Title: How WATERS Network scientific and engineering research will benefit science education

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Abstract
The WATERS Network will be a national cadre of environmental field facilities working to promote multidisciplinary research on critical environmental challenges. WATERS Network will enable the formulation and development of engineering solutions and policy options for the restoration and protection of water resources. This session will provide participants with an overview of the cyberinfrastructure of WATERS Network and its potential use by many audiences. The session will also serve as an opportunity to solicit feedback from the community regarding the structure and goals of the WATERS Network project.

Keywords (CyberCollaboratory, education, engineering, environmental, sensors).

1.0 Introduction
The Cooperative Large-scale Engineering Analysis Network for Environmental Research (CLEANER) project aims to transform and advance the scientific and engineering knowledge base necessary for addressing the challenges presented by large-scale, human-stressed and complex environmental systems. In particular, CLEANER will address how to detect, predict and manage the effects of human activities and natural perturbations on the quantity, distribution and quality of water in near real time.

CLEANER combined with the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) will form the WATer Environmental Research System (WATERS) Network. The WATERS Network planning effort is motivated by the national need to understand and restore lake, stream, and coastal water quality to achieve sustainable and secure water supply while improving and preserving aquatic habitats.

It is envisioned that the WATERS Network will:
- Transform environmental research by providing advanced sensor systems for data collection, advanced informatics tools for data mining, aggregation, analysis, and visualization and predictive modeling of large-scale dynamic environmental challenges;
- Enable more effective adaptive management approaches for human-stressed complex environmental systems based on enhanced observations, experimentation, modeling, engineering analysis, and design;
- Promote participation and improve interaction among the broader engineering and science communities, including social scientists; and
- Transform engineering education by engaging the academic community collaboratively in large-scale and complex real-world problems.

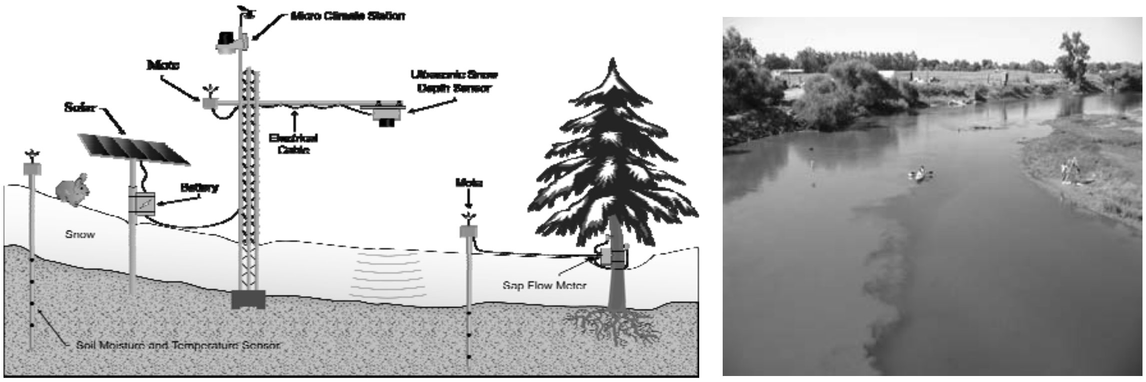

Figure 1: Major Elements of WATERS Network: a networked infrastructure of environmental field facilities.

To address and support these project goals, the WATERS Network will consist of four major elements. The first element is a network of highly instrumented field facilities for acquisition and analysis of environmental data. This is will be the backbone of WATERS. The network will be a series of well-instrumented Environmental Field Facilities (EFFs) that represent either distinctive stressed environments or environments that are representative of a common set of conditions and/or stressors. EFFs will be monitored with an array of remote and on-site sensors combined, when appropriate, with local and off-site sample analyses. Selection of EFFs will be driven by problems associated with anthropogenic stresses on environmental systems that require a national perspective.

The second element of WATERS will be a virtual repository of data and information technology for engineering modeling, analysis and visualization of data, i.e. an environmental cyberinfrastructure. The repository will include collection, organization and archiving of data within a unified database structure. The database will allow inter- and intra- site queries and facilitate new developments in data mining. WATERS will include the development of new models and the integration of existing models based upon the data collected within the virtual repository. Modular and open architecture will allow optimization and modification by a large number of researchers.

The third element of WATERS is a mechanism for multi-disciplinary research and education. The purpose of this mechanism is to exploit instrumented sites and networked information; formulate engineering and policy options to protect, remediate, and restore stressed environments and promote sustainable environmental resources. The activities pursued within WATERS will integrate research, education, and environmental analysis, decision-making, and management. The instrumented sites and virtual repository will enable the development of collaborative and multidisciplinary research projects.

The fourth and most critical element for establishing a network is fostering collaboration among engineers, natural and social scientists, educators, policy makers, industry, NGOs, the public, and other stakeholders. This type of collaboration specifically addresses the programmatic gaps in the current National Science Foundation environment portfolio identified by the National Science Board. This collaboration will be facilitated by cyberinfrastructure designed specifically to enable collaborative interactions in real time over networks and to aid in location and coordination of collaborative relationships.

Ultimately, the WATERS Network seeks to transform our ability to understand, monitor, forecast and communicate the future status of water availability in the United States in response to environmental stresses and change.

2.0 WATERS Network environmental engineering science research plan

The WATERS Network will address the challenge of providing adequate water quantity and quality for human use by striving to maintain the integrity of aquatic ecosystems by improving scientific understanding and engineering knowledge about water resources (National Research Council 2001).

The research questions on which the WATERS Network will focus efforts are:

- How do we detect, predict and manage the effects of human activities and natural perturbations on the quantity, distribution and quality of water in near real time? How do we detect, predict and manage the effects of shifts in population and land use on the quantity, distribution and quality of water?
- How do we detect, predict and manage the effects of changes in energy, water and material resource use on the quantity, distribution and quality of water?
- How do we detect, predict and manage the effects of changes in climate, especially human-induced climate change, on the quantity, distribution and quality of water?

In order to undertake such a significant research effort, employing cyberinfrastructure and sensor networks will be essential.

3. 0 WATERS Cyberinfrastructure

Cyberinfrastructure must enable the collection and dissemination of data, data analysis and modeling through use of collaboration tools. This will lead to the creation of a new kind of environmental scientist/engineer who will be able to capitalize on the potential of cyberinfrastructure. Within the environmental field, this role in archiving and integrating data is clearly critical. Environmental research is observationally-oriented, highly collaborative and interdisciplinary, and generates and uses significant quantities of geospatially indexed data currently in a host of non-interoperable data formats. Environmental engineering research is also highly hypothesis-driven and model-dependent, particularly where issues of temporal or spatial scale preclude observation. Thus, the WATERS Network will include an innovative and scalable cyberinfrastructure consisting of (1) a virtual repository to archive existing and new data and (2) information technology to enable data modeling, analysis and visualization, and (3) a collaboratory enabling researchers to access and use the tools created in (1) and (2).

Major components of WATERS Network cyberinfrastructure include:
1) Collaborative services including Email, web-broadcasts, online teaching environments, chat sessions to allow for “collective visualization and manipulation of data in real time.” (NCAR 2003)

2) Knowledge management, visualization, analysis and modeling to enable researchers to pursue research questions, produce information that is easily and meaningfully accessed by others, and provide an information archive mechanism.

3) Access to instruments that collect data and enable the observation of physical, chemical and biological phenomena.

The WATERS Network is envisioned as a collaborative scientific exploration and engineering analysis network encompassing the sensors and communications systems and the integrating cyberinfrastructure necessary to facilitate widespread use of the network.

4. 0 WATERS sensors and sensor networks

WATERS Network data will be acquired through a networked infrastructure of environmental field facilities aimed at promoting multidisciplinary research on critical environmental issues. This networked infrastructure will also serve as drivers for developing and deploying cyberinfrastructure investments.

A multiscale sensing approach will use a combination of remote sensing (e.g., satellite-based sensors) and sparsely deployed embedded sensor networks (e.g., semi-permanent river gauging stations) to observe interesting conditions or events occurring in aquatic, terrestrial, subsurface and atmospheric systems. These large-scale observations also enable delineation of background water quality, climate conditions, or other phenomena, thus providing context to develop research hypotheses and test them with higher resolution observations. Greater resolution observations are achieved though deployments ranging from higher granularity stationary sensor networks (continuous in time, intermittent in space), and mobile deployments (continuous in space, intermittent in time).

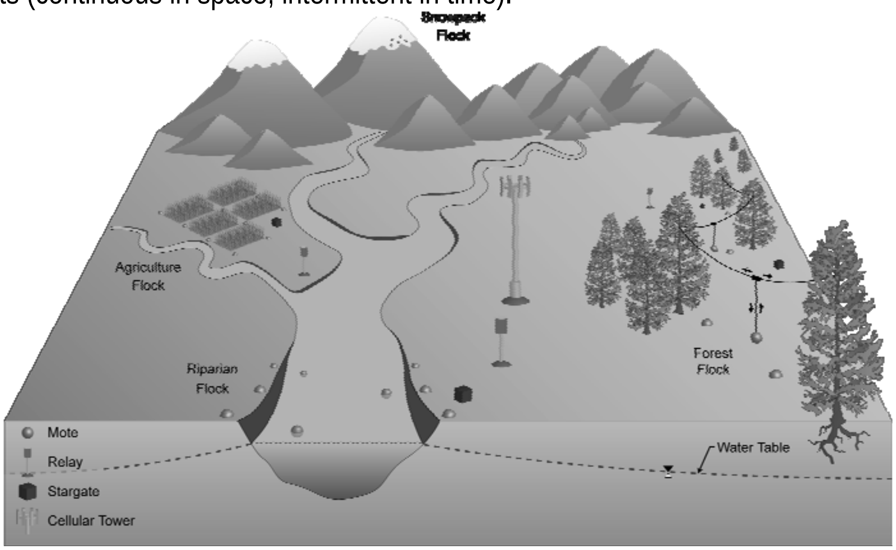

Figure 2: Example sensor array.

Although the potential uses and benefits of cyberinfrastructure are vast, the actual cyberinfrastructure requirements of practicing scientists and engineers are less well known. To encourage adoption of these technologies, as well as obtain sufficient funding and interest in maintaining these large, complex systems, it is important to communicate the opportunities to multiple potential stakeholders. Engagement of scientists and engineers is an obvious necessity. Perhaps not as obvious, but equally important is the engagement of educators, students, environmental resource managers, members of industry, politicians, and members of the general public. Indeed, local buy-in and participation is essential to addressing national as well as local problems within EFFs. Leveraging additional research funding and support is a critical component of the enabling role of the WATERS Network.

5.0 WATERS Network education and outreach

Effective educational efforts, both formal and informal are critical for the success of WATERS Network and collaboration. Educational programs based on cutting edge research presented through a state of the art delivery mechanism have the potential to transform environmental science and engineering education at all levels.

To facilitate this transformation, WATERS Network will:

- Bring together educators, scientists, engineers, administrators, and citizens.
- Propagate "effective 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.

From these goals, a range of educational reform objectives evolve – covering delivery of instruction, learning outcomes, teacher/instructor training, professional development, and societal impacts.

The tools WATERS Network will use to accomplish these goals include knowledge networks, collaborative environmental modeling interface, maintenance of a real time data collection network, and a CyberCollaboratory. A CyberCollaboratory is a web-enabled environment consisting of a variety of collaboration and scientific technologies. Users can perform a variety of tasks ranging from scientific investigations involving real-time data and large datasets to collaborative activities of a group of users involved (http://cleaner.ncsa.uiuc.edu/). The use of these tools can not only advance science and engineering, but also education. The WATERS CyberCollaboratory will be a multi-faceted knowledge center to support users. WATERS CyberCollaboratory tools will include:

1) A mechanism for communication and collaboration between educators, researchers and students. The forum will contain a chat system, blog, an audio and video communication system and other existing communication tools.

2) A visually oriented data retrieval system or 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 and analytical tools for discovery purposes by students from K-12 through graduate audiences. Access can enable learners to investigate local environmental problems with a global perspective and will enhance the relevance and quality of instructional materials.

4) A repository of lesson plans, learning activities, and learning materials. The repository will contain a mechanism for resource sharing.

5) Professional development for educators on how to incorporate current scientific data, CyberCollaboratory tools and analytical techniques into classrooms;

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.

WATERS Network will be committed to the integration of processes that promote a widening of the Science, Technology, Engineering and Mathematics (STEM) pipeline with inclusion and diversity using the following guiding principles:

- Embrace our responsibility to create an inclusive and respectful climate that enhances the scientific and educational experience of researchers, staff, educators and students involved with WATERS Network.
- Acknowledge the critical role of the WATERS Network scientific community, in collaboration with their educational partners, in developing and maintaining an environment that invites the participation of a diverse constituency.
- Recognize that an inclusive climate is rarely generated or maintained in the absence of supporting policy, structure, and oversight, and we commit to build systems supportive of inclusion and diversity into all strategic plans, both scientific and educational.

5.1.1 How can WATERS Network impact education?

The benefits of WATERS Network to transform education are numerous, ranging from improved secondary school curricula to the preparation of next generation scientists and engineers at participating universities. Congruous with recommendations from two National Science Foundation reports, *Geoscience Education and Cyberinfrastructure* (Marlino, Sumner and Wright, 2004) and *Cyberinfrastructure for Education and Learning for the Future* (CRA, 2005), WATERS Network potentially can:

- Provide real world data for exploration and demonstration by students from K-12 through graduate and informal audiences.
- Encourage and provide the mechanism for learners to investigate local environmental problems with a global perspective via the integration of research and education via the further integration of research and education.
- Enhance the relevance and quality of instructional materials with a focus on water quality, quantity and its distribution.
- Provide access to online environmental data acquisition instrumentation.
- Provide communication mechanisms to link educators and their students with research scientists.
- Provide a basis for learning about environmental policy through simulations.
- Provide a mechanism for high school and college students to conduct authentic environmental science and engineering research.
- Provide structured experiences for graduate students (assistantships, etc) to prepare them for leadership roles in science and engineering.
- Provide professional development for educators on incorporating current scientific data, tools, and analytical techniques into classrooms.
- Allow university faculty members access to contemporary research findings to enhance their research and teaching.
- Provide collaborative networks for educators, researchers and student to share and exchange ideas and approaches.
- Create methods for conducting educational research on how learners acquire and interpret information about the environment via WATERS Network.

The WATERS Network will forge partnerships with other environmental observatory systems such as National Ecological Observatory Network (NEON http://www.neoninc.org/), Ocean Research Interactive Observatory Networks (ORION http://www.orionprogram.org/), and several of the National Oceanic and Atmospheric Administration's (http://www.noaa.gov/) observing programs. This will facilitate an open exchange of ideas to support and extend existing 'effective practices', develop and disseminate multi-institutional curricular materials and form new pedagogical approaches. Strong partnerships with industry and federal and local agencies will facilitate the development of student service learning projects that fulfill the needs of industry and community stakeholders. Additionally, forming strong partnerships with other aligned programs will allow for leveraging funds for the WATERS Network.

5.1.2 Scenarios

The example scenarios described below are ways in which WATERS Network could be used in undergraduate and graduate education. Several other scenarios were developed and are available in the Education Committee report (http://cleaner.ncsa.uiuc.edu/), publicly available February 2007.

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, linking their research hypothesis with their educational objectives for student learning.

Graduate Student Researcher

Mr. Thompson is a Ph.D. student studying the fate of pharmaceutical chemicals in wastewater treatment plants in bench-scale laboratory research. As he nears the completion of his dissertation, he wants to know more about the concentrations and fate of the compounds he has been studying once they are released to the environment. His advisor suggests that he look into the WATERS Network. He finds a lot of interesting information, but none of it related to pharmaceutical compounds. Because Mr. Thompson also wants to complement his expertise in lab-scale experimentation with field-scale research, he signs up for a three week summer program on field sampling and data analysis organized by the WATERS Network and held each year at one of the environmental field facilities (EFFs). Mr. Thompson learns new skills at the workshop and he discusses his interests in pharmaceutical compounds with Dr. Carpenter, the director of the EFF. They use their complementary expertise in field monitoring and lab-scale analytical chemistry to develop a plan for monitoring selected compounds at the facility. Mr. Thompson integrates this work into his Ph.D. dissertation and then works as a post-doctoral researcher at the EFF further developing the sampling and analysis protocols.

6.0 Conclusions

The Education plan, along with the five other committee plans will be available for public review in February 2007 at the CLEANER Project Office (http://cleaner.ncsa.uiuc.edu/). The CLEANER Education Committee strongly encourages community critique of the proposed education framework and invites your comments and suggestions through contacting one of the authors or through participation in the CLEANER Project Office CyberCollaboratory (http://cleaner.ncsa.uiuc.edu/).

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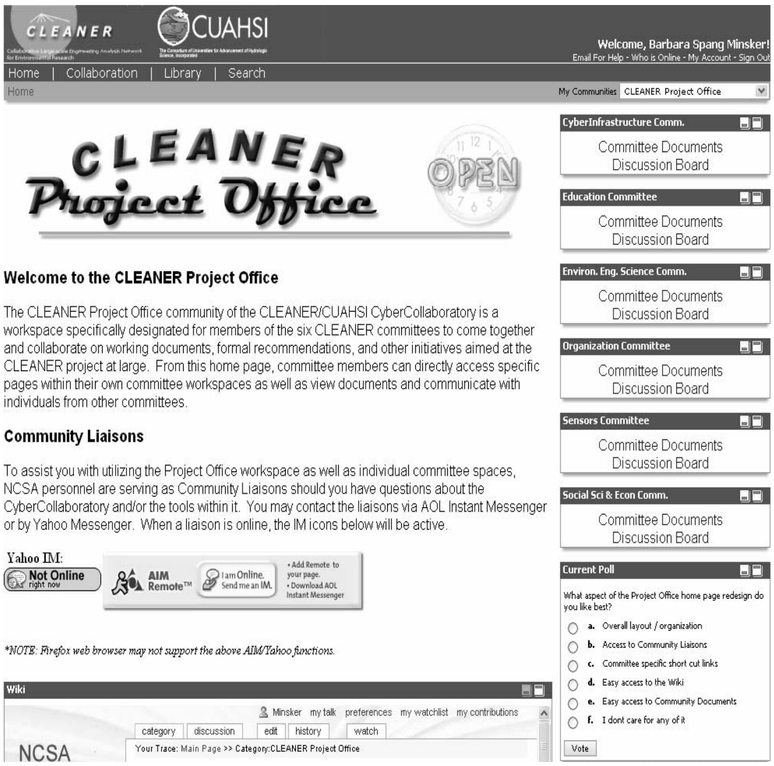

Figure 3:
CLEANER Project Office web site

7.0 Acknowledgements

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8.0 References

Atkins, D.E, 2003. Revolutionizing Science and Engineering Through Cyberinfrastructure: Report on the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure.
http://www.cise.nsf.gov/sci/reports/atkins.pdf

Computing Research Association, 2005. Cyberinfrastructure for Education and learning for the Future: A vision and research agenda. Summary report of four workshops sponsored by the National Science Foundation (NSF).
http://www.cra.org/reports/cyberinfrastructure.pdf

Marlino, M.R., T.R. Sumner, and M.J. Wright, 2004. Geoscience Education and Cyberinfrastructure. Report of a workshop sponsored by the National Science Foundation (NSF), April 19 – 20. Boulder, CO: Digital Library for Earth System Education (DLESE) Program Center; University Corporation for Atmospheric Research (UCAR), 43p.
http://www.dlese.org/documents/reports/GeoEd-CI.html

NCAR, 2002. Cyberinfrastructure for Environmental Research and Education, A report from a workshop held at the National Center for Atmospheric Research, Oct 30-Nov 1, 2002.

National Science Board (2003) The Science and Engineering Workforce: Realizing America's Potential. National Science Foundation. http://www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf

National Science Board (2004) An Emerging and Critical Problem of the Science and Labor Force. National Science Foundation. http://www.nsf.gov/statistics/seind04/.

NSF, 2006. NSF's Cyberinfrastructure Vision for 21st Century Discovery, NSF Cyberinfrastructure Council. January 20, 2006 Version 5.0.