# Environment and Natural Resources Trust Fund
# 2014 Request for Proposals (RFP)

**Project Title:** **ENRTF ID:** **053-B**

Simulating Surface Flows to Inform Water Resources Management

**Category:** B. Water Resources

**Total Project Budget: $** 336,000

**Proposed Project Time Period for the Funding Requested:** 3 Years, July 2014 - June 2017

**Summary:**

We will use computer simulations to obtain high-fidelity data of surface water flows. The simulation will be a cost-effective tool for gathering information for water resources management and ecosystem preservation.

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**Location**

**Region:** Statewide

**County Name:** Statewide

**City / Township:**

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

**PROJECT TITLE: Simulating Surface Flows to Inform Water Resources Management**

## I. PROJECT STATEMENT

The goal of this proposal is to use powerful computer simulation tools to study water flows in lakes, rivers, and streams. From computer simulations, we aim at obtaining high-fidelity data of water resources, such as three-dimensional instant flow velocity, water temperature, concentration of dissolved gases in water, and light variation in water. The data will be provided to policy makers, environmental scientists, and practicing engineers for water resources management and ecosystem preservation. The results of the proposed project will lead to the answers to many important questions, including: How do surface water flows respond to changing climate and extreme weather? Where do the contaminants at water surface go? What are the effects of surface flows on the variations of temperature and oxygen in water? How to quantify the variation of underwater light, which is another important factor in aquatic ecosystem besides temperature and nutrition? And, if wind farms are going to be massively deployed in the future, how will the turbine wakes affect water flows and ecosystems?

Being a state with about 93,000 miles of rivers and streams and 11,842 lakes with more than 10 acres in size, Minnesota has its water resources and ecosystems largely dependent on the surface water flows. There is a critical need to study surface water flows and the associated physical, chemical, and ecological effects. The nature of this problem determines that the study needs to be multidisciplinary. This proposed project has the advantage over many existing studies in that our computer simulations will address many processes across different fields, such as fluid dynamics, heat transfer in water, chemical properties of water surface that affect gas transfer, effect of turbine wakes, and light transmission and effect on ecosystem. As a result, the project will have multiple benefits to a variety of areas in water quality, ecology, as well as renewable energy.

The research tool to be used in the proposed project is computer simulation, which has become an increasingly important method. With the advent of modern computers, many complex processes in nature can be simulated with advanced computation algorithms. For example, we have successfully simulated wind turbulence interacting with water waves as well as wind turbines (see Figures 1 and 2), transfer of dissolved gases and heat at water surfaces (Figure 1), and light transmission in water (Figure 3). While field measurement, laboratory experiment, and remote sensing will continue to play an important role in water resource and ecology research, computer simulation can provide valuable data with unprecedented details at a relatively low cost. Using computer simulations, we can also consider different scenarios by changing the simulation parameters in a cost-effective way.

## II. DESCRIPTION OF PROJECT ACTIVITIES

**Activity 1: Study of surface water flows under wind and wave actions Budget: $134,400**

A powerful computer simulation tool for turbulent flows called large-eddy simulation (LES) will be employed in our simulations of surface water flows in lakes, rivers, and streams. A unique feature of our LES is that we are able to incorporate water waves and wind to the simulations. For surface flows, the wind and waves are two additional major driving forces besides pressure gradients and gravity effects, but were difficult to simulate directly in the past. Recent breakthroughs made in our research group have made coupled wind-wave-water simulation possible. Figure 1 shows an example of our results. Using this tool, we will simulate a variety of natural conditions with the inclusion of changing climate scenario of extreme weather such as storms, as well as the scenario of new deployment of massive wind turbines. We aim at obtaining the following outcomes.

| Outcome | Completion Date |
|---|---|
| 1. Assess the effect of wind and waves with various intensities, including those under storm conditions, on surface water flows. | 6/30/2016 |
| 2. Model the transport and fate of surface contaminants in surface water flows. | 6/30/2016 |
| 3. Predict the effect of wind turbine wakes on surface water flows. | 6/30/2017 |

**Activity 2: Study of gas and heat transfer at water surfaces** **Budget: $100,800**

The transport of heat and dissolved gases in water will be studied through the simulations of advection and diffusion processes. The bottom plot in Figures 1 shows an example of our simulations of gas flux rate at water surface and the variation of temperature in water. From the simulation data, we will examine the statistics and structures of the gas concentration and temperature fields, investigate their correlations with the flow field, and develop advanced models for the prediction of gas and heat fluxes at water surfaces.

| Outcome | Completion Date |
|---|---|
| 1. Quantify and model temperature variation in water, to help the efforts on ecosystem preservation. | 6/30/2016 |
| 2. Develop advanced models for the prediction of gas transfer rate at water surface, to inform water resources management on oxygen reaeration and nitrogen cycling. | 6/30/2017 |

**Activity 3: Study of light transmission in water and effects on ecosystem** **Budget: $100,800**

The light transmission in water will be modeled with a photon Monte Carlo simulation method. Our simulations will capture the deflection of light beams as they enter the water surface and the absorption and scattering of lights by suspended particles in water. Figure 3 shows an example of our simulations of lights under water waves. With the light field simulated, we will investigate the impact of underwater lights on ecosystem dynamics to help water quality management and the enhancement of biodiversity in lakes, rivers, and streams.

| Outcome | Completion Date |
|---|---|
| 1. Develop underwater radiative transfer models that can be used to predict light fields in lakes and rivers. | 6/30/2016 |
| 2. Assess impacts of light variation on aquatic ecosystems, to inform water quality management and ecosystem preservation. | 6/30/2017 |

## III. PROJECT STRATEGY

### A. Project Team/Partners

The proposed research will be carried out in the St. Anthony Falls Laboratory at University of Minnesota by Prof. Lian Shen as project manager, Dr. Xin Guo as postdoctoral associate, and a graduate student as research assistant. Details are provided in the Project Manager Quantifications and Organization Description section.

### B. Timeline Requirements

The proposed research requires three years to complete. The timeline is necessitated by the nature of the research, which is multidisciplinary and requires scientific study and practical engineering and environmental considerations.

### C. Long-Term Strategy and Future Funding Needs

The project is readily enabled by the expertise and experience of Prof. Lian Shen gained through his previous and on-going research on surface water flows with applications in pollutant transport, air-water exchange of oxygen and carbon dioxide, wind energy, and light and ecosystems in water. We have carefully planned the project milestones. We are confident that the outcomes will be accomplished within the 36-months timeframe.

# 2014 Detailed Project Budget

**Project Title: Simulating Surface Flows to Inform Water Resources Management**

## IV. TOTAL ENRTF REQUEST BUDGET [3 years]

| BUDGET ITEM | AMOUNT |
|---|---|
| **Personnel:** | |
| Lian Shen, PI, at 6% time with 74.8% salary and 25.2% fringe benefits (3 years; 1 person) | $ 34,682 |
| Post-doctoral Associate at 100% time with 83% salary and 17% fringe benefits (3 years; 1 person) | $ 167,465 |
| Graduate Research Assistant at 50% time with 58.7% salary and 41.3% fringe benefits (3 years; 1 person) | $ 130,878 |
| **Contracts: N/A** | $ - |
| **Equipment/Tools/Supplies: Cost of softwares for flow visualization and modeling** | $ 2,975 |
| **Acquisition (Fee Title or Permanent Easements): N/A** | $ - |
| **Travel: N/A** | $ - |
| **Additional Budget Items: N/A** | $ - |
| **TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =** | $ 336,000 |

## V. OTHER FUNDS

| SOURCE OF FUNDS | AMOUNT | Status |
|---|---|---|
| **Other Non-State $ Being Applied to Project During Project Period:**<br>**Startup funds from St Anthony Falls Lab of U of M that will be spent on this study: $25,000**<br>**Startup funds from Mech Engr Dept of U of M that will be spent on this study: $75,000** | $ 100,000 | Secured |
| **Other State $ Being Applied to Project During Project Period: N/A** | $ - | N/A |
| **In-kind Services During Project Period: N/A** | $ - | N/A |
| **Remaining $ from Current ENRTF Appropriation (if applicable): N/A** | $ - | N/A |
| **Funding History: N/A** | $ - | N/A |

As visual illustration, shown below are some results of our preliminary simulations intended for this project.

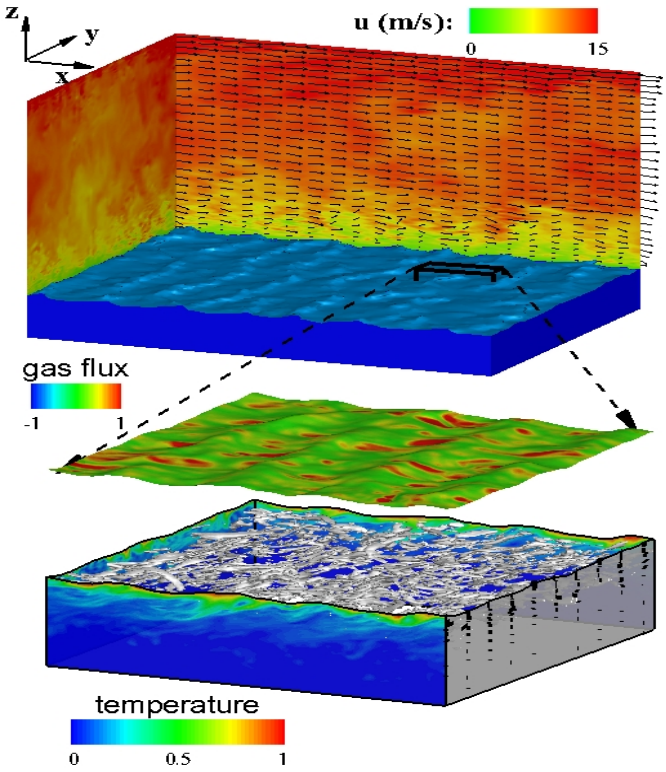


*Figure 1. This figure illustrates our computer simulation of surface water flows with waves and wind blowing. In the upper plot, water surface is plotted together with wind speed. In the plot below, zoom view of local water flows and turbulence transport near water surface is shown. Using computer simulation, we can get gas flux rate at the water surface, water temperature distribution, vortices in water, and water flow velocity vectors.*

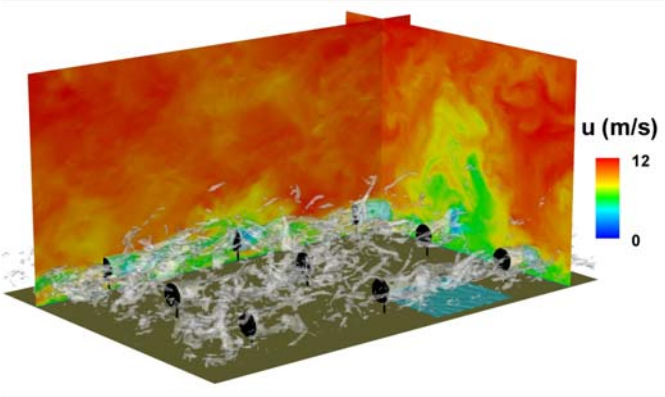


*Figure 2. This figure demonstrates our simulation of wind farm with a lake among the wind turbines. The wind turbines are represented by circular disks swept by the turbine blades. Plotted are instantaneous wind speed, the vortices in turbine wakes, and water surface of the lake.*

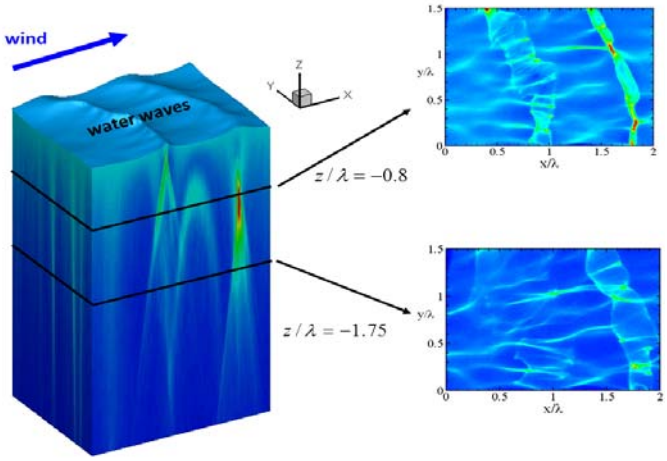


*Figure 3. This figure shows how the variation of light intensity in water can be computed in our simulation. Plotted are three-dimensional illustration on the left and horizontal distributions at two different depths on the right. Based on the data of such simulations, the aquatic ecosystem that depends on light availability can be further studied.*

## Project Manager Quantifications and Organization Description

The proposed research will be performed in the St. Anthony Falls Laboratory (SAFL, http://www.safl.umn.edu) at University of Minnesota, Twin Cities. SAFL is an interdisciplinary fluid mechanics research and educational facility. Its mission is: (1) to advance fundamental knowledge in engineering, environmental, geophysical, and biological fluid mechanics by conducting cross-cutting research that integrates disciplines in science and engineering; (2) to benefit society by implementing this knowledge to develop physics-based, cost-effective, and sustainable engineering solutions to major environmental, water, ecosystem, health, and energy-related problems; and (3) to disseminate new knowledge to University of Minnesota students, the engineering and scientific community, and the public through educational and outreach activities and partnerships with government and industry.

The research will be carried out by Prof. Lian Shen as project manager, together with Dr. Xin Guo as postdoctoral associate and a graduate student (TBN) as research assistant. Prof. Shen will oversee the proposed project, lead the research efforts, and supervise the postdoc and student. Dr. Guo will study surface water flows, light transmission in water, and the impacts on aquatic ecosystems. The student will perform simulations for the transfer of gasses and heat in water and the transport of pollutants at water surface.

Prof. Lian Shen currently holds the position of Benjamin Mayhugh Associate Professor in SAFL and Department of Mechanical Engineering at University of Minnesota. He obtained his Doctor of Science degree from Massachusetts Institute of Technology (MIT) in 2001. After three years of postdoctoral training at MIT, he joined the faculty at Johns Hopkins University (JHU). At JHU, Prof. Shen performed cutting-edge research on environmental air and water flows, transfer of greenhouse gases, and sustainable energy from wind and waves. He was recruited by University of Minnesota in 2012 to further strengthen the research on environmental flows and renewable energy.

The proposed research will be assisted by Dr. Xin Guo, who obtained his PhD degree at JHU recently. Dr. Guo is a very promising young scientist in the field of surface water turbulent flow study. The research will also involve a graduate research assistant, who will be selected from PhD candidates at University of Minnesota with excellent academic performance. The support from this project will enable the student to complete his/her PhD study, thus to add to the workforce to environmental flows study at the completion of the project. In addition to informing policy makers, environmental scientists, and engineers working on water resources management in the state of Minnesota, in this project we will also work closely with the educational and outreach program at SAFL to disseminate the knowledge to university students, local middle school and high school students and teachers, and the general public.