**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**

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| **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.

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| **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.

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| **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

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| --- | --- | --- | --- |
| 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

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| 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.