Environment and Natural Resources Trust Fund
2020 Request for Proposals (RFP)

Project Title: **ENRTF ID: 088-B**

Cheap Small Sensor Network for Water Pollutants Monitoring

Category: B. Water Resources

Sub-Category:

Total Project Budget: $ 635,000

Proposed Project Time Period for the Funding Requested: June 30, 2023 (3 yrs)

Summary:

This project is to develop practical sensor networks based on sensors in Phase I, a very cheap and highly efficient approach for pollutants monitoring of lakes and rivers in Minnesota.

Name: Tianhong Cui

Sponsoring Organization: U of MN

Job Title: Professor

Department:

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Location:

Region: Statewide

County Name: Statewide

City / Township: Minneapolis

Alternate Text for Visual:

Compared to current lab and on-site equipment for testing water pollutants, the proposed sensor network is 5 times more accurate, while it is 20 times cheaper.

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: Develop Cheap Sensor Networks for Remote Monitoring and Mapping of Pollutants in Minnesota Lakes and Rivers (Phase II)

I. PROJECT STATEMENT

Assuring sufficient clean water and sustainability of water resources is a complex grand challenge with far-reaching implications for human health, agriculture, energy production, the vitality of communities, the health of ecosystems, and the environment at large. The World Economic Forum recently identified shortage of clean water as the No. 1 global threat. By 2030 most of the world's population is expected to live under conditions of water stress. Water pollution accounts for 1.8 million premature deaths annually in the world. Minnesota is a water-rich state. We have more than 12,000 lakes and nearly 92,000 miles of rivers and streams. However, a big portion of lakes and rivers are contaminated.

This proposed project, building on an ongoing project funded through ENRTF 2016 appropriation, is to develop low-cost and high-performance sensor networks and infrastructure that can be used for monitoring and collecting big data on pollutants in lakes and rivers in Minnesota. In phase I, we successfully developed the sensors, proved their feasibility, and provided foundational knowledge for further development towards implementation. The sensors developed in Phase I are small, cheap, fast, and accurate. The low cost and high automation features of the technology will make large scale and frequent data collection technically and economically feasible. Phase II of this project will be focused on optimization of the sensors' performance in the complex conditions of actual lake and river waters, development of compact sensing units for harsh outdoor environments, and testing of sensor networks in multiple locations. Our techniques have the potential to replace off-site detections and analyses with bulky and expensive equipment currently practiced. The advanced manufacturing facilities at the University of Minnesota allow us to optimize and produce the sensors in a very high quantity at a super low cost, while surmounting the performance of pollutants detection using large equipment or devices. This will help the end-users including water quality control and regulatory agencies, researchers, and advocacy groups for continuous detection and analysis of Minnesota waters, and develop techniques to mitigate water contaminations

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Optimize sensors and develop sensing units in actual waters* **Budget: $420,000**

The objective of this activity is to optimize sensors and further develop sensor units, each of which consists of an array of the sensors for detection of target pollutants, i.e., phosphate, nitrate, mercury, and chloride. The four species are selected because these are primary water pollutants in Minnesota, according to the standards from MPCA and EPA. First, the performance of sensors and sensor arrays under different outdoor environmental conditions with actual pH, varied temperature, and presence of particles will be evaluated. Based on the experimental results, the sensors and sensor arrays will be conducted to optimize the performance. Next, a small prototype sensing unit with hardware and software for operation control, data acquisition and display, and wireless data transmission will be designed and fabricated. Data receiving protocol and infrastructure will be developed. The prototype unit will be subjected to lab and in-field tests. The performance of the unit will be evaluated against conventional methods. Last, test results will be used to design working units with improved sensing performance and operation features. Three working units will be fabricated for Activity 2.

Outcomes	Completion Date
1. The sensors and sensor arrays are optimized for monitoring of phosphate, nitrate, mercury, and chloride in harsh environments.	*6/30/2021*
2. Hardware and software are developed for a prototype unit with wireless data transmission capability. The prototype unit will be tested in lab and field. A design of working unit with improved performance and operation features will be produced.	*6/30/2021*
3. Three working sensing units will be fabricated for testing and operation described in Activity 2.	*6/30/2022*
4. Comprehensive assessment of the techniques of sensors and sensing units	*6/30/2022*

Activity 2: *Develop sensor networks for long-term field tests in lakes and rivers* **Budget: $215,000**

Working closely with MPCA staff, we will select three stations from the following locations for field tests: (1) Minnesota River at Fort Snelling State Park, MN (33143004), Site Type: Basin; (2) Cannon River at Morristown, CSAH16 (39091001), Site Type: Sub-Watershed; (3) Cannon River at Welch, MN (39004002), Site Type: Major Watershed; (4) St Croix River at Stillwater, MN36 (37061001), Site Type: Basin; and (5) Mississippi River L&D #3 Red Wing, Lock and Dam Rd (38014001), Site Type: Basin. Each unit installed on site will be protected from damage by debris and animals by proper housing. The data collection center will be located on the UMN campus. Tests will be conducted during spring, summer, and fall seasons. We will compare the data collected from the sites with lab tests and the Watershed Pollutant Load Monitoring Network (WPLMN), and calibrate our units when necessary. We will demonstrate the test stations to the stakeholders and LCCMR committee members and officials.

Outcomes	**Completion Date**
1. Select monitoring stations and install working units in stations to form sensor networks	*12/31/2022*
2. Acquire data and compare the results with those from MPCA labs	*12/31/2023*
3. Demonstrate the technology in on-site stations	*6/30/2023*

III. PROJECT PARTNERS:

A. Project team members receiving ENRTF funding

Name	Title	Affiliation	Role
Tianhong Cui	Professor	University of Minnesota	PI
Roger Ruan	Professor	University of Minnesota	Co-PI
Paul Chen	Professor	University of Minnesota	Co-PI

B. Partners NOT receiving ENRTF funding

Name	Title	Affiliation	Role
Lee Ganske	Agent	Minnesota Pollutant Control Agency (MPCA)	Collaborator
Leisa Thompson	General Manaager	Metropolitian Council Environmental Services MCES)	End-User

IV. LONG-TERM- IMPLEMENTATION AND FUNDING:

Water is an important resource for Minnesota. To monitor water quality, MPCA launched “Milestone” monitoring network and WPLMN. However, the water sample collection, testing and monitoring are tedious, costly and labor intensive, therefore only a few points in Minnesota can be monitored. Using the remote sensor networks, water quality information in vast water resources can be assessed and monitored remotely and continuously, making large-scale water monitoring and potentially large-scale water quality database feasible, reliable, convenient and cheap. With the establishment of the sensor network, more sites can be added to the network, and the collected large database could support more comprehensive analysis and assessment of the Minnesota waters. This will provide a solution to current expensive monitoring programs in Minnesota, ultimately help the MPCA’s clear water strategy, and enhance the ecological benefits of Minnesota waters.

The first two years will focus on the optimization of sensors and sensor networks, and the third year focuses on prototype unit, data transmission protocol and hardware, and field test. The results will be disseminated through presentations by faculty and students involved in the project, briefings to the LCCMR as requested, and other publications. We will work closely with the Minnesota Pollution Control Agency and Environmental Protection Agency (EPA). In the next phase of the research and development, we will closely collaborate with industry, state agencies, and water researchers, to implement and evaluate sensor networks for pollutants monitoring in broader water regions in Minnesota, and eventually commercialize the sensors and sensor networks in Phase III. The sensor networks can also be applied to medical devices or smart cities.

We will seek external funding to support our efforts and plan to file patents on the proposed sensors and sensor networks for commercialization in the future. In the meantime, we are planning to form a team to apply for a research center on microsystems for clean water sponsored by National Science Foundation or other funding agencies, to further develop and commercialize this technology.

Attachment A: Project Budget Spreadsheet
Environment and Natural Resources Trust Fund
M.L. 2020 Budget Spreadsheet
Legal Citation:
Project Manager: Dr. Tianhong Cui
Project Title: Develop Inexpensive Sensor Networks for Remote Monitoring and Mapping of Pollutants in Minnesota Lakes and Rivers (Phase II)
Organization: University of Minnesota-Twin Cities
Project Budget: $635,000
Project Length and Completion Date: 3 years; completion date of 06/30/2023
Today's Date: 04/15/2019

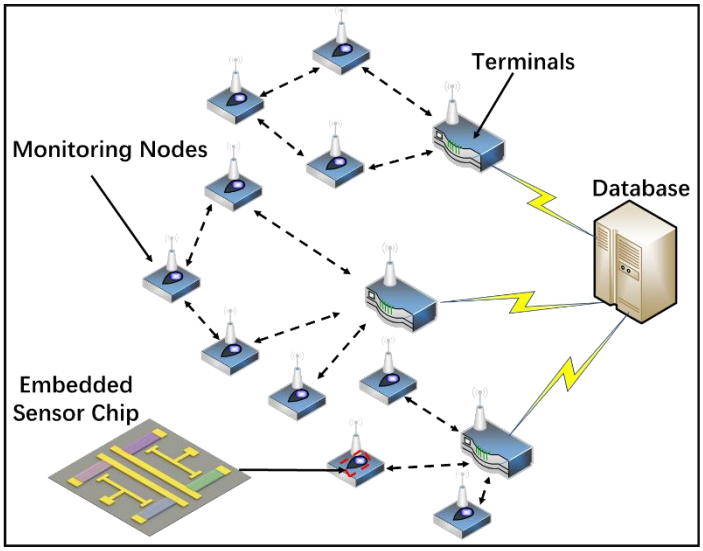
ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 476,000	$ -	$ 476,000
Tianghong Cui, PI/PD, 1.0 month/year, 3 years, including 36.0% benefits, managing the overall project, leading the design, fabrication, and testing of sensor networks, supervising Ph.D. students	$ 74,000		
Roger Ruan, PI/PD, 1 month/year, 3 years, including 36.0% benefits, leading and managing lab and field testing project, leading demonstration, supervising Ph.D. student	$ 67,000		
Paul Chen, co-PI, 1 month/year, 3yrs, including 36.0% benefits, project coordination, conducting R&D, project evaluation, progress report	$ 34,000		
1 BBE graduate student (50%RA), 3yrs, including tuition and benefits, conducting R&D, operations, demonstration, data analysis	$ 148,000		
1 ME Graduate Research Assistant, 50%, 3yrs, including 16.1% benefits plus tuitions, conducting R&D including design, fabrication, testing, and demonstration of sensor networks	$ 153,000		
Professional/Technical/Service Contracts			
	$ -	$ -	$ -
Equipment/Tools/Supplies			
Lab supplies, instrument and equipment consumables, minor equipments for settting up lab and field experimental and testing systems and equipment repairs and calibration costs	$ 76,000	$ -	$ 76,000
Capital Expenditures Over $5,000			
	$ -	$ -	$ -
Fee Title Acquisition			
	$ -	$ -	$ -
Easement Acquisition			
	$ -	$ -	$ -
Professional Services for Acquisition			
Scientific Services (i.e. Characterization Facility and MN Nano Center)	$ 71,000	$ -	$ 71,000
Printing			
	$ -	$ -	$ -
Travel expenses in Minnesota			
Per University of Minnesota travel policy, this is for researchers to travel to collect samples in fields and between campus and demonstration sites over the 3yrs project period.	$ 12,000	$ -	$ 12,000
Other			
	$ -	$ -	$ -
COLUMN TOTAL	$ 635,000	$ -	$ 635,000

SOURCE AND USE OF OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind: Indirect Cost at the University of Minnesota		$ 291,000	$ -	$ 291,000

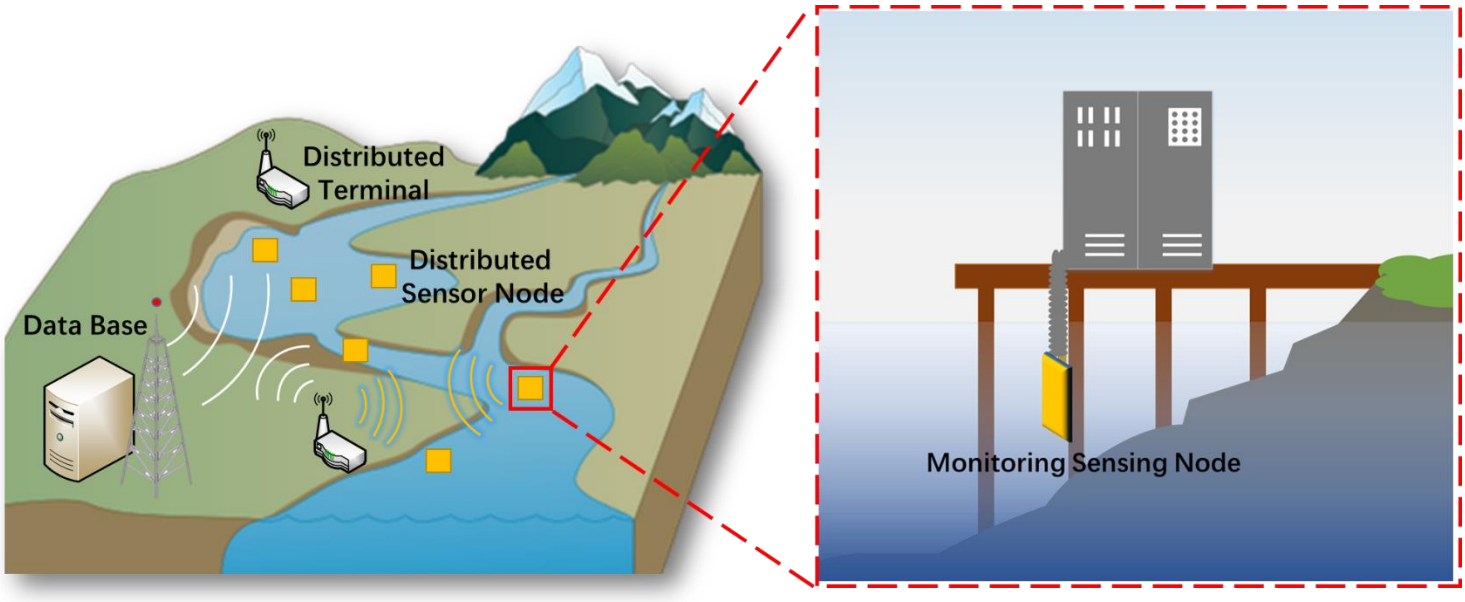
Other ENRTF APPROPRIATIONS AWARDED IN THE LAST SIX YEARS	Amount legally obligated but not yet spent	Budget	Spent	Balance
		$ -	$ -	$ -

The current equipment for laboratory testing or on-site monitoring water pollutants is expensive, large, and difficult to use. This is not cheap small sensor networks based on smart sensors and sensor networks. This project aims to optimize the cheap, accurate, small sensors for real waters in lakes and rivers, and to form sensor networks for monitoring pollutants in real environmental waters. Sensors and sensor arrays will be distributed in rivers or lakes. Through wireless transmission and terminals, data will be transmitted to the database center for monitoring and analysis of water pollutants. **Compared to current lab and on-site equipment for testing water pollutants, the proposed sensor network is 5 times more accurate, while it is 20 times cheaper.**

Current Technology



New Technology Proposed



Future applications to continuous pollutants monitoring in Minnesota waters

Project Manager Qualifications and Organization Description

Tianhong Cui is currently Distinguished McKnight University Professor in Mechanical Engineering and an Affiliate Senior Member of the graduate faculty in Department of Electrical and Computer Engineering at the University of Minnesota. He joined the faculty of the University of Minnesota in 2003. He was also a visiting professor at University of Freiburg in Germany in 2006. He is an international leading expert on micro sensors and advanced manufacturing. He has more than 310 publications and 8 US patents in the relevant area. As an editor-in-chief, he founded the first engineering journal of Nature Publishing Group titled *Microsystems & Nanoengineering*, and he is also responsible for another Nature Journal, *Light: Science & Applications*. In the meantime, he is serving as an associate editor for *Journal of Nanoscience and Nanotechnology* and *Journal of Nano Research*, and he was a past editor for *IEEE Sensors Journal*.

The proposed fabrication work will be done in Minnesota Nano Center (www.nfc.umn.edu) at the University of Minnesota in a 7000 square foot facility, including 3000 square feet of class 10 clean room. The Lab contains all of the major pieces of processing equipment. Minnesota Nano Center well maintains these systems, keeps safe operating procedures, and trains students. State support, support from NSF through the National Nano Coordinated Infrastructure Network (NNCI), and industry usage allows Minnesota Nano Center to offer academic rates that are normally less than half of the actual cost of operation. In 2014, NFC took possession of a second clean room as part of a new Physics and Nanotechnology Building. The new building is across the street from the ECE Building which houses the existing clean room. At 5000 square feet under filter and almost 10,000 square feet gross, it is more than double the existing space. In addition to expanding the suite of clean room tools available, the lab will also operate two new non-clean core labs that support research in nanomaterials and nanotechnology.

The design and characterization of the sensor networks proposed here will be performed in the Technology Integration & Advanced Nano/Microsystems Laboratory (TIAN Lab), located in room ME4128 of the Mechanical Engineering Building, on the Minneapolis campus of the University of Minnesota. The lab is equipped with the state-of-the-art instrument and facilities to conduct the proposed research. TIAN Lab resources include a variety of fabrication and characterization equipment and tools, sufficient for Professor Cui and his Ph.D. student to design, fabricate, characterize and analyse the proposed sensor networks for pollutant monitoring.

The Center for Biorefining directed by Professors Roger Ruan and Paul Chen is a University of Minnesota research center and helps coordinate the University efforts and resources to conduct exploratory fundamental and applied research on renewable energy, materials, and environmental mitigation. The Center's research programs are founded by DOE, USDA, DOT, DOD, LCCMR, IREE, Xcel Energy, and other federal and state agencies, NGOs, and private companies. The Center is equipped with state-of-the-art analytical instruments, and processing facilities ranging from bench to pilot scale for characterization and field testing of this project.

Professor Tianhong Cui in Mechanical Engineering will serve as the PI and project manager. He will be responsible for overseeing the project, all reports, and deliverables. He will also develop the sensor networks, portable units, and data transfer protocols. Professor Roger Ruan in Bioproducts and Biosystems will be a collaborator responsible for setting up and conduct field tests of the proposed techniques. Paul Chen, associate professor in Bioproducts and Biosystems, will be another collaborator responsible for lab analysis of water quality using conventional and the proposed techniques.