testing of innovative, low-cost solutions to improve water quality using integrated intelligent drainage water management systems with embedded miniature sensors. The convergence of these two technologies will diminish nitrogen and phosphorus loss in agricultural drainage resulting in reduced growth of nuisance, harmful algae and eutrophication. These systems have the potential to be deployed from local to international scales. Patent applications based on developed prototypes will be written for commercialization. Potential funding sources to maintain ongoing research, development, and implementation efforts include: MnDrive and federal funding from USDA, NRCS, USGS, NSF, EPA, and private foundations.

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 |
| Sustainable Irrigation Management: Expanding an Irrigation Web Application | M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 04e | \$1,139,000 |

Project Manager and Organization Qualifications

Project Manager Name: Jeffrey Strock

Job Title: Professor

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

Dr. Jeff Strock is a Soil Scientist and Professor in the Department of Soil, Water, and Climate at the University of Minnesota. He is located at the Southwest Research and Outreach Center near Lamberton, MN. He is an Affiliate Senior Member of the graduate faculty in Water Resources Science and Affiliate Associate Member of the graduate faculty in Sustainable Agriculture Systems. He is also a Fellow of the Soil and Water Conservation Society.

Dr. Strock has over 30 years of experience as an expert in the area of soil hydrology and agricultural drainage. He has published more than 100 publications in peer-reviewed journals, conference proceedings, and book chapters. Dr. Strock's research and public engagement activities focus on ways to create farming systems that are productive, profitable, resilient, and environmentally sound. Specific interests include integrated strategies for on-farm and beyond-

the-farm water quantity and quality management to temporarily store water on the landscape and reduce nitrogen and phosphorus mobility.

Organization: U of MN - Southwest Research and Outreach Center

Organization Description:

Activity 1 includes laboratory and field components. The laboratory component will be performed at the University of Minnesota Mechanical Engineering Building in the Technology Integration & Advanced Nano/Microsystems Laboratory (Cui lab) and the Convective Heat Transfer Lab (Simon lab). The labs are equipped with state-of-the-art instruments and facilities to conduct the proposed research, with a variety of fabrication and characterization equipment and tools, sufficient for Profs. Cui and Simon, the postdoc, and Ph.D. student to design, fabricate, characterize and analyze the proposed new sensor array for detection of nitrate and phosphate. The field component will be performed at the Experimental Drainage Research Facility located at University of Minnesota Southwest Research and Outreach Center near Lamberton, MN. The research facility consists of two ditch channels that enable researchers to evaluate various performance characteristics of the channels and implement management strategies such as the intelligent drainage water management system. The facility is equipped with water level control devices on the upstream and downstream ends, enabling partitioning of inflows and manipulation of flow velocities through the system. Activity 2 will be conducted in Profs. Cui's and Simon's labs, and Activity 3 will be conducted at Prof. Strock's Experimental Drainage Research Facility.

Budget Summary

| Category / Name | Subcategory or Type | Description | Purpose | Gen. Ineligible | % Benefits | # FTE | Classified Staff? | \$ Amount |
|--|---------------------|--|---|-----------------|------------|-------|-------------------|------------------|
| Personnel | | | | | | | | |
| Co-Principle Investigator 1/Tianhong Cui | | Supervise the design, fabrication, and characterization of the miniature nutrient sensors. | | | 36.8% | 0.24 | | \$79,220 |
| Co-Principle Investigator 2/Terrence Simon | | Characterization of mass transfer of nutrients to enhance sensor performance. | | | 36.8% | 0.24 | | \$86,504 |
| Post Doctoral Associate | | Collaborate with Co-Pis on design, fabrication, and testing of nutrient sensors, and study the proposed challenges. | | | 25.7% | 3 | | \$188,148 |
| Staff Scientist | | Collaborate with the project PI/PD and will be in charge of daily field data collection, maintenance, monitoring, data processing and analysis, report writing, and presentation preparation | | | 32% | 2.4 | | \$214,258 |
| Graduate Research Assistant | | Collaborate with Co-Pis on design, fabrication, and testing of nutrient sensors, and study the proposed challenges. | | | 19.9% | 1.5 | | \$165,987 |
| | | | | | | | Sub Total | \$734,117 |
| Contracts and Services | | | | | | | | |
| | | | | | | | Sub Total | - |
| Equipment, Tools, and Supplies | | | | | | | | |
| | Equipment | Commercially available nutrient Sensors | For side-by-side comparison of newly developed low cost, miniature sensors. | | | | | \$30,000 |
| | Tools and Supplies | Silicon wafers, polymer substrates, and other chemicals and components. | Items required for design, fabrication and testing of sensors. | | | | | \$48,000 |
| | Tools and Supplies | Batteries, solar panels, bottles, chemical reagents, equipment enclosures, and components for field testing set-up. | Items required to operate and maintain the experimental field site. | | | | | \$30,000 |
| | | | | | | | Sub Total | \$108,000 |

| | | | | | | | | |
|-------------------------------------|---|--|--|--|--|--|------------------|-----------------|
| Capital Expenditures | | | | | | | | |
| | | | | | | | Sub Total | - |
| Acquisitions and Stewardship | | | | | | | | |
| | | | | | | | Sub Total | - |
| Travel In Minnesota | | | | | | | | |
| | Miles/ Meals/ Lodging | 12 trips per year, 280 miles round trip, one to four people, \$.585 per mile. | Site visits PI/Co-PI's/Other Staff to sensor lab and field site. | | | | | \$5,897 |
| | Conference Registration Miles/ Meals/ Lodging | 1 trip per year, 280 miles round trip, one to four people, \$.585 per mile, plus meeting registration. | Presentation of project results at Minnesota Water Resources Conference. | | | | | \$1,311 |
| | | | | | | | Sub Total | \$7,208 |
| Travel Outside Minnesota | | | | | | | | |
| | Conference Registration Miles/ Meals/ Lodging | One to two trips per year, two to four people, professional conferences. | Presentation of project results at professional conferences. | | | | | \$11,675 |
| | | | | | | | Sub Total | \$11,675 |
| Printing and Publication | | | | | | | | |
| | | | | | | | Sub Total | - |
| Other Expenses | | | | | | | | |
| | | Scientific Services | University of Minnesota's Minnesota Nano Center for fabrication costs of the sensors and the University of Minnesota's Characterization facility for characterization of the electrochemical sensors | | | | | \$45,000 |
| | | Scientific Services | University of Minnesota's Research Analytical lab for characterization of | | | | | \$30,000 |

| | | | | | | | | |
|--|--|-------------------------|---|--|--|--|--------------------|------------------|
| | | | comparative nutrients from water samples collected at the experimental site. | | | | | |
| | | Maintenance and Repairs | This amount is for various items including, for example, annual sensor calibration, water sampler repair, and ditch maintenance at the experimental field site. | | | | | \$15,000 |
| | | | | | | | Sub Total | \$90,000 |
| | | | | | | | Grand Total | \$951,000 |

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 | | | | |
| | | | Non State Sub Total | - |
| | | | Funds Total | - |

Attachments

Required Attachments

Visual Component

File: [3ab74f85-8b6.pdf](#)

Alternate Text for Visual Component

Visual consists of three panels: 1) current technology, 2) new technology proposed; and 3) future applications of technology. Panel 1: current sensor technology and unmanaged drainage ditch. Panel 2: conceptual illustrations of an intelligent drainage water management system with embedded nutrient sensors. Panel 3: future application and integration of technologies....

Optional Attachments

Support Letter or Other

| Title | File |
|--|----------------------------------|
| Official UMN Board of Regents Endorsement letter | 3c0b63de-fa4.pdf |

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

Yes

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

Yes

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

No

Does your project include original, hypothesis-driven research?

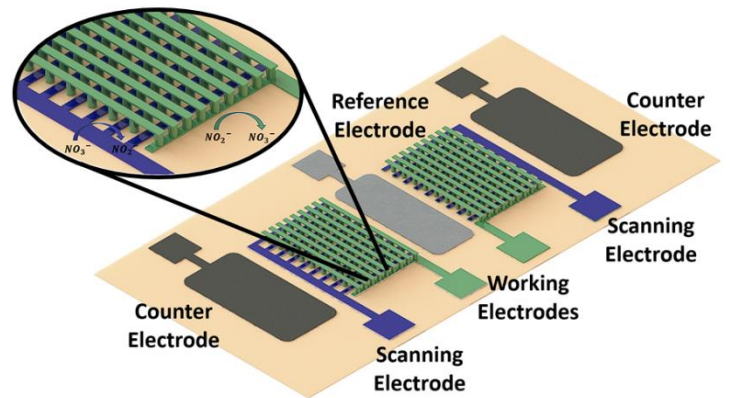
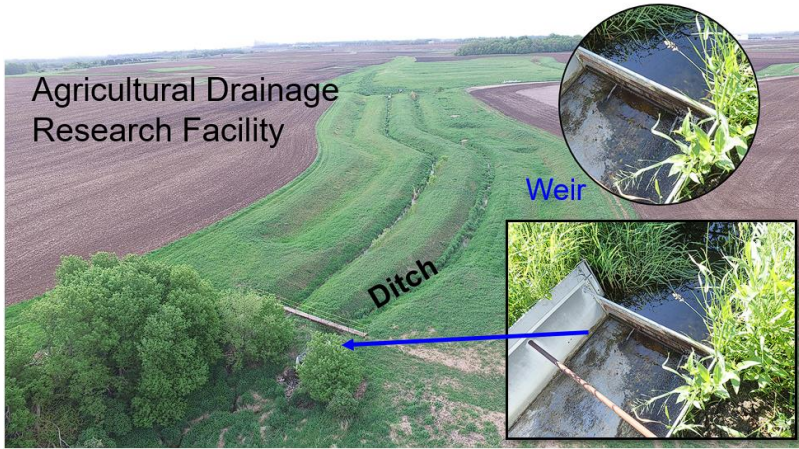
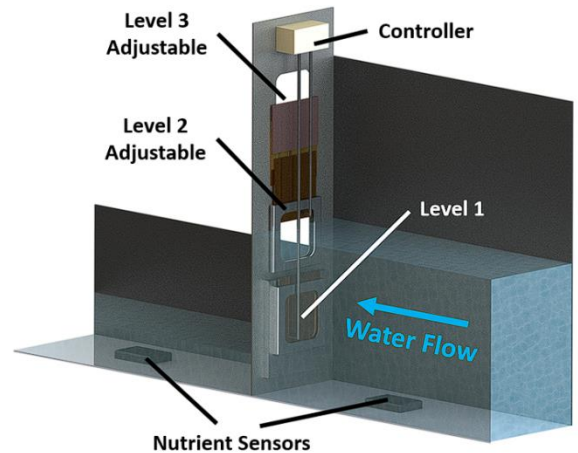
Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

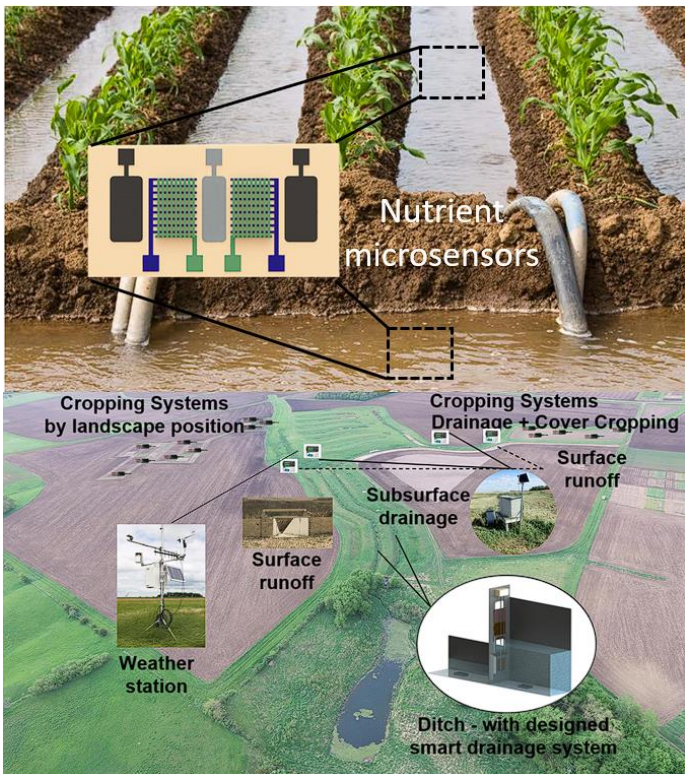
PIs: Jeff Strock, Tianhong Cui, Terrence Simon

Project Title: Intelligent Drainage Systems Embedded with Miniature Nutrient Sensors



Current Technology

New Technology Proposed



- Efficient
- Accurate
- Sensitive
- Stable
- Cheap

Future applications to pollutants monitoring in farmland and Minnesota waters

