A TRAINING DEMONSTRATION PROJECT FOR CURRENT AND FUTURE WORKFORCE IN A COUPLED NATURAL HUMAN AGRICULTURAL ECOSYSTEM

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EXTENDED ABSTRACT

The primary objective of this paper is to train current and future “workforce” to develop effective cyberinfrastructure (CI) components to support observatories gathering data in agricultural ecosystems and policy pertinent to engineering curriculum. This project aims to transform/enhance an existing University of Iowa (UI) watershed educational project from being a local-scale project to a more generalizable CI-based project that can serve as a pathfinder to effective larger-scale activities on future observatories.

To achieve a generalizable CI model, an emphasis would be placed on developing an open, web-based CI framework and prototype for data collection and servicing of the data from hydrological/environmental sensor networks including market analysis. The web-based model facilitates easier access of the data, and deployment of the sensor data service. More specifically, the project intends to develop a web-based cyber-infrastructure model for sensor data collection, retrieval, and analysis based on the prototype of HIDE – Hydrological Integrated Data Environment.

The study has taken place in Clear Creek watershed. Clear Creek watershed has been experiencing severe surface erosion (the highest in Iowa) due to gully erosion and current land-use practices. The watershed, due to its close proximity to the UI campus, is ideally suited for performing CI demonstration projects, such as CI sensor deployment, data storage, data retrieval, modeling and visualization. The existence of conventional (e.g. computer networks) and emerging (e.g. network of sensors) CI components in Clear Creek and on the UI campus allows versatile use of these components for training purposes.

The hallmark of this educational program is an interdisciplinary effort that emphasizes agency training & public outreach and university/college training. The active participants are: The University of Iowa (UI) and IIHR-Hydroscience & Engineering, and the USDA-NRCS, and the Clear Creek Watershed Enhancement Project Group (CCWEPG).

The impact of this study is significant in reshaping the educational curriculum of engineering and science disciplines and in providing training and outreach material for other user categories. Specifically, the demonstration project will:

1. Develop an integrated curriculum that promotes across the discipline courses for future engineers and scientists. This will be of the first kind in this country.
2. Train workforce to design and maintain CI tools to address future societal needs related to environments and extensive urbanization and other land uses.
3. Train engineers and researchers to exploit CI tools to understand major regional-scale problems that have impacts on the national contaminated scale such as hypoxia problems.
4. Encourage agencies and universities to change the traditional approaches for studying earth surface processes and adopt the CI framework.

5. Develop a conceptual CI framework that can help agencies and universities to deal with huge amount of continuous data to better manage, store, analyze and present their received information.

KEYWORDS

Water, Biogeochemistry, Environment, Scaling

1. INTRODUCTION

Human activity is intricately linked to the quality and quantity of water resources. Although many studies have examined human-water dynamics, the complexity of such coupled systems is not well understood, largely because: (a) there are gaps in our understanding of water-centric bio-geochemical processes; (b) the analyses are still strongly disciplinary and inward-looking; and (c) appropriate tools and data for multidisciplinary studies do not exist. Additionally, most of our “natural” water systems are heavily engineered (e.g., tiled agricultural fields, channelized streams, dammed rivers), resulting in systems that are inherently unbalanced. In the absence of a full understanding of natural hydrologic and biogeochemical system behavior, there is a risk of unintended consequences. The impact of human activities is greatly magnified in the Mississippi River by flood and navigational control systems. For example, expansion of plant-based fuel production in the upper Midwest is expected to increase inputs of nitrogen and phosphorus. The unintended consequences of bio-fuel development may be serious hypoxia and fish kills. Similarly, as we have increased the efficiency of food production, animal feeding operations grow in size and become more localized. This is resulting in heavier use of veterinary pharmaceuticals and antibiotics, which are rapidly released to tributaries of the Mississippi. New approaches are needed for researchers to conceptualize and simultaneously address the complexity of water quality and quantity and provide tools that allow them to capture and model the water cycle and its interactions with the physical environment. Research and effective management of these systems in the 21st century necessitates development of a new paradigm in science and engineering education (Felder and Brent 2010).

Another obstacle in understanding water resources challenges is manifested in the “cultural” differences between environmental and hydraulic engineers. Traditionally, environmental engineers have focused on the biological and chemical constituents of the water, with historical emphasis on sanitary engineering. Hydraulic engineers generally study physical aspects of freshwater transport, and have a historic emphasis in flood control. Their segregation from each other and other disciplines creates a barrier that prevents innovative, systems-level environmental problem-solving. Now is the time to bring these disciplines together to take advantage of emerging high-tech sensor and communication technologies and numerical simulation capabilities to address pressing environmental issues.

2. MAJOR INTERDISCIPLINARY EDUCATIONAL EFFORTS

Students funded by the interdisciplinary program will work within three broad, but closely related themes. Regardless of which theme each trainee focuses on, each will have close interaction with all other students, faculty, and agency team members.

Theme 1: Inputs of water and biogeochemical constituents

Watershed evolution, with its interwoven biogeochemical systems (vegetation, terrain, and soils), is strongly governed by the feedback interaction of different earth surface processes that are driven by water through precipitation and surface-subsurface flows. Other interfacial processes may sequester pollutants and enhance or limit bioavailability, so that calculations for total pollutant concentration may not accurately reflect the risk of these chemicals to human and ecosystem health. Thus, a fundamental understanding of the different scale interactions between water and biogeochemical constituents found at the fabric of the earth surface is vital for 1) discovery, use, and conservation of natural resources; 2) characterization and mitigation of natural hazards; and 3) stewardship of the environment.

This theme will include use of cyberinfrastructure with real-time in-situ local and remote sensing data with multiple frequencies and spatial distributions to create an integrated, real-time watershed modeling system. This integrated system will be used to make direct inferences about sediment, contaminant, and nutrient yields from non-point sources and to identify improved best management practices that have the greatest effect on reducing nonpoint nutrient loads to the Upper Mississippi River Basin. Data obtained through sensors will enhance data collected from traditional sampling expeditions. Moreover, the technology will demonstrate to Trainees real-time, event-driven performance evaluation and optimization of sensor networks for studying nonpoint source pollution at appropriate spatial and temporal scales. These are key capabilities necessary to address inputs of water and biogeochemical constituents into large riverine and other freshwater ecosystems.
Theme 1 objectives:

1. *Explore how cyberinfrastructure technology can be configured to support real-time observations.* An important capability for the proposed environmental observatories will be adaptive monitoring of critical events, e.g. meteorological events that generate significant nonpoint source pollution including resuspension of pollutants [8].
2. *Improve understanding of complex, multiscale processes such as nonpoint source pollution.* The integrated, cyber-enabled, sensing - modeling systems will be used to address the following questions:
   - What are the physicochemical or other processes that determine the source of sediment and associated pollutants within a watershed? Do the models correctly estimate residence time or renewal time for sediments and pollutants? What is the effect of the residence time or renewal time in simulating sediment transport, nutrients, and water quality?
   - What is the effect of predicted climate change on nonpoint nutrient loads? Will the effects be more dramatic in agricultural or urban settings?
   - Are intense agricultural or urban systems more amenable to improvement with best management practices to control nonpoint sources of nutrients?
   - Can optimal spatial patterns of land management changes be identified via cyber-technology?

Theme 2: Transport of water and biogeochemical constituents
Most geophysical, physical, and biological systems are remarkably complex and nonlinear. They reside far from equilibrium and contain three generic features: geometric, dynamic and statistical fluctuations. Many of these systems span multiple scales of space and time, and contain dynamic parameters that are unobservable. Surprisingly, many also show the presence of statistical power laws, or statistical scaling, which represents scale invariance, a fundamental organizing principle underlying such complex systems. The scientific challenge is to develop a multi-scale dynamical understanding of statistical scaling relationships of floods, and other coupled biological processes in river networks.

Research within the last decade has shown that statistical power laws for floods are not built into hydrodynamic conservation equations governing river flows, but emerge as a consequence of the complex interaction of physical processes acting within the constraints of channel networks. The response of the sedimentary patterns on flow controls to a large degree the transport time of derived pollutants associated with sediments. Finally, it has been demonstrated that particulates and phytoplankton characterize historical samples and provide greater clarity of longer-term trends in a river. It is predicted that 1) phytoplankton production and particulates will be greatest in river regions with intermediate hydrologic retention time and connectivity; and 2) flooding will increase ecosystem connectivity and equalize conditions across the floodplain, but its spatial extent at a given moment will depend on amplitude, duration and frequency of flooding.

Understanding transport of water and biogeochemical constituents requires division of a river basin into a network of distributed channel and hillslopes as they naturally exist on the landscape. Partitioning of a landscape into hillslope – channel link pairs rise to three characteristic scales: a) watershed scale (~1,000 km); b) hillslope – channel link scale (~0.01 – 1 km); and c) hydrodynamic continuum (or Darcy) scale (~0.01 – 10 m). Two challenges in formulating multi-scale dynamics constitute theme 2 objectives:

1. *Up scale existing biogeochemical models to link hillslope – channel scales using different methods including probabilistic tools.* Related questions include:
   - How do flow and sediment transport change in terms of land use patterns and terrain characteristics?
   - To what degree and at what scale do different land use types affect residence times of pollutants? What is the effect of residence or renewal time in simulating sediment or nutrient transport and water quality?
   - What are the key biogeochemical processes that determine the transport of pollutants within a watershed?
2. *How do we address the challenge of dynamic parametric complexity that is introduced by the non-linear interaction of different processes.*

Theme 3: Transformation of water and biogeochemical constituents

The large river processes that drive the transformation of water and biogeochemical constituents, including the distribution and abundance of organisms, are largely unknown because of the temporal and spatial complexity of these systems. Within aquatic ecosystems, for example, there may exist stationary plants, slow-moving mussels, and fish that migrate great distances. The life cycle of these organisms may encompass a few hours or days to a century or more. It is very challenging to design studies that capture the long- and short-term changes (including those caused by chronic exposure to pollutants) that are caused by large- and small-scale changes in the river. Therefore, most studies address a small component and work within a narrow scientific discipline.

This theme's research goal is to create an overarching conceptual and mathematical framework that will enable both scientific research and discovery of natural systems and serve as a forecasting tool for natural resource managers. This new framework is based on an innovative evolution of three numerical modeling methods to integrate traditionally disparate system components. The proposal team recently demonstrated its success in coupling numerical methods by linking Eulerian hydrodynamic models with Lagrangian and Agent models of fish behavior and mussel life history. The objective of this theme is to couple the fish behavior and mussel life history models, and toxicity models and to include multiple system components (plants, nutrients, and/or other aquatic species) to simulate interactions between biological species and their physical and biogeochemical environment. This integration will result in "virtual realities" that consolidate and archive scientists' understanding of the natural world and systematically address the problems of pattern and scale in ecosystems. It will also forecast the impacts of different natural resource utilization strategies by society and serve as a platform for education and training (Theregowda et al., 2006).

Students will participate in development of numerical models for Navigation Pool 16 of the Upper Mississippi River Basin (UMRB). Models will feature a two-scale Eulerian module comprised of: 1) a high resolution computational fluid dynamics model (CFD) to characterize detailed, 3-D hydrodynamics for several hydrologic conditions; and 2) coarser scale water quality, toxicity, and biogeochemical models to characterize water quality and nutrient dynamics. These will be linked with Lagrangian- and Agent-based ecological models. Pool 16 has extensive existing data resources and embodies many of the challenges inherent in large-scale ecosystem restoration and environmental management. The field experience for this theme will be conducted from The University of Iowa's Lucille A. Carver Mississippi Riverside Environmental Research Station (LACMRERS), located along the Pool. This theme is innovative because it brings together an interdisciplinary team of biologists, ecologists, hydrologists, and engineers to share expertise and resources to address the fundamental challenges in modeling natural systems. This integration will result in a transformative new simulation-based discovery and design platform that can be used to generate hypotheses that guide ecosystem science, analysis, and restoration.

Theme 3 objectives:

1. *Develop an integrated scientific framework to simulate and study natural aquatic ecosystems*, while considering issues of spatial and temporal scaling, coupled physical and biological systems, and non-linear dynamic processes. Related questions include:
   - Can distribution of freshwater mussel assemblages be predicted using organic matter retention zones as a physical surrogate?
   - Can the mussel dynamics model accurately predict the pool-wide population and distribution of freshwater mussels in a navigation pool of the UMRS?
   - What impact does food competition with invasive zebra mussels and limited host fish availability have on the distribution of native, freshwater unionid mussel populations in pools of the UMRS?
   - Does habitat loss and floodplain fragmentation from flood control levees have a greater impact on species diversity and abundance than longitudinal connectivity impacts of navigation locks and dams?
2. *Significant redesign of existing numerical models to create an efficient and robust computational framework* using "hybrid" parallel computer architectures for application to long-term simulations of complex aquatic ecosystems.

3. EDUCATION AND TRAINING

Twenty-seven PhD students will enter this program in the first three years. Central to IGERT: Mighty Mississippi is the integration of engineers and scientists who represent all elements of natural water resources. This program will draw upon faculty from the UI College of Engineering and recruit students from many backgrounds. Graduate trainees may enter with either a B.S. or an M.S. degree and obtain a Ph.D. in 4 to 5.5 years, depending on their previous degree, in one of the departments listed in Figure 3. A trainee entering the program with a bachelor's degree will be expected to devote most of the first academic year to course work, the first summer to intensive research work, the second year to a mixture of course work and research, and subsequent years almost entirely to research. A trainee with a masters degree may require less formal course work, and thus will be involved intensively in research from an earlier stage.

A new curriculum will be developed centered around five new courses specifically designed to teach an integrated approach to water resources managements (Table 1). These courses will help students integrate our key three research themes by asking questions, posing and testing hypotheses, and by making interpretations. Seven additional classes will be required of the students to comprise the twelve required courses. The seven additional courses are core fundamental courses from both the hydraulics program (Fluids, Open Channel Flow, Stochastic Approaches) and the environmental program (Chemistry, Microbiology, Water Quality, Groundwater).

A unique aspect of this program is the opportunity for Trainees coming from a science background to become licensed as Professional Engineers (PE). Licensure requires taking a Fundamentals of Engineering (FE) Exam, followed by several years of experience working with a licensed PE. Depending on their background, they will be able to take a set of 3 to 5 undergraduate courses as pass/fail that will provide them the background to take the FE Exam, which normally requires an undergraduate degree in engineering. The CEE department has a long track record of students from a science background passing the exam and going on to become Professional Engineers.

Five New IGERT Courses	*Seven Fundamental Courses (already existing)*
Ecohydrology & Ecohydraulics (Civil & Environmental Engineering)	Fluid Mechanics (Hydraulics & Water Resources)
Wireless Sensor Technology (Electrical & Computer Engineering)	Open Channel Flow (Hydraulics & Water Resources)
Fate & Transport (Civil & Environmental Engineering)	Stochastic Approaches (Hydraulics & Water Resources)
Hydro-Informatics (Civil & Environmental Engineering)	Environmental Chemistry (Environmental Engineering and Science)
Ecology of Large Rivers (agency-taught)	Microbiology (Environmental Engineering and Science)
	Water Quality (Environmental Engineering and Science)
	Groundwater / Contaminant Hydrology (Environmental Engineering and Science)

Table 1. IGERT: Mighty Mississippi Curriculum

4. CONCLUDING REMARKS

This education and training program will advance discovery and understanding in other relevant fields where environmental and socioeconomic services of natural systems are impeded while promoting teaching, training, and learning. Results of this study will be disseminated through journal publications and conference presentations at meetings by the American Geophysical Union or Biogeochemistry Society, as well as integrated into course curriculums. Finally, this study will provide exciting training for students in this growth area and build connections between the cooperating universities, state/federal agencies, and local producers through innovative educational outreach (e.g., an investigator-student-run web page). This project provides many opportunities to integrate research and education, public outreach and education, and enhance collaboration among researchers from four disciplines, as well as increase interaction among students of these departments and universities.

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