AC 2007-1459: WATERS NETWORK'S POTENTIAL TO TRANSFORM ENVIRONMENTAL ENGINEERING EDUCATION

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WATERS Network's Potential to Transform Environmental Engineering Education

Abstract

The WATERS Network (**WAT**er and **E**nvironmental **R**esearch **S**ystems Network) will be an integrated real-time distributed observing system which will enable academic and government scientists, engineers, educators, and practitioners to advance effective management of our nation's water resources by understanding human interactions with water and the natural and built environment. WATERS will provide easily accessible real time environmental data as well as analysis tools to engineers, scientists, educators, K- graduate students and policymakers so they can better understand how water quantity, quality and related components of the hydrologic cycle are impacted by natural and human influences. The WATERS strategic plan will be completed by July 2007 and requires constituent input. This paper describes the draft Conceptual Design and the Education Plan of WATERS Network. This paper will highlight the potential impact of WATERS on undergraduate and graduate environmental engineering education in order to elicit input from the environmental engineering education community on how WATERS Network could better meet the future needs of undergraduate and graduate students and educators. More information can be found at www.watersnet.org.

Overview

With support of the Geosciences and Engineering Directorates at the National Science Foundation (NSF) the WATERS Project Office, a joint initiative of the Collaborative Large-scale Engineering Analysis Network for Environmental Research (CLEANER) project[1] and the Consortium of Universities for the Advancement of Hydrologic Sciences, Inc**.** (CUAHSI)[2], is developing a strategic plan for the **WAT**er and **E**nvironmental **R**esearch **S**ystems (**WATERS**) Network. The WATERS Network aims to transform and advance the scientific and engineering knowledge base by developing a collaborative scientific exploration and engineering analysis network that will transform our scientific understanding of how water quantity, quality, and related earth system processes are affected by natural and human-induced changes to the environment. WATERS will allow environmental engineers, scientists and other professionals to advance the scientific understanding of human impacts on water resources and improve and inform the management of environmental issues[1].

NSF has funded 11 WATERS Network test bed project grants that focus on sensors and deployment of sensor networks; development of new modeling tools; and development of cyberinfrastructure, especially as it relates to enabling models and making sensor data accessible. In two years, additional testbedding opportunities are expected to further develop technology and determine the best path forward for building the WATERS Network. The WATERS Project Office is also meeting with other NSF environmental observatory programs (e.g., National Ecological Observatory Network (NEON)[3], Ocean Observatories Initiative (OOI)[4] and governmental monitoring agencies to coordinate program efforts and develop partnerships to ensure effective integration with existing monitoring efforts. Table 1 summarizes the major milestones required for completing WATERS Network by the year 2015.

Table 1: WATERS Network Timeline

July 2005	Establish CLEANER Project office
March 2006	Initial drafts of CLEANER science, education, and sensor network plans, strategy for integrating social sciences, and proposed organizational structure for the WATERS Network
June 2006	Complete draft of all planning documents for CLEANER's vision for the WATERS Network
February 2007	Complete high-level draft of joint WATERS Network conceptual design and final committee documents
April - June 2007	Public comment period for WATERS Network conceptual design and preliminary program plan documents
July 2007	Submit Integrated Science and Education Plan (ISEP) and conceptual design to NSF
March 2008	Finalize WATERS Network conceptual design and ISEP
April 2008	NSF Conceptual Design Review of WATERS program plan
August 2007 – November 2009	Develop preliminary design plan and submit to NSF
Summer 2008	Establish WATERS Inc. consortium
December 2009	Preliminary Design Review of WATERS program plan
January 2011	President announces FY 2012 proposed budget
Fall 2011	NSF makes award to consortium for construction of network
Fall 2015	Network launched

The four main components of WATERS Network are[1]:

1. A **network** of highly instrumented field facilities for acquisition and analysis of environmental data
2. An environmental **cyberinfrastructure** that provides data archives, collaboration, and networking among community members, and information technology for engineering modeling, analysis, and visualization of data
3. **Multidisciplinary synthesis** of research and education to exploit instrumented sites and networked information; formulate engineering and policy options to protect, remediate, and restore stressed environments and promote sustainable environmental resources
4. A **measurement facility** that assists with and provides training on sensor deployments, measurement campaigns, and sensor development

Examples of the types of sensor packages that would provide data include: microclimate, water balance, eddy flux and storage, soil moisture, groundwater, snow pack, stream gauge, and water quality packages. In addition, there would be mobile robotic and remote sensing sensor packages. These sensors could provide data such as air temperature, relative humidity, soil moisture content, soil temperature, snow depth, pH, salinity, turbidity, water temperature, and chlorophyll fluorescence, as well as concentrations of dissolved oxygen, nitrate or phosphate. Access to this data, (some of it in real-time) along with the associated analysis and communication tools available via the proposed cyberinfrastructure would allow environmental engineers and hydrologists to address science questions at a scale and depth that has not yet been possible.

WATERS Network can help attract and train the next generation of environmental scientists and engineers by transforming environmental engineering education in multiple ways. WATERS will facilitate collaboration and the integration of research and education by providing: 1) A mechanism for communication and collaboration between educators, researchers and students via new and existing communication tools such as chat boards, blogs, etc; 2) A visually oriented data retrieval system/search engine for users to locate and collect relevant documents, images, and other forms of knowledge that exist in the public domain; 3) Access to real time data, high-resolution archived data and analytical tools for discovery purposes by students from K-12 through graduate audiences; 4) A repository of lesson plans, learning activities, and learning materials that allows resource sharing; and 5) Professional development for educators on how to incorporate current scientific data, cybercollaboratory tools and analytical techniques into classrooms.

This paper summarizes the draft Conceptual Design Plan for the WATERS Network and the Education Plan prepared by the Education and Outreach committee. (There are also 6 additional committee documents for: Environmental Engineering and Science, CyberInfrastruture, Modeling, Organization, Sensors, and Social Science and Economics.) This paper highlights the potential impact of WATERS on undergraduate and graduate environmental engineering education in order to elicit input from the environmental engineering education community on how WATERS Network can best meet the future needs of undergraduate and graduate students and their educators.

WATERS Network Conceptual Design

The following is the draft Vision Statement of WATERS Network[5]

> *WATERS Network will transform our understanding of the Earth's water and related biogeochemical cycles across multiple spatial and temporal scales to enable forecasting and management of critical water processes affected by human activities. It will revolutionize the way we perform environmental research and educate future scientists and engineers.*

The following is the draft Mission Statement of WATERS Network[5]

> *WATERS Network will be an integrated real-time distributed observing system which will enable academic and government scientists, engineers, educators, and practitioners to advance effective management of our nation's water resources by understanding human interactions with water and the natural and built environment.*

The following is the draft list of Grand Challenges for WATERS Network (taken directly from the latest draft WATERS Network Conceptual Design)[5]

1. To detect the interactions of human activities and natural perturbations with the quantity, distribution and quality of water in real time.

2. To predict the patterns and variability of processes affecting the quantity and quality of water at scales from local to continental.

3. To achieve optimal management of water resources through the use of institutional and economic instruments.

4. To educate a larger and more inclusive population of environmental engineers and hydrologists; to increase and diversify the next generation of these professionals while engaging our citizenry in water science and management.

The human activities that are having the greatest effect on our ability to sustainably manage water resources in the U.S. are "*largely driven by shifts in population and land use, changes in energy, water and material resource use, and human-induced climate change*."[6] Consequently, the above challenges should be considered in light of the effect of these drivers on the quantity, distribution and quality of water.

The following is the draft list of Major Science Questions for WATERS Network (taken directly from the latest draft of the WATERS Network Conceptual Design)[5]

1. How are the fate and transport of water, sediments, and contaminants affected by spatial and temporal variability?

2. How do we scale our knowledge of water processes from point to plot to basin scales for management decisions?

3. What sensor systems are needed to improve identification of the spatial and temporal sources of water contaminants, their pathways through the environment, and their reaction rates?

4. What engineering and policy designs provide appropriate incentives for reducing large scale contaminant and sediment transport and for improving human and ecological health? What are the appropriate indicators for ecosystem services and how do we determine people's preferences? How do we properly value ecosystem services to help people evaluate the impacts of their decisions?

5. What treatment/management practices have the greatest net benefits for reducing large-scale contaminant and sediment transport and for improving human and ecological health?

6. How can human uses of water be made sustainable in light of long-term environmental and demographic changes?

Education Plan

The WATERS Network has the potential to significantly change the way students, researchers, citizens, policy makers and industry members learn about environmental problems and solutions regarding water quality, quantity and distribution. Through the use of technology that connects students, faculty, researchers, policymakers and others, WATERS Network can provide learning opportunities and teaching efficiencies that can revolutionize environmental engineering and science education. WATERS Network will provide the means to further integrate research and education by providing access to professional communities that are focused on important aspects of environmental quality. Thus students and others can share and participate in the development of the outputs of these research communities.

Education and outreach components are critical for the success of WATERS Network as they address significant workforce issues and have the potential to transform environmental education at all levels. They will have the broadest impact and possibly the most long-lasting influence of all elements of the WATERS Network. Educational programs based on state-of-the-art delivery of cutting edge research have the potential to transform environmental science and engineering education at all levels bringing about broad-based, systemic change that will, in turn, strengthen the Science, Technology, Engineering and Mathematics (STEM) pipeline. The National Research Council notes that "if CLEANER (aka WATERS Network) and the other environmental observatory initiatives fail to transform environmental education and outreach, then they will fail to meet their full potential. The observatory initiative has the potential to make knowledge of the status of environmental resources a basic component of day-to-day life."[7]

The Education Committee has four strategic goals for WATERS Network

- Bring together educators, scientists, engineers, administrators, and citizens to form a powerful collaborative that will transform the current state of formal and informal education in environmental engineering and hydrologic science.

- Propagate "best practices" in education that are informed by rigorous cognitive and pedagogical research in order to create a diverse, internationally competitive workforce.

- Enable synergistic interactions among scientists and pre-collegiate/collegiate/graduate educators in setting research agendas and distributing results for the benefit of society.

- Provide broadly accessible, state-of-the-art information bases and shared research and education tools.

With proper training and financial support, it is anticipated that the WATERS Network will lead to:

- modernization of curricula content and pedagogical approaches to reflect critical competencies for the 21st century including trans-disciplinary instructional units and project learning that integrate advanced information and instructional technologies into teaching, learning, and advocacy of water resources issues

- reciprocal relationships between research and education and increased vertical collaboration among all levels within the education community around water quality and quantity issues

- sustained professional development for students, educators, and researchers throughout the educational pipeline

Multiple reports point to the decline in recruitment and retention of students studying STEM as well as to the increased rate of professionals leaving STEM [8,9,10,11]. U.S. Government Accountability Office reported to Congress that despite an increase in college enrollments over the past decade, the proportion of students obtaining degrees in STEM fields has fallen. For example, 27% of students received degrees in the STEM fields in 2003-04, compared with 32% in 1994-95[12]. The Task Force on American Innovation reports that the number of job openings in STEM fields is currently growing at a rate more than five times higher than the number of US students graduating in those fields. As an example, in the area of environmental engineering, the U.S. Bureau of Labor Statistics [13] anticipates that the number of environmental engineering jobs will increase by more than 27% in the next 10 years while the number of students studying environmental engineering in the U.S. has not increased to meet the coming demand and Fortune Magazine lists environmental engineering as one of its top 20 careers[14]. The NSF has noted that the lack of an available, scientifically competent workforce looms as a significant limiting factor to the development and deployment of sensor networks required for large environmental observatory systems (Sensors for Environmental Observatories 2006).[15]

WATERS Network holds the potential to increase STEM student recruitment and retention by transforming education through research experiences and engaging curricula delivered with effective pedagogies. These experiences and curricula could reach a diverse audience, especially populations that are underrepresented in STEM. WATERS Network will provide professional development for K-12 teachers as well as university faculty. WATERS Network will also play a role in developing strategies for supporting highly qualified instructors who are well-versed both in their content areas and in modern methods for effective teaching.

Organization

The Education Committee envisions the following organization to support local, regional and national WATERS Network educational efforts. At the national office, and at each observatory, there will be at least one staff person to facilitate Education, Outreach & Training (E&O) activities as well as educational research work. In addition, at the national office and at each observatory there would be a facility for E&O activities. This facility would have the technology and space that would facilitate E&O activities such as computers, projectors, video link, etc, similar to the NCSA Access Office. The facility would be used to train people on the use of WATERS Network models, communication/collaboration software and hardware, such as sensors as well as provide a venue for education and outreach activities.

At each observatory, K-12 partners and citizen science organizations would be provided sensor systems to enhance the core and research data collection. The equipment required for these groups is under consideration but might include off-the-shelf monitoring items (e.g., pH meters and DO probes). Thus, these groups could submit their data and become part of the sensor network.

Appropriate infrastructure is required within the cyborenvironment that will allow the access to data, analysis tools and communication tools to the all participating communities. In their WATERS Network test-bed project and in previous test-bed work, Piasecki et al (2006), have already noted the importance of using a parallel (rather than sequential) approach to develop the necessary cyberinfrastructure required for research and education. They strongly recommend that the design of education and outreach efforts and associated tools be designed in parallel with any tools required for the research effort.[16]

Undergraduate and Graduate WATERS Network Scenarios

The benefits of WATERS Network to undergraduate and graduate education are numerous. The following is a partial list of benefits to education that can accrue from WATERS Network:

- Providing real world data for exploration and demonstration by students from K-12 through graduate.
- Training K-12 teachers in environmental science and engineering education, thus increasing the pipeline.
- Enhancing the relevance and quality of instructional materials via the distribution and communication of best practices and results of educational research.
- Linking educators (and their students) with scientists via the cybercollaboratory.
- Providing a basis for learning about environmental policy through simulations.

The two scenarios below highlight some of the innovations that could be available to environmental engineering college students and educators.

Undergraduate Introduction to Environmental Engineering Course - Professor Eckstein teaches Introduction to Environmental Engineering, a common course in the curriculum of civil and environmental engineering departments. He has always liked incorporating real-world and real-time data into this course, and he wants to use the WATERS Network to provide context-based learning opportunities for the various topics covered in his course. In assignments on water resources (e.g., water supply and flooding), water quality, and water treatment, he has his students use the WATERS Network to find the answers to questions. Activities include examining the relationships between water quantity and water quality in different regions, looking at the impacts of water quality on aquatic ecosystems, and evaluating the fate and transport of pharmaceuticals and personal care products in the aquatic environment. Because his course is widely taught at other universities, Professor Eckstein uses the WATERS Network to coordinate the sharing of successful context-based learning assignments among his colleagues. For a course project, Professor Eckstein has his students work in groups to examine specific impacts of human activities on different regional water systems (each group is assigned a different region). In addition to evaluating existing information, each group is charged with the task of developing a hypothesis on human-water system interactions and using the WATERS Network to test the hypothesis. The students' project reports are made available to the WATERS Network. Professor Cruz has been conducting research in an area of one of the group's hypotheses. He reads their report and contacts Professor Eckstein. They realize that additional field sites would be necessary to truly test the hypothesis using the WATERS Network, and they write a joint proposal to develop those sites. The proposal includes partnering with local high schools. Those high schools send AP Environmental Science instructors to serve as summer researchers. During the academic year, the AP Environmental Science students participate in the data collection and in research communications on the WATERS Network Cybercollaboratory

Graduate Student Researcher - Ms. Thompson is a Ph.D. student studying the fate of pharmaceutical chemicals in wastewater treatment plants in bench-scale laboratory research. As she nears the completion of her dissertation, she wants to know more about the concentrations and fate of the compounds she has been studying once they are released to the environment. Her advisor suggests using WATERS Network. She finds interesting information, but none related to pharmaceutical compounds. Because Ms. Thompson seeks to complement her expertise in lab-scale experimentation with field-scale research, she signs up for a three week summer program on field sampling and data analysis. The programs are organized by WATERS Network and held each year at one of the observatories. Ms. Thompson learns several new skills at the workshop. In addition, she has the opportunity to discuss her interests in pharmaceutical compounds with Dr. Carpenter, the director of the observatory. They use their complementary expertise in field monitoring and lab-scale analytical chemistry to develop a plan for monitoring selected compounds at the facility. Ms. Thompson integrates this work into her Ph.D. dissertation and then works as a post-doctoral researcher at the observatory further developing the sampling and analysis protocols.

While continuing her research at the observatory, now Dr. Thompson is joined by Ms. Nguyen, a graduate student in civil engineering and Mr. Thilges, a high school earth science teacher. Ms. Nguyen and Mr. Thilges work as interns with Dr. Thompson over the summer learning sampling techniques and data analysis. Ms. Nguyen creates a poster presentation and paper on her research which she presents at an environmental engineering conference as a part of her master's studies. Mr. Thilges collects data which he incorporates into his classroom study of the effects of human activities on water quality. He also earns graduate credit in environmental engineering from a University associated with the observatory which he applies toward his continuing education requirements.

Input from Environmental Engineering Education Community

The focus of this paper is the undergraduate and graduate target populations (students and instructors). Input on how best to construct a plan so that WATERS Network can positively impact environmental engineering and science education within this context is being sought from the audience. More specifically, the following questions are posed:

- **Curriculum and Pedagogy –**How can undergraduate and graduate curricula benefit from the use WATERS Network facilities, infrastructure, and data outputs? What pedagogical approaches will be developed or already exist that use real-time and real-world environmental data?

- **Education and Research Inform Each Other –Vertical Collaboration Among Researchers, Educators, and Learners –** In what ways can undergraduate and graduate students and instructors work with researchers to develop new knowledge and to disseminate that knowledge? How can the WATERS Network increase collaboration between researchers and undergraduate and graduate students**?**

- **Sustainable Professional Development –** What avenues can the WATERS Network provide for the continuous refreshing of the knowledge base of undergraduate and graduate educators?

Other questions the authors have for the audience include:

- What funding mechanisms can be used to fund innovative collaborations?
- How can undergraduate and graduate students and educators be directly involved in WATERS research?
- What are example projects that can be used as models for educational components of WATERS?
- What are possible educational experiences undergraduate and graduate students could have with WATERS that they do not have now?

The WATERS Network Education Committee requires constituent participation in the development of this plan. Below are a number of methods to contribute to the development of the WATERS Education Plan.

- Visit the WATERS Network website **http://www.watersnet.org**

- Visit the CLEANER Project Office website[1] **http://cleaner.ncsa.uiuc.edu**
  To involve the broader community, this Web site includes documents, working papers, and a CyberCollaboratory (a portal with various technologies to access cyberinfrastructure demonstrations and facilitate collaboration).

- Visit the CUAHSI website: **http://www.cuahsi.org**

- Subscribe to our newsletter*: WATERS Quarterly Update* to keep apprised of developments related to WATERS Network. To **subscribe**, please send an email to majordomo@ncsa.uiuc.edu with the following in the email body:
  subscribe waters Your Name < youremail@somewhere >
  (subscribe waters John Doe < johndoe@home.com >)

- Sign up for the CyberCollaboratory at http://cleaner.ncsa.uiuc.edu to provide feedback on the tools and the environment of the CyberCollaboratory.

- Contact any of the authors of this paper directly.

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