Preliminary Review of the Draft Science, Education, and Design Strategy for the Water and Environmental Research Systems (WATERS) Network

DETAILS

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Water Science and Technology Board

Division on Earth and Life Studies

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We wish to thank the following individuals for their review of this report: William P. Ball, Johns Hopkins University; Kenneth Bencala, U.S. Geological Survey; Richard Conway, Union Carbide Corporation (retired); Patricia A. Maurice, University of Notre Dame; William K. Michener, University of New Mexico; Leslie L. Shoemaker, Tetra Tech, Inc.; Donald I. Siegel, Syracuse University; and Shalini Vajjhala, Resources for the Future.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Mary P. Anderson, University of Wisconsin-Madison. Appointed by the National Research Council, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

WATER AND ENVIRONMENTAL RESEARCH SYSTEMS NETWORK

One of the most critical issues facing the United States today is the proper management of our water resources. Water availability and quality are changing due to increasing population, urbanization, and land use and climate change. Despite the fact that overall water use in the U.S. has remained relatively constant since about 1980, shortages in water supply have been increasing in frequency in many parts of the country, in part because of population increases in coastal and arid to semi-arid areas (Hutson et al., 2005). Water quality is declining in some areas due to the introduction of nutrients, toxics, pathogens, pharmaceuticals, and a variety of household products (see *http://iaspub.epa.gov/waters10/attains_nation_cy.control; http://water.usgs.gov/nawqa/*). As a society, we must learn to manage our valuable water resources more effectively to meet current and future demands for water.

The National Science Foundation (NSF) has proposed the Water and Environmental Research Systems (WATERS) Network as one possible initiative whereby NSF could provide the advances in the basic science needed to respond effectively to the challenge of managing water resources. The WATERS Network is one of several national observatory networks[1] being planned by NSF designed to collect and integrate the necessary data over the appropriate spatial and temporal scales to help scientists, engineers, and managers better understand, model, and forecast environmental processes.

The WATERS Network is the result of a 2005 merger of two environmental observatory initiatives: the Collaborative Large-scale Engineering Analysis Network for Environmental Research (CLEANER) and the Consortium of Universities for the Advancement of Hydrologic Science, Incorporated's (CUAHSI's) Hydrologic Observatories initiative[2]. In 2007, the community represented by the Critical Zone Exploration Network (CZEN)[3] joined the WATERS effort.

WATERS is to be an integrated network of observatories supporting research, outreach, and education on large-scale, water-related environmental problems. Though the exact locations have not yet been determined, WATERS observatory sites will likely be some combination of: (1) large watersheds selected to represent a range of climatic, geomorphic, and land-use and land-cover characteristics; (2) coastal sites; and (3) urban water systems. The network may also contain several experimental facilities in conjunction with or outside of the observatories that will enable research via manipulation of the water environment (WNPO, 2008). The proposed observatories would provide researchers with access to linked sensing networks, data repositories, and characterization and computational tools for integrated assessment modeling, connected through high-performance computing and telecommunications networks.

[1] These networks include the National Ecological Observatory Network (NEON), the Geosciences Network (GEON), the Ocean Observatory Initiative (OOI), and the Arctic Observing Network.
[2] CUAHSI's Hydrologic Observatories initiative is only one component of the consortium's activities. Additional information on CUAHSI programming and projects that fall outside of the Hydrologic Observatories and the WATERS Network is available on-line at *http://www.cuahsi.org/*.
[3] In 2007, NSF funded three Critical Zone Observatories (CZOs) through the CZEN. The goal of the CZOs is to foster collaboration among interdisciplinary scientists and engineers interested in the coupling between chemistry, biology, and geology at the surface of the earth. Additional information on the CZOs is available on-line at *http://www.czen.org/og/czo*.

Currently, the WATERS Network is a joint initiative of the Engineering and Geosciences Directorates at NSF. NSF has proposed that the WATERS Network be built using funds from the Major Research Equipment and Facilities Construction (MREFC) appropriation which is available to NSF "for necessary expenses for the acquisition, construction, commissioning and upgrading of major research equipment, facilities and other such capital assets" (NSF, 2007). The lifetime of an MREFC project is made up of the following stages[4], as defined by the NSF's *Large Facilities Manual* (2007):

- facility/infrastructure concept development;
- project development;
- project construction/acquisition;
- facility/infrastructure operation; and
- facility/infrastructure renewal, upgrade or phase-out/termination.

The WATERS Network is in the conceptual design stage (see Figure 1) and the WATERS Network Project Office aims to complete the conceptual design review in Fall of 2009. According to current timelines, construction of the network would begin in 2012 and the target launch date is 2016[5].

STUDY SCOPE AND PURPOSE OF THIS REPORT

In 2006, NSF requested that the National Research Council's (NRC's) Water Science and Technology Board (WSTB) convene a committee to provide advice as WATERS navigates the multi-year planning process for MREFC funding (Figure 1). This current study is a follow-on activity to a previous NRC report, *CLEANER and NSF's Environmental Observatories* (2006), which evaluated the CLEANER science plan and identified potential research questions that the network might address. The current NRC committee, composed of experts in the fields of hydrologic and environmental engineering and science, coastal and marine science, computer science, and economics, has been charged to review and assess the adequacy of the conceptual design and planning process for the WATERS Network, to provide advice on collaborating with other federal agencies, and to comment on the operations and maintenance costs for the network (see Box 1 for the complete statement of task and Appendix A for committee member biographies). The committee was not asked to comment on the validity of the observatory approach[6] or endorse or reject the WATERS Network concept. Due to changes in the WATERS planning schedule and the availability of planning documents, the NRC and NSF opted to have the committee address its statement of task in phases.

[4] MREFC funds only cover the costs of project construction, though funding for more significant upgrades may come from the MREFC account. In that case, the approval process is the same as that for a new MREFC project (NSF, 2007).
[5] *http://www.watersnet.org/timeline.html*.
[6] See *CLEANER and NSF's Environmental Observatories* (NRC, 2006) for some discussion on the potential benefits and pitfalls of a national observatory network such as WATERS.

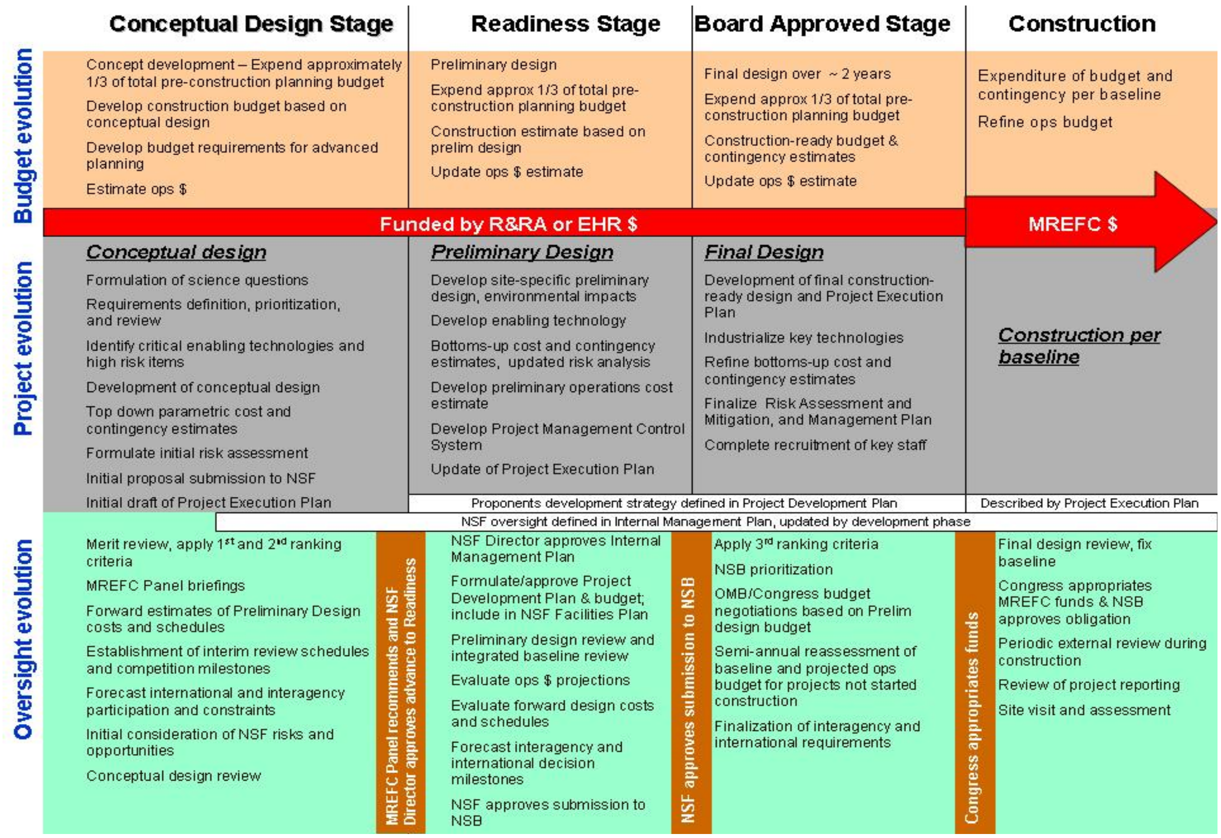

FIGURE 1 The MREFC process.
SOURCE: NSF (2007).

This report contains the committee's preliminary assessment of the *Draft Science, Education, and Design Strategy for the WATer and Environmental Research Systems Network* (WNPO, 2008; hereafter referred to as SEDS)[7], a document that incorporates the ideas presented in multiple planning documents generated over the past several years (including CLEANER committee reports on various topics such as cyberinfrastructure, sensor networks, and education and outreach [Bonner and Harmon, 2007; Driscoll and Reible, 2007; Eschenbach and Johnson, 2007; Finholt and Van Briesen, 2007; Small and Krupnick, 2007; Woldt, 2007] and the CUAHSI Science Plan [2007]), meetings, and workshops involving hundreds of researchers and educators across the country. The draft SEDS aims to present the overall conceptual design for the WATERS Network, and is therefore the focus of the committee's review under Task #1 (see Box 1). This interim report does not address Tasks #2-5, which will be addressed in the committee's final report, to be issued at the completion of the study. This final report may also contain further comments on Task #1 and on the revised SEDS document.

The assessment contained in this report is based on the collective expertise of the committee members and their review of planning documents supplied by NSF and the WATERS Network Project Office. The committee also benefited from presentations and discussions at the two committee meetings involving NSF staff; members of the WATERS community and its

[7] At the time the task statement was crafted and through the first committee meeting in June 2007, NSF planned to deliver two documents to the committee for review: the Conceptual Design Plan and the Integrated Science and Education Plan. The SEDS supplanted these documents.

BOX 1
Statement of Task

In response to NSF's request, the WSTB has assembled a committee to:

1. Review the draft report on conceptual design for the WATERS Network and associated planning documents, including project office committee reports and reports prepared by CUAHSI to be supplied as "background" information. This review will include an assessment of the adequacy of the design plan relative to the stated mission and goals of the WATERS Network, the grand challenges it is being established to address, and the specific science questions and environmental drivers on which the design is based.

2. Review and comment on the adequacy of the planning process for WATERS Network, particularly with regard to (a) the use of test-beds and prototypes and other related awards as described to the committee to gain experience in building and operating the network, and (b) the needs to fund research to develop "enabling technologies" in the areas of sensors and sensor networks and cyberinfrastructure that may not currently exist (or be adequate) but will be needed to operate the Network.

3. Provide advice and comment on how the WATERS Network can be used effectively in the support and transformation of water science and engineering. Issues here include proposal solicitation and review, observatory governance and management, and synthesis of research findings among observatories and disciplines.

4. Advise on how the WATERS Network can be integrated efficiently and effectively with similar efforts and activities of other federal agencies, particularly in view of the different missions of these agencies (including NSF, whose "mission" is to support fundamental science and education).

5. Assess and comment on whether the facility design for the WATERS Network is likely to result in reasonable operations and maintenance (O&M) costs for the NSF programs that will be responsible for it.

leadership team; representatives from federal agencies with programs related to WATERS; and leaders from other MREFC efforts such as the National Ecological Observatory Network (NEON), the Ocean Observatory Initiative (OOI), and EarthScope (see Appendix B for a list of guest speakers and panelists). Annual status reports from 11 test bed projects[8] were also made available to the committee.

The following report does not review the seven chapters of the SEDS document individually, rather, the committee has identified and provides advice in several key categories related to the WATERS plan: science questions; observatory design; sensors; cyberinfrastructure; education and outreach; and governance and management. The committee's comments are summarized at the end of the report.

[8] These 11 two-year projects (2006 to 2008) sited in different environments throughout the country are testing various aspects of the observatory design and operation. See *http://www.watersnet.org/wtbs/index.html* for more information on the test bed projects.

EVALUATION OF THE CURRENT SEDS DRAFT

The committee appreciates the substantial efforts of the WATERS leadership team in preparing the SEDS document and recognizes the contributions of those involved through CUAHSI, CLEANER, CZEN, and the hydrology and engineering communities at large. The committee also commends the WATERS team for reaching out to various federal agencies early in the planning effort to discuss potential opportunities for collaboration and partnership through the network. The committee acknowledges the complexities involved in scoping and constructing a continental-scale network that aims to serve multiple stakeholders. The following critique is meant to provide constructive advice as the WATERS team moves forward with the planning process.

At the committee's second meeting, much of the discourse on the SEDS focused on reconciling what the committee expected to see in a design plan and what was actually presented in the document. As written, the SEDS reflects a high level vision statement for the WATERS Network rather than a design plan, and it lacks the clarity needed for the committee to accomplish its full statement of task (see Box 1).

The committee sees the WATERS initiative as a complex venture that is envisioned to be active for at least 20 years. As Figure 1 indicates, and as the NSF's Large Facilities Manual (2007) describes, the conceptual design stage involves the formulation and prioritization of science questions, the description of the research infrastructure and technical requirements needed to meet the science, and the development of construction budgets and operations estimates. The case for building a WATERS Network would be stronger if the SEDS clearly communicated the rationale and decision processes that led to determinations about the network design, the affiliated components of the enterprise, and the governance structure. Completing a basic design planning matrix (see Table 1 for example) that lays out a timeline for the principal components of the network along with estimated costs would go a long way in communicating the scope of the network. Such an exercise should also lead to a final conceptual design document that would ultimately satisfy NSF's MREFC planning requirements and that the committee could use to satisfy their statement of task.

Science Questions

The committee was asked to review the conceptual design plan for WATERS and comment on the adequacy of the plan relative to "the stated mission and goals of the WATERS Network, the grand challenges it is being established to address, and the specific science questions and environmental drivers on which the design is based." According to the SEDS, "the goal of the WATERS Network is to understand and predict the multi-scale processes coupling water with Earth and human systems." Though no discrete mission was stated in the SEDS, the WATERS community envisions the network as "a bold environmental observatory initiative to transform research on the water environment through new infrastructure investments to enable investigations that cannot be done under the current single-investigator or collaborative projects."

TABLE 1 Sample Planning Matrix for WATERS Network

WATERS Network Conceptual Design				
Network Component	**Targets 0 to 5 Years**	**Targets 5 to 10 Years**	**Targets 10 to 15 Years**	**Targets 15 to 20 Years**
Observatory				
Sensor				
CI				
E&O				
Management Structure				
Governance				
Capital Budget				
O&M Budget				

NOTE: CI=cyberinfrastructure; E&O=education and outreach; O&M=operations and maintenance. The committee chose the four five-year time windows as a reasonable example of how plans might be organized.

The draft SEDS does put forward three principal science questions (what the committee interpreted as "grand challenges;" see Box 2) but it does not present a finalized set of "specific science questions." Instead, the SEDS proposes many example research questions that the network might potentially address.

The draft SEDS makes a number of points regarding why WATERS is important but fails to make a compelling case for why the initiative needs to be funded now. The committee deliberated on the comprehensiveness of the three principal science questions and whether they would allow the network to achieve its goals and mission. It is not the committee's place to define those questions for the communities to be served by WATERS and the committee appreciates that the WATERS leadership has sought input through various channels in developing these questions. The scope of the three principal science questions in the SEDS document is very broad, it overlaps with the mission statements of some federal agencies, and it does not focus directly on the major problems facing the nation with regard to water resources management. The need for an integrated research effort related to water resources is palpable (e.g., Milly et al., 2008; NRC, 2004) and the case for funding WATERS should reflect this information. For WATERS to move forward with the planning process and ultimately secure support from NSF, it is essential that the principal science questions (i.e., grand challenges) be compelling, that a clear statement of the nature of the transformative science to be accomplished be made, and that a description of the path to achieve the envisioned results be

BOX 2
Principal Science Questions for WATERS Network

1. How do hydrologic and related Earth surface systems respond to natural and human induced changes in climate and the environment?

2. How do multi-scale natural, managed and engineered processes and systems affect the water environment, and how can those processes and systems be modeled, designed, and optimized for sustainability?

3. How do people understand water processes and organize themselves, individually and collectively at different scales, to respond to challenges in the water environment?

SOURCE: WNPO (2008).

provided. The argument that, with the installation of an observatory network, scientists will do "good things" and transformative science will emerge is not entirely convincing. The proposed path from observations to analysis and models and then to transformative science should be explained.

Furthermore, in describing the path from observations through transformative science, the overall context—the backdrop of existing knowledge and programs—should be described. The draft SEDS lacks this context, i.e., there is essentially no discussion of past accomplishments in the area of observing hydrologic and environmental systems. For many decades, federal agencies such as the U.S. Department of Agriculture (USDA), National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), the U.S. Geological Survey (USGS), and Environmental Protection Agency (EPA) have conducted research and collected data to address water issues. Scientists at other institutions and universities also have accumulated much data and knowledge regarding water resources. Therefore there is a substantial amount that is already known as well as an existing and robust measurement infrastructure. Furthermore, if the data collected by the proposed WATERS network is to be fully utilized, there should be an ability to look back at historic trends in land use, flow, and water quality at various scales. This context will help to define the relationship to historic data systems and the integration with ongoing studies.

The committee believes that the WATERS concept would be more convincing if the justification for the network rested on the science questions it seeks to address. The WATERS community should determine a set of important science questions and review current available data to determine whether the appropriate data exist to address those questions. If existing data are not sufficient to address the science questions, is a continental-scale observatory network such as WATERS the best means to acquire those data? If so, the WATERS Network design should be based around filling those data gaps. In addition to collecting information directed at addressing specific research questions, the observatories would provide a platform for conducting discovery science.

The WATERS team should review and assess the current status of relevant science and technology to identify the gaps that the network might fill. The suggested review of past accomplishments to provide context could include the results of federal government reports (e.g., CCSP and Subcommittee on Global Change Research, 2003; Hornberger et al., 2001; SWAQ, 2007); federal science programs and networks under the USDA (2008), USGS (2008), EPA (2007), NOAA (2007), the U.S. Bureau of Reclamation (2005), and the U.S. Army Corps of Engineers (2005), to name a few; former NRC reports (e.g., 1991, 2004); and the scientific literature in general. Once the data and knowledge gaps have been identified, the WATERS niche will be clearer and the justification for building the network will be more compelling. It is essential that the supporting background material be developed thoughtfully in the SEDS. Unsupported or false statements (e.g., "Moreover, across the U.S. we know very little about how much water is available in aquifers,") will not be seen as acceptable surrogates for the rigorous identification of the research agenda for WATERS.

After identifying the three principal science questions that guide the science agenda and scope for the WATERS Network, the SEDS document goes on to list 30 example science questions, lumped into ten separate categories. Individually, each of the 30 questions may have merit, but the organization and presentation of the questions are such that the committee found it intractable to evaluate the science that would be conducted under WATERS. In part, the questions added to the confusion, as they were numerous, overlapping, and did not appear to flow naturally from the three principal science questions. In addition, rather than using the example science questions to limit or define the scope of the science, the document gives the impression that any water-related science question could fit under the WATERS Network umbrella.

The scope of the SEDS needs to be more focused to allow a sensible review of the scientific advances that would flow from the proposed effort. One approach would be for the design team to identify one overarching question that is narrower in scope than the three principal science questions in the draft SEDS, and then articulate 3 to 5 major science themes that would emanate from this overarching question. If this is done effectively, a description of how the science themes could only be addressed by a national network of observatories should follow logically. As the case is developed, it would be useful if the authors would review the list of science questions to see how well they map back to the overarching question and determine whether the overarching question is a reflection of the WATERS vision and societal needs. This "relevance-test" procedure should reduce the number of science questions, allow a clear case to be made for a truly integrated plan, and lead to an emphasis on research related to those societal issues that will most directly benefit from WATERS. Furthermore, the test bed results have added valuable information for the design of WATERS, demonstrating the development of an integrated modeling system, wireless technology, use of sensors, water quality measurements, and design elements for a network, and this information could be integral to formulating the final SEDS plan.

Below the committee offers some more specific comments regarding three main themes (among others) that may emerge in further discussions as the draft SEDS is revised. These three themes are highlighted because the committee thinks that they are underdeveloped in the draft document.

Coupled Human-Natural Systems

We think that the draft SEDS is right to focus attention on the coupling of natural and human processes involving water. A large and rapidly growing literature recognizes the important links and feedback effects between natural and human components of systems. Some examples of recent efforts analyzing the coupled nature of systems are articles published in the new section of the *Proceedings of the National Academy of Sciences* on "sustainability science," the Millennium Ecosystem Assessment[9], several NRC reports including *Valuing Ecosystem Services: Towards Better Environmental Decision-making* (NRC, 2005), research from NSF funded under the Biocomplexity and Coupled Human Natural Systems requests for proposals, NSF funded long term ecological research (LTER) urban center studies, and programs of other federal agencies. The WATERS plan should reference and build from this existing body of work and describe how the network will contribute to it. Efforts should be made to link with existing programs that are dealing with these issues (e.g. the Global Water System Project)

Scientific Inferences from Measurements at Different Scales

The SEDS makes a convincing case that multi-scale analysis is important but is vague on what is intended for the network in this regard. The document notes that scaling from small scale (e.g., laboratory) to large scale (e.g., fields or watershed) cannot be done accurately at present, but it does not describe how the WATERS Network will solve or address this problem. There is a substantial amount of literature on "scaling" problems in hydrology, including that which addresses statistical patterns in precipitation fields (e.g., Venugopal et al., 2006), in channel networks (e.g., Turcotte, 2007), in soil moisture (e.g., Famiglietti et al., 2008), and the "downscaling" of results from global climate models to investigate impacts (e.g., Fowler et al., 2007). New ideas have evolved about determining appropriate models of processes at relatively large scales using upscaling approaches (e.g., Zehe et al., 2006). Which of the scaling problems can be addressed with data that would be collected under the proposed WATERS network? How would the problems be addressed—with different measurements, with nested data collection systems? The committee hopes that the revised SEDS document would include a much clearer discussion of how data sets obtained from across the spectrum of space-based platforms to high resolution *in situ* measurements would be used to address one or more of the general scaling problems.

Social Science

The committee agrees that one of the challenges in water policy and management involves a better understanding of human behavior. Humans are drivers of environmental change and are the beneficiaries of services from the use of water. Clearly human responses to environmental change are an important topic for research. What was unclear to the committee from the draft SEDS was how the WATERS Network would attempt to measure human responses. Would this be done through the application of sensors or would there be a targeted survey conducted at repeated intervals? If it is the latter, who would administer the survey and

[9] *http://www.millenniumassessment.org/en/article.aspx?id=58*

analyze the results? There is one economist among the science writing team and no experts in cognitive sciences, sociology, or other social sciences besides economics. There was little mention of issues related to institutions (i.e., laws, regulations, markets, social norms) and incentives. How people respond to change depends on incentives. For example, farmers use fertilizers to increase yields but may not be concerned with the downstream effects of nutrient runoff (e.g., hypoxia in the Gulf of Mexico). Similarly, water use is responsive to water prices and efforts are made to reduce water use during times of drought. WATERS should incorporate research on institutions related to water use and contamination of water. The SEDS also paid little attention to measuring the direct benefits from consumptive and non-consumptive uses of water (e.g., recreation, aesthetics, etc.). Large bodies of work exist on institutions related to both water use and pollution and on the valuation of the benefits of water to people and the proposed future work should build on this base.

The WATERS planning team could go in one of two directions regarding social science as they proceed to revise the draft plan. They could make social science a more prominent focus and include a more robust team of social scientists that represent the set of skills needed for survey research and understanding behavioral responses, institutions, and incentives; or, the WATERS team could pare back the focus of the proposal and not attempt to address human behavior in an all encompassing manner. Humans are important drivers of the system and, if the team elects the second option, the committee suggests paring back the emphasis on social science while still acknowledging the impact of anthropogenic activity on water issues. In the event that social science considerations are limited, it is still important to emphasize that the variables being monitored, and their spatial and temporal distributions, need to be compatible with wider use of the data for coupled human-natural systems evaluations (Vajjhala et al., 2007).

Observatories

A rationale for the need for observatories, a plan for a national design for placement of observatories, and a schedule for implementation is not clear in the draft document. The rationale in the document would be stronger if it included a description of how the observatories would be related to the science questions. For example, would one observatory be sited in a wetland environment to deal with wetland science questions if those are a priority and would another be in a semiarid region?

The SEDS does not discuss how the observation networks of other agencies will be integrated into the WATERS program. This oversight leads to a more fundamental question that is also not discussed in the report, which is whether or not the WATERS observatories constitute a "network." Some hydrologic networks consist of specific instruments deployed across the nation. For example, many federal and state agencies operate networks of instrument stations that measure hydrologic variables such as precipitation, climate variables, stream discharge, stream temperatures, groundwater levels, and some aspects of water chemistry. The WATERS program needs to present specifically how their activities will integrate and compliment these pre-existing networks as stated earlier. Another definition of networks could be areas of study having a common theme that are distributed across the nation; such as, LTER networks. A network of common instruments is useful because it may observe a phenomenon that leads to research questions. A network of areas having a common theme is useful for addressing research questions, but it may not lend itself to a national synthesis or a map of "national conditions."

Sensors

The SEDS provides good justification for the use of sensors to monitor physical and water quality parameters in watersheds of different scales and types. The document recognizes that many technologies are on the horizon, but are not ready for large-scale field deployment. To compensate for this knowledge gap, the WATERS design team suggests using discrete sampling methods to take "snapshots" of chemical constituents e.g., organic and inorganic macro and microconstituents, pathogens, and compounds of emerging concern.

In the experience of members of the committee, it seems logical to orient the design for the network toward selection of probes that (1) can provide data to address the basic science questions identified for the system, (2) are easily deployable and serviceable, (3) are easily standardized and (4) are robust. Other probes that are in the development stages can be used to answer compelling questions at some observatory sites, but not in a routine manner to monitor water quality.

While the WATERS design team recognizes the need for such an approach it was not reflected in the SEDS where the application of undeveloped sensors was proposed (e.g., isotopic analyses, biological oxygen demand (BOD) assays, pathogens, and noble gases in water samples collected on 5-30 minute timescales). Moreover, it was unclear how proposed discrete samples i.e., samplers triggered by a "hydrologic event," would be handled to measure other water constituents (e.g., endocrine disruptors, pharmaceuticals, heavy metals, etc.) because the type of vessel used and volume of water needed is highly analyte dependent. The initial plan for the observatories should have an "open architecture" design whereby sensors capable of measuring other constituents could be added in the future as they become available. Optical instruments and membrane based sensors are highly prone to both biofouling and instrument drift, as the WATERS design team recognizes. Other aspects of sensor maintenance such as drift can be potentially addressed through recalibration or resetting the instrument, but the frequency of such recalibration is instrument dependent. The revised SEDS document would be improved if it realistically discussed the potential difficulties of the procedures and costs for maintaining a network that employs sensitive sensors.

The SEDS provides an excellent assessment of the readiness of commercially available sensors. However, the readiness of an integrated system is not clearly communicated. How will these sensors be integrated together into a single information system and what steps will be taken to ensure that implementation of an integrated system takes place? How far will WATERS go in integrating data systems and what will WATERS have to do to achieve its goals in this area? It is abundantly clear that embedded sensor networks, even ones utilizing off-the-shelf technology, can provide avenues to accomplishing transformative science (e.g., see Hamilton et al., 2007). While the WATERS team is well aware of this information, the case for the use of sensor technology with linkages to the cyberinfrastructure needs to be spelled out in the science plan.

Cyberinfrastructure

The draft SEDS does not provide the information necessary for a thorough evaluation of the plan for cyberinfrastructure (CI), and the WATERS design team acknowledged in discussions with the committee the superficiality of the CI description in the SEDS. The SEDS section entitled "Networking and Informatics Cyberinfrastructure Requirements" claims to "provide(s) only a brief overview of the advanced networking and informatics cyberinfrastructure that will be required to implement the WATERS Network science and education plans." Although broad and general, the CI discussion in the SEDS does provide a consistent vision of the necessary infrastructure. The CI design team clearly is aware of the key CI issues facing the WATERS community and has provided a reasonable summary of these issues. The net result of having only a very high-level description, however, is that the WATERS documentation on CI is too general and vague to provide a basis for evaluation as described in the NRC committee's statement of task.

The additional material that the committee will need to complete its statement of task relative to CI has been described previously (e.g., NRC, 2006; NSF, 2003). The necessary documentation includes, but is not limited to, the following:

1) a design document rather than a high-level vision statement;
2) a set of clear and specific CI requirements derived from the science and education plan;
3) a synthesis of previous work, including, the CUASHI Hydrologic Information System and the WATERS prototypes; and
4) a review of relevant systems, networks, and programs, including other observatories and MREFC projects (not just a passing mention to NEON and OOI).

Because of the immaturity of the CI plan in SEDS, there are significant issues that need to be addressed as the plan is revised. In going forward it will be important to quickly move beyond vision statements of CI to actual design documents. The overall design approach of OOI and NEON is described in their design documents and it would be useful to structure the WATERS design documents to provide comparable organization, scope, and details. In fact, it will be essential in the revised SEDS documentation to describe proposed interactions between WATERS and other environmental observatories and to outline specific areas of CI cooperation.

As an example, the structure of the OOI design illustrates the kind of information needed to evaluate a high-level design (Consortium for Ocean Leadership, 2007). We provide the following excerpt merely as an example and are not suggesting that WATERS adopt this exact approach.

> "The OOI CI design consists of two infrastructure elements and five services networks:
>
> - Common Operating Infrastructure (COI) Services Network provides the technologies and services to play the role of an integration platform, communication conduit, and orchestration, for crosscutting issues including identity, policy, and governance.
> - Common Execution Infrastructure (CEI) Services Network provides configuration management and demand-driven provisioning of capability at selected locations (CyberPoPs and other computing resources) within the CI network. The CEI is elastic, having the ability to expand and contract the configuration of computing resources as the need rises and falls.

- Data Services Network provides an automated data distribution and preservation network with pervasive and universal access subject to *OOI Data Policy*.
- Control Services Network provides the services required to establish the standard models for the management of stateful and taskable resources.
- Modeling Services Network provides a coherent framework for modeling, analysis, and consumption of data.
- Processing Services Network provides access and scheduling of computations/execution.
- Instrument Services Network provides interactive and coordinated access to instrument platforms and instruments."

There are a host of challenges to be faced in developing the cyberinfrastructure needed for continental-scale environmental observatories (Withey et al., 2002). A significant challenge for the WATERS design team will be to articulate a plan that transitions the current test bed and prototype activities into a continental-scale observatory network. Practices and policies that are adequate for small-scale independent systems will not suffice for an integrated system of the scale envisioned for WATERS. How does the WATERS team propose to move from prototypes developed by academic teams to a robust and reliable observatory network, both in terms of development and operations? An answer to this question in the revised document should include an evaluation of code development and management practices and tools. Similarly, there is a need to define explicitly CI risks and proposed approaches to risk reduction. These activities will be critical for realistic cost estimates required for the next planning phase.

As part of the next design phase, the WATERS team proposes to perform a study based on simulation models to help identify key requirements for the WATERS network. The current SEDS documentation fails to provide details on the models and methods that would be needed for this study. To evaluate the feasibility of this approach would require a specification of the models and methods for the proposed Phase 2 simulation study. It would be useful to identify the "full range of relevant models" that will "enable the development of integrated models of the water environment." It would be useful to the committee to see a detailed treatment of the challenges, both logical and engineering, of building and employing these integrated models.

Metadata specifications are also critical for the success of the WATERS network. The information that the committee will need to evaluate the final SEDS includes the approach to create and get consensus on appropriate metadata standards for both deployment details (e.g., sensors, locations, and calibration histories) and data products. In addition to providing the standards, it could be useful for the WATERS design team to create detailed case scenarios to demonstrate the operational roles of various metadata tagging and processing activities.

Education and Outreach

Environmental observatories provide unique opportunities for the public to interface with the scientific community at large. Much thought has gone into the way that these observatories can make education and outreach activities successful. For example, a report from a workshop

(NSF, 2005) suggests that opportunities can be identified in four categories—technology, data, people, and curricula. The draft SEDS has elements in all of these categories.

The ideas presented in the SEDS document appear to cover the key elements of an education and outreach strategy. The signature activities described—summer research opportunities for K-12 educators, various activities characterized as continuing education, and integrating research and education through novel technology such as virtual observatories—are potential paths to success. Starting a K-12 outreach program (WaterTREC) based upon the highly successful Polar Teachers and Researchers Exploring and Collaborating (PolarTREC) program, for example, is sensible given the success of the latter. The main need in the revised SEDS is to provide a timeline for the education and outreach plans, along with cost estimates for the various elements.

The committee also urges the WATERS team to consider another aspect of education and outreach—the inclusion of input from academics representing a broad range of disciplines. The WATERS initiative is designed in part to help address the problems of water management that the United States faces now and will face in the future and this clearly has a strong education and outreach component. In particular, the committee would like to understand the extent to which this aspect of the program will require inputs from the social science community.

Governance and Management

The formation of a Water Science and Engineering Consortium is proposed in the SEDS to "enable understanding and responsible management of water resources, including trade-offs among human, natural and economic development, by providing the necessary infrastructure (data sets, advanced instrumentation and cyberinfrastructure) and a platform for synthesis and interdisciplinary initiatives." According to the SEDS, the mission of the Consortium would be: "(1) facilitate disciplinary research and catalyze interdisciplinary research on water, including its scientific, technological, and social aspects, by bringing together natural scientists, engineers, and social scientists through integrated projects, (2) develop the infrastructure necessary to conduct innovative research and to translate that research into knowledge for the use of the nation, and (3) to support education of the next generation of water scientists and engineers who are prepared to address our nation's complex water challenges." Colleges and universities would be full members, while a variety of other institutions would be affiliate members. While the WATERS Network is a logical component of such a Consortium, the Consortium's goals and mission appear to extend beyond that which is directly associated with the operation and management of the WATERS Network. No alternatives to formation of the Consortium are offered, nor is it stated that the formation of such a Consortium is the only available option. A fairly traditional approach to the organization and governance of this Consortium is proposed, but why these member types are specified is not clear and the rights and responsibilities of the members are not stated. The governance rules for the WATERS Network need to be clearly articulated in a Patterns of Administration (POA) document[10]. No analysis is provided linking the

[10] Governance refers to definition of the members of the WATERS Network enterprise, their rights and responsibilities, and how they will participate in overall decision-making. The term enterprise is selected here to mean the entity responsible for operating and managing the WATERS Network to see that the long-term objectives are delivered and that the legitimate interests of the various stakeholders are met. Operational rules for governance

magnitude of the Consortium activities with the proposed management structure of the WATERS Network. Consortium management will obviously be developed in a phased fashion, although this is not noted in the document. The SEDS briefly discusses two options for constitution of the Consortium: (1) modify the organizational structure of CUAHSI to enfranchise the larger WATERS Network community or (2) form a new organization.

There are several open questions that require attention as the SEDS document is revised:

1) Is the formation of the proposed Consortium the only logical approach? If so, what is the logic for this conclusion? If alternatives exist, why is this one the best?
2) What is the rationale for the specific types of Consortium members, how will they be selected, and what are their rights and responsibilities as they relate to accomplishing the specified goals and mission?
3) How will the Consortium be financed?
4) What is the process for deciding between the two approaches identified to form the Consortium?

SUMMARY

The committee commends the WATERS team for the impressive work that they have done over the past several years and looks forward to reviewing the revised WATERS plan. In regard to the SEDS draft, the committee found that the current document presents a vision statement rather than a concrete design plan, which constrains the committee's ability to address its full statement of task.

The 30 example science questions cover too broad of a research agenda for the WATERS Network. The WATERS team needs to determine a mechanism to narrow the scope of the enterprise. The justification for the network would be more convincing if it was presented in the context of the substantial monitoring and assessment work that has been and is being undertaken by other government and non-government organizations. The WATERS concept would be more compelling if the justification for the network rested on the science questions it seeks to address. The WATERS community should determine a set of important science questions and review the current available data to determine whether the appropriate data exist to address those questions. If existing data are not sufficient to address the science questions, is a continental-scale observatory network such as WATERS the best means to acquire that data? If so, the WATERS Network design should be based around filling those data gaps.

The test beds have generated valuable information in terms of demonstrating the development of an integrated modeling system, wireless technology, use of sensors, water quality measurements, and design elements for a network. This information could be integral to formulating the WATERS design. A significant challenge for the WATERS design team will be to articulate a plan that transitions the current test bed and prototype activities into a continental-scale observatory network.

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typically are elaborated in a Patterns of Administration document. The POA document includes a description of the physical infrastructure required, but also the broader organizational structure and may include, for example, a specified legal entity or the responsibility assumed by an existing legal entity.

The SEDS report provides good justification for the use of sensors to monitor physical and water quality parameters in watersheds of different scales and types. The SEDS provides an excellent assessment of the readiness of commercially available sensors, however, the readiness of an integrated system is not clearly communicated. The revised SEDS document would be improved if it realistically discussed the potential difficulties of the procedures and costs for maintaining a network that employs sensitive sensors.

Although broad and general, the CI discussion in the SEDS does provide a consistent vision of the necessary infrastructure. The WATERS documentation on CI is too general and vague to provide a basis for evaluation as described in the NRC panel's statement of task. In going forward it will be important to move quickly beyond vision statements of CI to actual design documents. The revised plan should describe proposed interactions between WATERS and other environmental observatories and outline specific areas of CI cooperation.

The ideas presented in the SEDS document appear to cover the key elements of an education and outreach strategy. The signature activities described—summer research opportunities for K-12 educators, various activities characterized as continuing education, and integrating research and education through novel technology such as virtual observatories—are potential paths to success.

For WATERS to move forward with the planning process and ultimately secure support from NSF, it is essential that the revised SEDS present compelling science questions, define the nature of the transformative science to be accomplished, and clearly describe the path to achieve the envisioned results. A rationale for the need for observatories, a plan for a national design for placement of observatories, and a schedule for implementation is not clear in the draft document. The SEDS would be more useful to the committee and to its other target audiences if a clear rationale was given for the conceptual design of the network.

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Acronyms

BOD	biological oxygen demand
CI	Cyberinfrastructure
CCSP	Climate Change Science Program
CEI	Common Execution Infrastructure
CLEANER	Collaborative Large-scale Engineering Analysis Network for Environmental Research
COI	Common Operating Infrastructure
CUAHSI	Consortium of Universities for the Advancement of Hydrologic Science
CZEN	Critical Zone Exploration Network
CZO	Critical Zone Observatory
E&O	Education and Outreach
EPA	Environmental Protection Agency
GEON	Geosciences Network
LTER	long term ecological research
MREFC	Major Research Equipment and Facilities Construction
NAE	National Academy of Engineering
NASA	National Aeronautics and Space Administration
NEON	National Ecological Observatory Network
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
O&M	Operations and Maintenance
OOI	Ocean Observatory Initiative
POA	Patterns of Administration
SEDS	Science, Education, and Design Strategy
SWAQ	Subcommittee on Water Availability and Quality
TREC	Teachers and Researchers Exploring and Collaborating
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WATERS	WATer and Environmental Research Systems
WNPO	WATERS Network Project Office
WSTB	Water Science and Technology Board

Appendix A

Biographical Sketches for Committee on the Review of the Water Environmental Research Systems Network

George M. Hornberger (NAE), *Chair,* is the Ernest H. Ern Professor of Environmental Sciences at the University of Virigina. His research interests are catchment hydrology and hydrochemistry, as well as the transport of colloids in geological media. His work centers on the coupling of field observations with mathematical modeling, with a focus on understanding how water is routed physically through soils and rocks to streams and how hydrological processes and geochemical processes combine to produce observed stream dynamics. This modeling work allows the extension of work on individual catchments to regional scales and to the investigation of the impact of meteorological driving variables on catchment hydrology. Dr. Hornberger is a member of the American Geophysical Union, the Geological Society of America, the Society of Sigma Xi, and the American Women in Science. He has served on numerous NRC studies and is currently a member of the Committee on Hydrologic Science, the Report Review Committee, and is the chair of the Board on Earth Sciences and Resources. Dr. Hornberger received his Ph.D. in hydrology from Stanford University.

Mary Jo Baedecker is scientist emeritus at the U.S. Geological Survey (USGS). She previously served as Chief Scientist for Hydrology where she provided oversight for the National Research Program in the hydrologic sciences and represented the hydrology discipline in long-range program planning at the USGS. Dr. Baedecker's research interests include the degradation and attenuation of organic contaminants in hydrologic environments and microbial ecology in soils. She is a member of the National Research Council's (NRC) Water Science and Technology Board (WSTB) and has served on several NRC committees including the Committee on Ground Water Cleanup Alternatives, the Committee on Source Removal of Contaminants in the Subsurface, and most recently was a member of the committee that reviewed CLEANER and NSF's environmental observatories. Dr. Baedecker holds a B.A. in chemistry from Vanderbilt University, an M.S. in chemistry from the University of Kentucky, and a Ph.D. in geochemistry from George Washington University.

Yu-Ping Chin is professor and division chair of Global and Environmental Change for the Department of Geological Sciences at The Ohio State University, where he has been on the faculty for more than 15 years. Prior to joining The Ohio State University, Dr. Chin conducted research at the Swiss Federal Institute of Environmental Science and Technology on photochemical cycling in lacustrine systems and at the Ralph M. Parsons Laboratory on the properties of organic humic materials in marine and lacustrine porewaters and on the fluxes of particle reactive contaminants across the sediment/water interface. Dr. Chin's work has been published in over 50 peer-reviewed articles and book chapters, and he has served as a peer reviewer for numerous National Science Foundation studies. Dr. Chin received his A.B in geology from Columbia University, and his M.S. and Ph.D. in aquatic chemistry from the University of Michigan.

Glen T. Daigger (NAE) is the Senior Vice President and Chief Technology Officer of CH2M Hill, Inc. He is interested in water management, especially management of water to meet urban needs, while preserving and enhancing the natural environment. Dr. Daigger's technical expertise and professional practice has historically been in the treatment of wastewaters for various purposes, including environmental enhancement (discharge) and reuse. In more recent years he has become involved in the development of more efficient and environmentally friendly urban water management and treatment systems, including approaches that reduce water use and increase water recycling. Dr. Daigger has served on many NRC committees and currently serves on the Committee on Engineering Education and the Committee on Energy Futures and Air Pollution in Urban China and the United States. He received his Ph.D. in environmental engineering from Purdue University.

Tony R. Fountain is director of the Cyberinfrastructure Laboratory for Environmental Observing Systems (CLEOS) at the San Diego Supercomputer Center (SDSC) of the University of California, San Diego. SDSC serves as an international resource for data cyberinfrastructure and focuses on data-oriented and computational science and engineering applications. Dr. Fountain's group is involved in a number of sensornet and observation system projects that aim to address the issue of sensor network management and data accessibility. His research focuses on data mining, machine learning, and computational infrastructure for a variety of science and engineering applications. Of particular interest are applications in ecology and environmental science involving sensor networks, complex data analysis, and real-time decision support. Dr. Fountain is a member of the National Ecological Observatory Network's (NEON) Facilities and Infrastructure Committee and advises the development of NEON's communication and information technology. He was a member of the NRC committee that produced the report *CLEANER and NSF's Environmental Observatories*. Dr. Fountain holds a B.S. in cognitive psychology and statistics and a B.S. in computer science and mathematics from North Arizona University. Dr. Fountain received his M.S. and Ph.D. in computer science from Oregon State University.

Timothy K. Kratz is the director of the Trout Lake Station at the Center for Limnology at the University of Wisconsin. His research focuses on the long-term, regional ecology of lakes; carbon dynamics in lakes; lake metabolism; and the formation and ecology of kettle-hole peatlands. Dr. Kratz is a principal investigator for the North Temperate Lakes LTER and has served on the LTER's Executive Committee. He serves on the steering committee of the Global Lakes Ecological Observatory Network (GLEON). He has participated on the NRC's Committee to Assess EPA's Environmental Monitoring and Assessment Project and the Committee on Grand Canyon Monitoring and Research, as well as the NRC study on CLEANER and NSF's Environmental Observatories. Dr. Kratz earned his B.S. in botany from the University of Wisconsin, Madison, his M.S. in ecology and behavioral biology from the University of Minnesota, and his Ph.D. in botany from the University of Wisconsin.

Richard G. Lawford works as a Senior Scientist at the University of Maryland Baltimore County where he serves as the Director of the International GEWEX Project Office and as a contractor to McGill University where he is the Network Manager for the Canadian Drought Research Initiative. He also serves as the Chair of the Integrated Global Water Cycle

Observations theme of the IGOS-P (Integrated Global Observing Strategy Partnership) and the Task Lead for several international GEO tasks. Previous to occupying these positions he worked with the University Corporation for Atmospheric Research (UCAR) as a NOAA Program Manager for the GEWEX Continental Scale International Project (GCIP) and then the GEWEX Americas Prediction Project (GAPP) for eight years. For part of this time he also co-chaired the CCSP/USGCRP interagency committee on the water cycle and served as director of the CCSP Water Cycle Office. Prior to this time he spent approximately 30 years with Environment Canada in line management, corporate and operational positions dealing with research management (including eight years as Chief of the Hydrometeorological Research Division and one year as Deputy Director of the National Hydrology Research Institute) and coordination, policy development, program evaluation and planning for Science and Technology and for the federal Inland Waters Directorate and applied climate research. Prior to working in program management and coordination he occupied posts in research, training, and forecasting. Mr. Lawford received his undergraduate degree in Physics at the University of Manitoba (Brandon College) and undertook graduate studies in meteorology at the University of Alberta and McGill University.

Daniel P. Loucks (NAE) is a professor in the Department of Civil and Environmental Engineering at Cornell University where he works in the application of systems analysis, economic theory, ecology, and environmental engineering to problems in regional development and environmental quality management including air, land, and water resource systems. At Cornell, he has served as Chair of the Department of Civil and Environmental Engineering and as Associate Dean for Research and Graduate Studies in the College of Engineering. Dr. Loucks has also worked as a consultant to private and government agencies and various organizations of the United Nations, World Bank, and NATO on regional water resources development planning throughout the world. He has been a member of various committees of the NRC, currently serves on the Committee on Integrated Observations for Hydrologic and Related Sciences, and was chair of the NRC study on CLEANER and NSF's Environmental Observatories. Dr. Loucks was elected to the National Academy of Engineering in 1989. He received his M.F. in forestry from Yale University and his Ph.D. in environmental engineering from Cornell University.

Charles R. O'Melia (NAE) is the Abel Wolman Professor of Environmental Engineering Emeritus in the Department of Geography and Environmental Engineering at The Johns Hopkins University. His professional experience includes positions at Hazen & Sawyer Engineers, University of Michigan, Georgia Institute of Technology, Harvard University, and the University of North Carolina, Chapel Hill. His research interests are in aquatic chemistry, environmental fate and transport, predictive modeling of natural systems, and the theory of water and wastewater treatment. He is a member of the National Academy of Engineering and past member of the WSTB and BEST. He has served on numerous NRC committees, including the review of CLEANER and NSF's Environmental Observatories, the Committee on Research Opportunities and Priorities for EPA, the Committee on Wastewater Management for Coastal Urban Areas, and he was chair of the Committee to Review the New York City Watershed Management Strategy. Dr. O'Melia received a B.C.E. from Manhattan College and an M.S.E. and Ph.D. in sanitary engineering from the University of Michigan.

Stephen Polasky holds the Fesler-Lampert Chair in Ecological/Environmental Economics at the University of Minnesota and previously held faculty positions in the Department of Agricultural and Resource Economics at Oregon State University and the Department of Economics at Boston College. His research interests include biodiversity conservation, endangered species policy, integrating ecological and economic analysis, ecosystem services, renewable energy, environmental regulation, and common property resources. Dr. Polasky was the senior staff economist for environment and resources for the President's Council of Economic Advisers from 1998-1999. He has also served on the Environmental Protection Agency's Environmental Economics Advisory Committee of the Science Advisory Board and the Science Council of the Nature Conservancy. Dr. Polasky has served as associate editor and co-editor for the *Journal of Environmental Economics and Management* and his work has been published in numerous journals. He received a Ph.D. in economics from the University of Michigan in 1986.

Nancy N. Rabalais is Executive Director and a professor at the Louisiana Universities Marine Consortium. Dr. Rabalais' research includes the dynamics of hypoxic environments, interactions of large rivers with the coastal ocean, estuarine and coastal eutrophication, and environmental effects of habitat alterations and contaminants. Dr. Rabalais is a AAAS Fellow, an Aldo Leopold Leadership Program Fellow, Past President of the Estuarine Research Federation, a National Associate of the National Academies of Science, a member of the Scientific Steering Committee of LOICZ/IGBP, and past chair of the NRC Ocean Studies Board. She received the 2002 Bostwick H. Ketchum Award for coastal research from the Woods Hole Oceanographic Institution and was the Ian Morris Scholar in Residence at the University of Maryland Center for Environmental Studies in 2004. Her studies on the causes and consequences of Gulf hypoxia have garnered several awards, including the Blasker award (shared with R.E. Turner), NOAA Environmental Hero, Clean Water Act Hero, and Gulf Guardian award. Dr. Rabalais received her B.S and M.S. degrees in biology from Texas A&I University, Kingsville and her Ph.D. degree in zoology from the University of Texas at Austin in 1983.

Thomas C. Winter is a Senior Research Hydrologist Emeritus with the U.S. Geological Survey in Denver, Colorado. From 1961 to 1972 he conducted geological and water-resource studies in Minnesota, and was in charge of USGS ground-water studies there from 1968 to 1972. Since 1973 Dr. Winter has conducted research on the hydrology of lakes and wetlands, with emphasis on their interaction with ground water and evaporation. In the late 1970s he helped establish, and has since been a principal investigator at, four long-term field research sites: the Mirror Lake watershed in New Hampshire, the Shingobee River headwaters area in Minnesota, the Cottonwood Lake wetland complex in North Dakota, and the Island Lake area of the Crescent Lake National Wildlife Refuge in Nebraska. Dr. Winter also has been involved with lake and wetland studies in Washington, California, Colorado, Wisconsin, Massachusetts, and Florida. He has received the Distinguished Service Award from the U.S. Department of the Interior, the W.R. Boggess Award from the American Water Resources Association, the M. King Hubbert Science Award as well as the Life Member Award from the National Ground Water Association, the Lifetime Achievement Award from the Society of Wetland Scientists, the O.E. Meinzer Award from the Geological Society of America, and the Outstanding Achievement Award from the University of Minnesota. Dr. Winter earned B.A. and M.S. degrees in geology and a Ph.D. in hydrogeology at the University of Minnesota.

Appendix B

Guest Speakers and Panelists

Many individuals assisted the committee and the National Research Council staff in their task to create this report. We would like to express our appreciation to the following people who have provided presentations and comments to the committee:

Presentations

Roger Bales, University of California, Merced
Thomas Barnwell, U.S. Environmental Protection Agency
Elizabeth Blood, National Science Foundation
John Braden, University of Illinois, Urbana-Champaign
Patrick Brezonik, University of Minnesota, Minneapolis
Nicholas Clesceri, Rensselaer Polytechnic Institute, Troy, New York
Martha Conklin, University of California, Merced
Patrick Deliman, U.S. Army Corps of Engineers
Jared Entin, National Aeronautics and Space Administration
Bruce Hamilton, National Science Foundation
Thomas Harmon, University of California, Merced
Charles Hass, Drexel University
Rick Hooper, Consortium of Universities for the Advancement of Hydrologic Science
Alexandra Isern, National Science Foundation
Douglas James, National Science Foundation
Michael Jasinski, National Aeronautics and Space Administration
Matthew Larsen, U.S. Geological Survey
Barbara Minsker, University of Illinois, Urbana-Champaign
Jami Montgomery, WATERS Network Project Office
Michael O'Neill, U.S. Department of Agriculture
Kenneth Potter, University of Wisconsin, Madison
Pedro Restropo, National Oceanic and Atmospheric Administration
Mary Ann Rozum, U.S. Department of Agriculture
Jerald Schnoor, University of Iowa, Iowa City
David Simpson, Incorporated Research Institutions for Seismology
Charles Spooner, Environmental Protection Agency
Deanna Stouder, U.S. Forest Service
David Tarboton, Utah State University, Logan