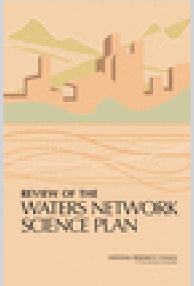

Review of the WATERS Network Science Plan

ISBN
978-0-309-15313-3

80 pages
6 x 9
PAPERBACK (2010)

Committee on the Review of Water and Environmental Research Systems (WATERS) Network; National Research Council

REVIEW OF THE
WATERS NETWORK SCIENCE PLAN

Committee on the Review of Water and Environmental
Research Systems (WATERS) Network

Water Science and Technology Board

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

Support for this study was provided by the National Science Foundation under grant number CBET-0715260. Any opinions, findings, or conclusions and recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-15313-3
International Standard Book Number-10: 0-309-15313-1

Additional copies of this report are available from the National Academies Press, 500 5th Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu.

Printed in the United States of America.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

COMMITTEE ON THE REVIEW OF THE WATER AND ENVIRONMENTAL RESEARCH SYSTEMS (WATERS) NETWORK

GEORGE M. HORNBERGER, *Chair*, Vanderbilt University, Nashville, Tennessee
MARY JO BAEDECKER, U.S. Geological Survey, Scientist Emeritus, Reston, Virginia
YU-PING CHIN, Ohio State University, Columbus
GLEN T. DAIGGER, CH2M Hill, Englewood, Colorado
TONY R. FOUNTAIN, University of California, San Diego
TIMOTHY K. KRATZ, University of Wisconsin, Boulder Junction
RICHARD G. LAWFORD, Global Energy and Water Cycle Experiment, Winnipeg, Manitoba, Canada
DANIEL P. LOUCKS, Cornell University, Ithaca, New York
CHARLES R. O'MELIA, Johns Hopkins University, Baltimore, Maryland
STEPHEN POLASKY, University of Minnesota, St. Paul
NANCY N. RABALAIS, Louisiana Universities Marine Consortium, Chauvin
JOHN T. SCHOLZ, Florida State University, Tallahassee
THOMAS C. WINTER, U.S. Geological Survey, Denver, Colorado

NRC Staff

STEPHANIE E. JOHNSON, Study Director
MICHAEL J. STOEVER, Research Associate

WATER SCIENCE AND TECHNOLOGY BOARD

CLAIRE WELTY, *Chair*, University of Maryland, Baltimore County
YU-PING CHIN, Ohio State University, Columbus
OTTO C. DOERING, Purdue University, West Lafayette, Indiana
JOAN G. EHRENFELD, Rutgers University, New Brunswick, New Jersey
GERALD E. GALLOWAY, University of Maryland, College Park
CHARLES N. HAAS, Drexel University, Philadelphia, Pennsylvania
KENNETH R. HERD, Southwest Florida Water Management District, Brooksville
JAMES M. HUGHES, Emory University, Atlanta, Georgia
KIMBERLY L. JONES, Howard University, Washington, DC
MICHAEL J. MCGUIRE, Michael J. McGuire, Inc., Los Angeles, California
G. TRACY MEHAN, The Cadmus Group, Inc., Arlington, Virginia
DAVID H. MOREAU, University of North Carolina, Chapel Hill
DENNIS D. MURPHY, University of Nevada, Reno
THOMAS D. O'ROURKE, Cornell University, Ithaca, New York
DONALD I. SIEGEL, Syracuse University, New York
SOROOSH SOROOSHIAN, University of California, Irvine

STAFF

STEPHEN D. PARKER, Director
JEFFREY W. JACOBS, Scholar
LAURA J. EHLERS, Senior Program Officer
STEPHANIE E. JOHNSON, Senior Program Officer
LAURA E. HELSABECK, Program Officer
M. JEANNE AQUILINO, Financial and Administrative Associate
ELLEN A. DE GUZMAN, Senior Program Associate
ANITA A. HALL, Senior Program Associate
MICHAEL J. STOEVER, Research Associate
STEPHEN T. RUSSELL, Senior Program Assistant

Copyright © National Academy of Sciences. All rights reserved.

Preface

For nearly a decade, a substantial group from the hydrologic sciences community has been engaged in discussions about formation of a network of hydrologic observatories. This coincided with a time when the National Science Foundation (NSF) was considering how to achieve the goals of "big-science" through environmental observing systems. With encouragement from NSF to proceed with plans for a network of hydrologic observatories, the WATERS initiative was born in 2005. This committee reviewed the Draft Science, Education, and Design Strategy (SEDS) document in 2008 and criticized the absence of a clear scientific vision for the project. Between August 2008 and May 2009, a team of scientists and engineers, led by Professor Jeff Dozier, prepared a Science Plan presenting the vision for an observatory network. It was the privilege of the committee who prepared this report to review this WATERS Science Plan.

The committee brought to its task a breadth of knowledge gained from experience with field research as well as from related scientific literature and reports produced during the planning of hydrologic observatories. The WATERS Science Plan was read and reviewed within this broad contextual background. The committee benefited greatly from frank and open briefings provided by members of the WATERS team and by NSF leaders from three directorates, briefings that led to much greater appreciation of both the great potential for an observatory network and also some of the challenges associated with it.

As chair of the committee, I thank the members of the committee for their hard work in preparing three reports, of which this is the final one, and for the way that everyone interacted with great good nature throughout our work together. This report, like all National Research Council (NRC) reports, was made possible by excellent staff work. My thanks to Michael Stoever for managing logistics for the committee and to Dorothy

Weir, who very ably served as study director for the committee for the first year and a half. I especially want to thank Stephanie Johnson for her major contributions to our work. Stephanie served as the study director for the interim and final reports. Special thanks are due for both editorial and substantive suggestions she made on the reports and for shepherding the reports through the NRC publication process.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with the procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments to 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:

A. ALLEN BRADLEY, University of Iowa
JAMES R. GOSZ, University of Idaho
WENDY D. GRAHAM, University of Florida
SALLY MACINTYRE, University of California, Santa Barbara
DAVID L. SEDLAK, University of California, Berkeley
EDELLA C. SCHLAGER, University of Arizona

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by **Mary Anderson**, University of Wisconsin. Appointed by the NRC, 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.

George Hornberger, *Chair*

Committee on the Review of Water and Environmental
Research Systems (WATERS) Network

Contents

APPENDICES

Summary

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, and shortages in water supply have been increasing in frequency in many parts of the country. The National Science Foundation (NSF) has entertained 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, a joint initiative of the Engineering, the Geosciences, and the Social, Behavioral and Economic Sciences directorates at NSF, is envisioned as an integrated national network of observatories and experimental facilities supporting research, outreach, and education on large-scale, water-related environmental problems. The proposed observatories would provide researchers with access to linked sensing networks, data repositories, and computational tools connected through high-performance computing and telecommunications networks. Because of the magnitude of this envisioned network, NSF proposed that the WATERS Network be built using funds from the Major Research Equipment and Facilities Construction (MREFC) appropriation, which is available to NSF to support the acquisition, construction, and upgrading of major research equipment and facilities.

In 2006, NSF requested that the National Research Council (NRC) Water Science and Technology Board convene a committee to provide advice as the WATERS Network navigates the multiyear planning process for MREFC funding. In 2006, a previous NRC committee considered potential research questions that the network might address (NRC, 2006). This current committee, formed in 2007, was tasked to review the WATERS draft conceptual design and its science plan and provide advice on integrating the WATERS Network with other related observational systems (see statement of task in Box 1-1). The committee previously authored two reports: (1) an interim report that evaluated the Draft Science, Education, and Design Strategy for the WATERS Network (Task #1; NRC, 2008) and (2) a letter report issued in July 2009 that summarized the committee's assessment of whether the Science Plan "sets forth a vision of what could be accomplished with an observing network to transform water science and engineering research and education" and "whether the Science Plan makes a compelling case for establishing the WATERS Network with Major Research and Facilities Construction (MREFC) funding" (Task #2; NRC, 2009). This report, the committee's final, provides a more detailed review of the Science Plan (Task #2) and provides advice on collaborating with other federal agencies (Task #3).

ASSESSMENT OF THE SCIENCE PLAN

The Science Plan was intended as a broad vision document, and in this light, the document succeeds in communicating a high-level vision for transforming water science and engineering research through the establishment of an observatory network. The plan outlines the opportunity to collect, analyze, and integrate hydrologic, environmental science and engineering, and social science data at a level that has not previously been possible. Overall, the committee finds that the presentation of the overarching science question and the three grand challenges in hydrology, engineering, and social sciences provides compelling arguments in support of the WATERS Network.

The integration of social sciences with engineering and hydrology is a key benefit of the WATERS Network. The committee commends the WATERS team for its efforts to bring together the community of researchers and encourages the team to continue to nurture the integration of multiple disciplines.

While the Science Plan makes a convincing case that the WATERS Network will likely lead to strong, transformative science *in its individual pieces*, it is not clear that a collection of such pieces will meet the MREFC criterion that the WATERS Network will "exhibit systems characteristics greater than inferred simply by the connectivity of its parts" (NSF, 2005). Each of the three hypothetical examples of regional, theme-based science in the Science Plan (i.e., snow hydrology, eutrophication of estuaries, and urban water systems) illustrates how our understanding of particular issues could be significantly advanced. However, there do not appear to be clearly articulated, compelling questions or hypotheses in the Science Plan that require integration across individual observatories at the same time. The document also does not explain clearly why any of the three major questions cannot be approached regionally and, in fact, why some current efforts are not addressing the science questions, at least in part. **As the WATERS team goes forward, it should bolster its case that a national network of observatories is *required* to address the science questions that are posed.** The committee believes that such a case can be made, especially with a strong social science component as part of the interdisciplinary water science network. However, the persuasiveness of the argument for WATERS as a unified facility also requires a strong case for the scientific and engineering knowledge to be gained from a national network. **Alternatively, a different funding mechanism within NSF might be considered, if feasible, for establishing a phased network of observatories that could address the questions posed in the WATERS Science Plan while taking better advantage of advances in technology over time.**

The committee finds the high-level vision for science to be well done in the Science Plan, but as the WATERS Network moves ahead through conceptual design phase, a much more detailed "science plan" will need to be developed in parallel with the design. Additional development and refinement of the Science Plan will be needed in the future to make sure that the necessary coordination between the desired science and the feasibility of network construction is accomplished. That is, the natural progression from high-level vision to detailed description of scientific objectives will have to occur. In support of this anticipated need, the committee in Chapter 2 offers some guidance with regard to cyberinfrastructure—a critical element of the WATERS Network to link the local observatories and to enable multiscale and networkwide analyses by a wide array of researchers. Additionally, issues to be considered in the development of a network of observatories, including factors that facilitate intersite comparisons, are discussed in Chapter 3.

INTEGRATION AND COORDINATION

The WATERS Network could serve as a catalyst for bringing agencies together to contribute to a broader integrated agenda. Descriptions of federal and state agency water-related activities tend to provide a picture of projects that are compartmentalized and directed by agency mandates and authorities. Given the breadth of the WATERS agenda, the program will gain from interactions with these diverse agency programs. Interagency collaboration could entail at least four possible levels of coordination: (1) interaction among researchers so that the WATERS Network team stays abreast of the objectives and findings of related programs and can learn from the experience of agency staff working at similar large-scale data collection and management projects, (2) development of policies for sharing data collected through independent initiatives, (3) coordination of future data acquisition plans, and (4) development of cyberinfrastructure for data sharing and other collaborative activities. Many possible benefits from improved coordination and integration have been summarized in Chapter 5. The degree of coordination that can reasonably be achieved, however, may depend upon the data sharing and cyberinfrastructure challenges encountered, as discussed in Chapter 2.

To enhance coordination and integration, the WATERS team should involve appropriate federal agencies, state and local governments, organizations, and international programs at an early stage. Interactions and relationships that are developed in a coordinated and planned way will have more impact than ad hoc opportunism by individual scientists.

OVERARCHING CONCLUSIONS

The WATERS Network Science Plan outlines a compelling vision for ways in which new, integrative hydrologic, environmental science and engineering, and social science research can help address pressing water management concerns while advancing water science and education. The argument for construction of a simultaneously operated national observatory network with funding from the MREFC program is not as convincing in the Science Plan, and the WATERS team should consider whether the case for a national network can be strengthened or whether another funding mechanism can be considered. Many design challenges remain to be addressed in future planning efforts, including selecting observatory sites, determining second-level research questions, and developing a cyberinfrastructure plan. As the details of the WATERS Network evolve, the Science Plan should be developed and refined in parallel. To optimize the potential contributions of the WATERS Network, the team should coordinate and collaborate with related government and nongovernment agencies and organizations at an early stage.

1

Introduction

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 United States has remained relatively constant since about 1980 (Hutson et al., 2004), 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 semiarid areas. Water quality is a concern in many of the nation's waters due to excess levels of nutrients, toxics, pathogens, and contaminants from a variety of household products.[1] As a society, if we are to meet current and future demands for water, we must learn to manage our valuable water resources more effectively.

The National Science Foundation (NSF) has entertained 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 being planned under NSF sponsorship[2] that are 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 Univer-

---

[1] See *http://iaspub.epa.gov/waters10/attains_nation_cy.control*; *http://water.usgs.gov/nawqa/.*

[2] These networks include the National Ecological Observatory Network (NEON), the Geosciences Network, the Ocean Observatory Initiative (OOI), and the Arctic Observing Network.

sities for the Advancement of Hydrologic Science, Incorporated's (CUAHSI's) Hydrologic Observatories initiative.[3]

WATERS is envisioned as an integrated national 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 would 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. These observatories would be sited within representative areas that could be compared and contrasted to address the program's research questions. The network may also contain several experimental facilities 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. As an additional benefit, the WATERS Network also has the potential to bring together and strengthen the hydrologic research community.

The WATERS Network is a joint initiative of the Engineering directorate, Geosciences directorate, and Social, Behavioral and Economic Sciences directorate at NSF. NSF originally 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, as defined by 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.

---

[3] CUAHSI's Hydrologic Observatories initiative is only one component of the consortium's activities. Additional information on CUAHSI programming and projects that fall outside the Hydrologic Observatories and the WATERS Network is available online at *http://www.cuahsi.org/*.

MREFC funds only cover the costs of project construction, although MREFC funding may also be provided for significant facility upgrades. In that case, the approval process is the same as that for a new MREFC project (NSF, 2007). The remaining phases of the project are supported with funding from the research budgets of the supporting directorates or with support from the Education and Human Resources directorate.

At the time this report was written, the WATERS Network was in an early phase of the conceptual design stage (part of "facility concept development"). NSF staff estimated that the remaining steps of the MREFC planning process prior to construction would take about 10 years if the WATERS Network project were to successfully advance through the planning and appropriation process.

STUDY SCOPE AND PURPOSE OF THIS REPORT

In 2006, NSF requested that the National Research Council's (NRC's) Water Science and Technology Board convene a committee to provide advice as the WATERS Network navigates the multiyear planning process for MREFC funding. This committee followed a previous NRC study (NRC, 2006), which 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, biology, computer science, and social sciences, was originally charged to review a draft WATERS Network conceptual design plan, titled the Draft Science, Education, and Design Strategy for the WATERS Network (WNPO, 2008, also called SEDS). In 2008, the NRC issued an interim report evaluating the SEDS (see Box 1-1, Task #1; NRC, 2008) and recommended that the WATERS Network team narrow the scope of the compelling science questions to be addressed, define the nature of the transformative science to be accomplished, and clearly describe the path to achieve the envisioned results.

Subsequently, the WATERS Network team refocused its efforts toward the development of a vision-level Science Plan, and in response to a request from NSF, the statement of task for the NRC committee was modified to include the review of that document. The committee met two times, in February and June 2009 to discuss the document with NSF staff and the WATERS leadership team. The final draft of the Science Plan (Dozier et al., 2009) was released in May 2009. The NRC agreed to

BOX 1-1
Statement of Task

In response to NSF's request, the Water Science and Technology Board 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 the WATERS Science Plan, and the associated documents to be provided (e.g., WATERS Network Project Office committee reports on education, modeling, etc.), to assess whether the Science Plan makes a compelling case for establishing the WATERS Network with Major Research Equipment and Facilities Construction funding. The Science Plan should articulate grand challenges that will attract widespread support; provide a foundation for formulation of second-level science questions; and set forth a vision of what could be accomplished with an observing network to transform water science and engineering research and education.

3. Advise the WATERS Network Project Office and NSF on how the WATERS Network can be integrated efficiently and effectively with the observational programs related to water resources of other federal agencies, state and local governments, and the private sector, considering the different missions of these agencies (including NSF, whose "mission" is to support fundamental research and education).

provide quick advice on Task #2 of the statement of task (see Box 1-1), and a letter report was issued in July 2009 that summarizes the committee's assessment of whether the Science Plan "sets forth a vision of what could be accomplished with an observing network to transform water science and engineering research and education" and "whether the Science Plan makes a compelling case for establishing the WATERS Network with Major Research and Facilities Construction (MREFC) funding." The letter report is provided in Appendix A.

This report, the committee's final, provides a more detailed review of the Science Plan (Task #2) and provides advice on collaborating with other federal agencies (Task #3). The assessment contained in this report is based on the collective expertise of the committee members, their review of planning documents supplied by the WATERS Network Team, and presentations and discussions with NSF staff; the WATERS Network leadership team; representatives from federal agencies with programs related to WATERS; and leaders from other MREFC efforts, such as NEON, OOI, and EarthScope.

In March 2010, as this report was nearing completion, the assistant directors of the Engineering, the Geosciences, and the Social, Behavioral, and Economic Sciences directorates announced that "NSF has decided not to move forward with WATERS as an MREFC project at the present time" (T. Peterson, T. Killeen, and M. Gutman, NSF, personal communication to Jeff Dozier, 2010). NSF cited the committee's 2009 letter report (Appendix A), and stated, "In particular, we were not convinced that the simultaneous construction of the entire infrastructure of a national network is essential to answer the science questions posed by WATERS." They concurred with NRC (2009), which stated, "it is probably more sensible to build the network incrementally and let the questions and experiments evolve in an adaptive framework. This approach, which is not constrained by MREFC timelines for design and construction phases, could take better advantage of advances in technology over time, such as for sensors and components of the cyberinfrastructure." NSF also noted that an incremental strategy for implementation would have a potentially less disruptive impact on the directorates' budgets than the sudden increase in operations and maintenance costs in an MREFC approach. However, the assistant directors stated that they "remain strongly committed to addressing the important scientific questions outlined in the WATERS Network Science Plan."

The committee structured its evaluation around several key points that are seen as critical for the WATERS Network as it moves forward in any form, including via more incremental steps outside of the MREFC process. First and foremost, the science questions and challenges put forth in the Science Plan are evaluated (Chapter 2). Identification of the fundamental science questions is an essential step in the development of the WATERS Network. Second, the committee explored the idea of a "network" and how the Science Plan is successful in describing the characteristics that define the unique attributes of the proposed WATERS Network (Chapter 3). Third, because the primary option envisioned for securing funding for WATERS was the MREFC Program, the committee evaluated the Science Plan with respect to meeting required criteria for this program (Chapter 4). Much of Chapter 4 summarizes and expands upon the advice provided in the committee's 2009 letter report (NRC, 2009). Although the material may seem outdated by the recent NSF announcement, the text is included for completeness and to communicate the committee's expectations for a network under the MREFC program, if such an initiative is again pursued in the future. There is overlap between Chapters 3 and 4, in that part of the MREFC criteria relates to the need to have a *network*. In addition to the network concept, however, the MREFC requires that WATERS be a *facility*, which adds an additional layer of refinement. Finally, the committee considered potential linkages of WATERS with a host of other programs (Chapter 5). Because water resources are so critical for many sectors in the nation, the need for WATERS to coordinate with state, national, and international entities presents a tremendous opportunity but also offers daunting challenges.

2

Evaluation of the WATERS Network Science Plan

The WATERS Science Plan (Dozier et al., 2009) presents a high-level vision for interdisciplinary water research that would be enabled by the construction of a network of observatories. The Science Plan envisions an integrated approach involving the natural, engineering, and social sciences to study fundamental processes and activities in the built and natural environments. The overarching science question presented in the plan is: "*How can we protect ecosystems and better manage and predict water availability and quality for future generations, given changes to the water cycle caused by human activities and climate trends?*" Three "grand challenges" or high-level research questions, which also are at the level of a vision statement rather than a detailed plan, are posed in the Science Plan as natural extensions of the overarching question:

1. How is fresh water availability changing and how can we understand and predict these changes?
2. How can we engineer water infrastructure to be reliable, resilient, and sustainable?
3. How will human behavior, policy design, and institutional decisions affect and be affected by changes in water?

These three questions reflect the focus on the natural, engineering, and social sciences respectively. The committee's comments are organized around the overarching question and the three grand-challenge questions that flow from it.

OVERARCHING SCIENCE QUESTION

The WATERS investigators have identified an important overarching science question, which inextricably links the welfare of humans and ecosystems to the accessibility of high-quality water. The research path forward suggested by the overarching question requires not only additional and better data, but integration of information from various disciplines. In the Science Plan, Dozier et al. (2009) argue that an observatory network is the preferred, and perhaps the only, feasible mechanism for addressing the challenge. The WATERS Network science team further argues that research to support decisions about water-related issues is needed urgently and, given that the envisioned network will require almost a decade for detailed planning and implementation prior to construction and operation, there is a need to act now to initiate the program. As noted in the committee's July 2009 letter report (see Appendix A), the Science Plan was intended as a broad vision document, and in this light, the document succeeds in communicating a high-level vision for transforming water science and engineering research through establishment of an observatory network. In particular, the overarching question presented in the Science Plan successfully conveys the broad rationale for a major research undertaking.

THE THREE GRAND CHALLENGES

The WATERS investigators extended the overarching question by posing three "grand challenges" as embodied in the three high-level questions noted earlier. These three questions pose challenges associated with (1) closing the water balance (i.e., independently determining the fluxes and storage of water in both natural and engineered water systems), (2) providing research to support engineered water infrastructure to provide society with safe and reliable water services and protection from hydrologic events (e.g., floods, droughts), and (3) providing a better grasp of the complex interactions and uncertainty between human behavior and variability in the water cycle. In the Science Plan, Dozier and colleagues (2009) argue that the "business as usual" approach to tackling scientific problems drawn upon disciplinary lines will not succeed in answering the challenges as defined. The three grand challenges do, in fact, provide an excellent basis for organizing the plan for the WATERS Network. Furthermore, the challenges embrace the interdisciplinary framework that is a hallmark of the WATERS Science Plan. The committee judged that the proposed approach to span natural sciences, social sciences, and engineering could lead to WATERS becoming a model for conducting interdisciplinary research within the National Science Foundation (NSF). In particular, the integrated WATERS Network could provide a valuable opportunity to integrate the social sciences and water science.[4]

The Science Plan was conceived as a high-level vision statement and not as a design document. Thus, comments on and critiques of details are not possible. The committee recognizes, however, that careful attention to details will be quite important if the WATERS Network proceeds in the future. Therefore, the committee offers some observations on issues that will need to be addressed in the future to elaborate successfully an approach to meet the three challenges stated in the vision in the Science Plan.

Characterizing the Water Balance and Predicting Changes in Water Availability

One of the central arguments for hydrologic observatories at various locations or regions of the United States is to enable hydrologists to understand better what happens to water in different types of watersheds. As described in the Science Plan, determining a water balance for a given region involves measurement of fluxes of water (e.g., streamflow, groundwater flow, evapotranspiration) and stocks (e.g., volume of a surface reservoir, amount of water stored in soils). Most often in current practice, one or more of the important fluxes is not measured and must be approximated by calculating the difference (e.g., evapotranspiration as the difference between measured precipitation and measured river runoff) or by some other means. The term "closing the water balance" refers to the notion that appropriate measurements of all important fluxes and stocks be made or estimated independently before determining whether the measurements are internally consistent. Satellite systems and surface-based sensors in the WATERS Network will measure fluxes of water between various stores in the atmosphere, cryosphere, soil, and groundwater (Dozier et al., 2009). Understanding and quantifying the various components of the water cycle are fundamentally important objectives for water science in general and for the broader goals of under-

---

[4] Similar initiatives centered around ecological issues and sustainability are under way in urban Long-Term Ecological Research (LTER) Network sites and through the LTER's Integrative Science for Society and Environment initiative.

standing and predicting future changes in water availability within a changing climate. Closing the water balance is critical for Earth System and climate models, which otherwise will not be reliable for long-term predictions of the water cycle or related variables. Thus, these are appropriate long-range goals for the WATERS Network.

The WATERS objective extends beyond physical measurements and models of water per se. The Science Plan calls for extensive chemical measurements as well, to allow for closure of chemical balances linked to water to complement the water balance. Addressing challenges concerning sensors will be particularly important.

A better understanding of the hydrologic water balance on the watershed scale would provide opportunities for improved management of the surface water and groundwater in those watersheds. Water balance analyses, however, are highly dependent on scale, as judged by space, time, and purpose. As planning for WATERS proceeds, the argument that a network of long-term hydrologic observatories is required to observe processes over a spectrum of scales should be articulated convincingly and clearly and be tied to detailed research descriptions and to implementation plans. In summary, the first grand challenge remains as a critical science need, and the WATERS team will have to elaborate the details required to meet the challenge effectively as the project proceeds.

There are many difficult issues that will have to be engaged to move WATERS ahead to accomplish the stated goals. These include network design, choice and deployment of sensors, integration of NSF-supported efforts with those of other agencies, and cyberinfrastructure. The committee offers some extended comments on networks and linkages with other programs in Chapters 3 and 5. The committee's interim report (NRC, 2008) contained some discussions related to sensors and cyberinfrastructure. Because the latter topic is of critical importance to the pursuit of all of the science questions outlined, cyberinfrastructure issues are discussed later in this chapter.

Engineering Improved Water Infrastructure

A second challenge put forth in the WATERS Science Plan is to understand better how to construct and operate engineered infrastructure to manage water quantity and quality. Sufficient data are lacking on the complex interactions among chemical constituents, pathogenic organisms, and water infrastructure, as is the research infrastructure to test entirely new configurations to optimize water and energy management.

The WATERS Network would address this deficiency by deploying a system of physical and chemical sensors in a variety of water systems and environments to accumulate an empirical base of field data. Another goal as envisaged by the team is the construction of a facility that would be used to test an engineered system's response to different environmental stresses and novel configurations. Such a facility would also allow researchers to test systems to failure, which cannot be done in existing water and wastewater systems.

The committee finds that this grand challenge is well posed as one of the underpinnings for justifying the WATERS Network. Urban water use, conveyance, and treatment are essential components of the overarching question regarding management of water availability and quality for future generations. There are serious issues, however, that will need to be addressed as the planning process moves forward. These include many of the same details alluded to in the previous comments about the first of the grand challenges (e.g., sensor design and operation, linkages with other programs, cyberinfrastructure). Sensors, in particular, can be costly to purchase, maintain, and implement in a widespread area, and sensor development requires extensive research. Thus, the WATERS Network science team will need to consider what key second-level science questions on water quality have the greatest potential to transform the decisions of water managers and improve ecological integrity and human health and how data collected from sensors contribute toward these objectives.

Although the proposed experimental facility for testing water infrastructure would be an important contribution to science and engineering research, the committee also questioned whether such a facility stretches the concept of an observatory network too far, thereby diluting limited resources for the network as a whole. Future planning efforts should carefully examine the value of these specific test facilities to the WATERS Network. The WATERS team should either make a better case as to how a test facility could increase the knowledge gained across a network of observatory sites or decide that these facilities might more appropriately be of a portable nature that could be deployed to numerous locations for testing which would be integrated into the distributed sensing network.

Understanding People, Institutions, and Their Water Decisions

The third grand challenge posed in the Science Plan seeks to understand how human behavior, policies, and institutional decisions both influence and are influenced by water. A major component of the social science questions facing the WATERS team is to understand and predict water use under a variety of conditions. Major tasks would involve quantifying water use by the human system and using surveys, archival studies of governmental and utility data, and experiments to predict water demand and factors that influence demand (especially in areas where water is scarce). This challenge also requires research to understand the ability of alternative institutional forms to govern water usage, respond to fluctuations in availability and water quality, and balance the costs of developing reliable water supply for human use—be it snowpack, lakes, groundwater, or rivers—with the need to protect these resources and the natural systems that depend on them. One goal of the WATERS Network is to provide scientists, engineers, policy makers, and other stakeholders with the knowledge and tools needed to maintain a reliable and sustainable supply of potable water for the public without damaging watersheds and ecosystems. If properly designed, the WATERS Network could assist water resource managers and stakeholders, in altering human impacts on water use, to adapt to shifts in population and economic dynamics, enhanced knowledge about the human and natural environments, and the consequences of climate change.

The social science vision put forth in the Science Plan outlines the critical research needs in this important area. Key research gaps have been identified in assessing the effectiveness of water policies and management, in understanding the determinants of consumptive water use, and in developing improved water management institutions (NRC, 2001). All of these, as well as others suggested in the Science Plan, will depend critically on integrating work in the natural and social sciences and on linking data from physical observatories with longitudinal archival and survey data that allow social scientists to track changes in the human system over time. For example, archival data on the program and policy decisions of water-related authorities combined with surveys of affected users, user organizations, and the general public in areas of intense hydrologic observations can be used to analyze the interaction between observed fluctuations in the natural system and the human system response. The WATERS Network is an excellent vehicle for achieving the needed research and integration.

Linkages Among the Grand Challenges

The three grand challenges posed in the Science Plan represent the disciplinary perspectives of the three supporting NSF directorates (i.e., Geosciences; Engineering; and Social, Behavioral, and Economic Sciences). Each challenge alone might be substantial enough to support the development of large hydrologic observatories, but the WATERS team argues that all three challenges must be addressed to answer the overarching question: "How can we protect ecosystems and better manage and predict water availability and quality for future generations, given changes to the water cycle caused by human activities and climate trends?"

Dozier et al. (2009, p. 9) state, "As climate and land use change, populations grow and relocate, and our engineered systems age and are taxed with new contaminants, the empirical methods we have traditionally relied on have become inadequate and inaccurate." The WATERS team clearly recognizes that answers to the questions posed require integration across the natural, engineering, and social sciences, given the coupled nature of natural and human processes within water resources issues. Maintaining a truly interdisciplinary perspective as WATERS moves forward with more detailed planning, however, will be challenging because true integration of social sciences with engineering and hydrologic sciences is currently in its infancy. To nurture this interdisciplinary approach to water research and strengthen future large-scale collaborations between the geosciences, engineering, and social sciences, NSF should consider sponsoring interdisciplinary requests for proposals, jointly issued by the three directorates, that support research projects of sufficient size and duration to enable advancement in this area.

PROTOTYPE NETWORK

To lend a bit more specificity to what might be accomplished in addressing the three grand challenges, the Science Plan presents a "prototype network" to illustrate how the proposed WATERS Network would allow the combination of models and data to address pressing societal problems through interdisciplinary research. The Science Plan includes three example observatories in this prototype network that leverage prior work from WATERS test-bed projects and elsewhere: the Sierra Nevada for "Snow-Dominated Water Resources in the Mountain West," the Chesapeake Bay for "Non-Point Source Pollution into Receiving Waters," and an engineered system in Pittsburgh for "Integrated and Adaptive Water Cycle Management in Urban Systems." Note that these examples do not reflect selected observatory sites for the WATERS Network and were only developed for illustrative purposes. The committee appreciated the use of example systems and offers the following comments on them.

Snow-Dominated Water Resources in the Mountain West

Earth's glaciers and ice caps have been undergoing recession in recent decades, and mountain snowpack in areas such as the intermountain West has been in decline. These changes have significant implications for water resources and ecosystems. The state of the cryosphere has been cited as having "a unique sensitivity to climate change at all spatial and temporal scales" (Slaymaker and Kelly, 2007).

In the United States, snowpack changes in the West are the best documented current hydrologic manifestation of climate change (Barnett et al., 2008; Pierce et al., 2008). About half of the observed decline in snowpack in western mountains (with concomitant changes in the amount and seasonality of river discharge) is clearly linked to a warming climate due to anthropogenic influences. The largest losses in snowpack are occurring in the lower elevations of the Sierra Nevada and Cascade mountains of the Northwest and California, as a result of more rain than snow falling under higher temperature. In climates where the summer growing season is the dry season, as is the case for much of the western United States, this concentration of runoff in the spring season and reduction in later summer runoff stresses the water supply systems and can lead to water shortages in summer (Barnett et al., 2005).

The Science Plan's mountain snowpack example lays out the societal issues and science challenges well. This example emphasizes the hydrologic science questions (i.e., how is fresh water availability changing and how can we understand and predict these changes?). Some questions, however, are included that address social sciences (e.g., what institutional arrangements would best manage the watershed for ecosystem services?) and the engineered water systems (e.g., what are the effects of changing patterns of water delivery on the provision of drinking water and the management of wastewater and stormwater?). Thus, the mountain snowpack example touches on all three grand challenges, albeit unevenly. The example contains a convincing explanation on how an observatory would provide information that could lead to fundamental new insights about processes, allow the development and testing of new theory, and lead to much-improved decision making by water managers.

Chesapeake Bay

Cultural eutrophication is a serious and ubiquitous global water quality problem in lacustrine, estuarine, and coastal aquatic environments. It is normally the result of inputs of nutrients—nitrogen and phosphorus—resulting from a variety of human activities (Vollenweider, 1971). Estuarine and coastal waters along all coasts of the United States are severely impacted. Eutrophication is often accompanied by massive algal blooms, reduced transparency, development of littoral mats of filamentous algae in near-shore areas, disappearance of submerged aquatic vegetation, speciation changes, development of low-oxygen conditions, decline of fisheries, obnoxious tastes and odors, and the production and release of toxins that impair human and animal health.

The link between increased nutrients and increased primary production is well established. Difficulties in understanding the problems associated with eutrophication are related to the changes in fluxes of materials from the watershed and airshed, their speciation and quantity, and the sources. Point sources of pollution are more readily identifiable than nonpoint and diffuse sources. An additional difficulty in defining impaired water quality related to nutrient increases and its negative impacts are the multiple stressors impinging on a water body, such as habitat loss, changes in fishing pressures, hydrologic modifications, dredging, and the presence of other chemical contaminants such as metals and pesticides. Water quality management related to nutrients is severely hampered by the complexity of the aquatic ecosystem, its human inhabitants, and the multiple sources of nutrient inputs.

The Chesapeake Bay is a sensible example for the illustrative purposes of the Science Plan. The overarching societal questions are well developed, and the example emphasizes the hydrologic and social science challenges in the Chesapeake Bay. The discussion is not as effective as that for the Sierra example, however, in part because the Science Plan does not clearly explain how the WATERS Network would complement the extensive long-term research, monitoring, and management efforts in the Chesapeake Bay to create significant advances in understanding. Moreover, the monitoring strategies discussed in the Science Plan appear to focus on physical parameter measurements (e.g., flow, temperature) to elucidate the physical causes of the problem (e.g., stratification, turbidity) while eutrophication is dominantly a biogeochemical phenomenon. Linkages to the grand challenge on engineered infrastructure involve management practices in the watershed to control nutrient loadings, although the associated scientific challenges are not explored in the same depth as the hydrologic and social sciences challenges.

The ubiquity of the problem across the nation does indicate that the overall choice of impacts of nutrient additions to the nation's waters is an excellent vehicle to express the advantages of the WATERS Network approach. The Science Plan example would be more compelling if it included an expanded description of the problem and a broader vision of the network to extend the discussion to the nation as a whole.

Pittsburgh Engineered Water System

The third example observatory in the Science Plan examines how society can better sustain the engineered water cycle despite changing land use and population growth. The Science Plan describes the compelling science challenges associated with the urban water cycle. It uses the example of the Pittsburgh watershed to outline ways that the WATERS Network could help address these challenges in an urban setting and at the interface between the engineered and natural environments.

The WATERS team emphasized the importance of designing the engineered observatory correctly because it is nested within a larger watershed observatory. The hypothetical observatory could provide valuable information regarding the state of the existing built water infrastructure and insights into how future upgrades can be designed in a smarter, more adaptive, and sustainable manner, while examining issues of water quality and availability in the broader watershed. The linkages between the three grand challenges—water infrastructure, changing availability of freshwater (focused primarily on water quality in this example), and human and institutional decisions—are particularly compelling.

The WATERS team also proposed the use of test facilities to overcome the challenges of research in an existing built environment, including the inability to test changes to treatment processes (e.g., the use of a different disinfectant) or alterations in water quality (e.g., chemical spills, introduction of pathogens) or to test an existing system to failure. Their vision of the proposed experimental facilities for the built environment effectively describes the research advantages associated with such facilities. However, as noted previously, the committee questions whether this experimental facility is consistent with the concept and resources of an observatory network.

Building Linkages Within the Network

Each of the example observatories in the prototype network, discussed in the previous sections, addresses the overarching interdisciplinary question posed in the Science Plan. The examples also all touch on each of the three grand challenges, albeit sometimes unevenly. Important synergies are evident from addressing social science questions concurrently with engineering and hydrologic science questions. The linkages between the example observatories, however, are not clear, nor are they explained. Are there compelling reasons why *simultaneously* answering the questions posed, in common locations, across a network of sites, is important and provides important synergies over answering them separately? To justify a national network, the WATERS team should make a stronger case that these science questions require intersite comparison to answer or identify other integrated questions and hypotheses that are posed across sites.

ADDITIONAL BENEFITS OF THE WATERS NETWORK

In addition to the benefits noted above and also in the Science Plan, the WATERS project has the potential to bring several widespread benefits to the global scientific community. The nation's applied research and operational programs can benefit from the modernization and transformation that the WATERS Network would bring. For example, the WATERS Network would bring new technologies, such as novel remote sensing capabilities, into common use in water science. Although data collection has been headed in this direction for several years, the WATERS Network could accelerate the development of technologies that are less dependent on the collection of data by humans and save funding, and perhaps lives, while enabling faster, more accurate monitoring.

The WATERS Network could also make significant contributions to areas such as water and human health, water–energy linkages, and water economics. For example, societal benefits could be realized from the redesign of coupled built and natural water systems to maximize the availability of clean water. Also, the WATERS Network could spur the development of sensors to detect drinking water contaminants such as harmful microorganisms, pesticides and herbicides, and emerging pollutants such as pharmaceuticals and personal care products that enter potable water supplies. In the area of water and energy, the WATERS Network could examine the societal trade-offs between increasing domestic energy production and the resulting impacts on water resources, both quality and quantity. As an example, increased use of irrigated crops for the production of biofuels could have significant impacts on water supplies and cause much greater water quality problems, including increased nitrogen and phosphorus loads (NRC, 2008). As fresh water becomes scarcer in certain parts of the nation, economics will play an increasing role in determining water policy and promoting conservation. One of the strengths of the WATERS Science Plan is that social sciences is an integral component of the network and can address some of these economic considerations.

The inclusion of social science data not only strengthens timely policy-related analyses, but can also encourage transformative research that is not currently possible. For example, research on collaborative governance institutions for watershed planning now uses only expert judgments to assess the performance of alternative institutional design. An integrated database that includes both institutional and hydrologic measures of performance would allow more meaningful analysis. Similarly, long-term measurement series focused on changes relating to climate and water quality can be linked to the responses of water users as well as water managers and political overseers to study the adaptive capacity of the system.

Another important benefit of the WATERS program is the potential for affecting water science in the international arena, particularly in developing countries where water supply and water quality problems are typically much greater than in the United States. For example, climate change is a global issue, yet many countries cannot provide adequate safe drinking water much less the resources to examine the impacts of climate change on their water resources. For example, WATERS could make major contributions on behalf of the United States to the Global Water System Project, which is addressing human interactions with the hydrologic cycle in terms of natural and built environments; the Group on Earth Observations, which is developing the data and information components of the Global Earth Observation System of Systems; and the Global Energy and Water Cycle Experiment, which is focusing on hydrologic prediction systems. The WATERS research findings also could become an important U.S. contribution to international development programs, particularly for those countries where water issues are critical.

FUTURE CHALLENGES: CYBERINFRASTRUCTURE

As discussed previously in this chapter, cyberinfrastructure is a critical element of the WATERS Network to link the local observatories and to enable multiscale and networkwide analyses by a wide array of researchers. Considering the lack of cyberinfrastructure details in the Science Plan, the most that the committee can offer in terms of a critique is to note several general areas that deserve attention. Once WATERS moves toward more detailed planning, the design team will derive cyberinfrastructure requirements that will inform their design decisions and architecture. This could lead to a conceptual design with sufficient detail to support a rigorous review. In the absence of a conceptual design, the committee can only speculate on what the needs will be.

1. **Scope of services**: It will be important to clarify the scope of the cyberinfrastructure services that the WATERS Network will provide. The Science Plan mentions data products, workflows, models, and collaboration services. Mention is made of "real-time" observational data, including synthesized "real-time" observations. Observations, forecasts, and decision support are listed among the network services that will be enabled by cyberinfrastructure. Other observational Major Research and Facilities Construction (MREFC) projects (e.g., National Ecological Observatory Network, USArray) have a more limited focus, namely standardized data product publication. It will be important that the detailed plans for WATERS cyberinfrastructure be evaluated within the context of technical feasibility and budgetary reality to determine the appropriate scope of services.
2. **Integration with existing facilities**: The proposed integration of WATERS cyberinfrastructure with existing facilities and other agencies raises numerous issues in cyberinfrastructure development and operations. Although the intention to leverage existing systems is commendable, and probably necessary, the actual execution of this idea will be a challenge. It is relatively straightforward to exchange data products, but it is significantly more difficult to develop and manage complex cyberinfrastructure systems across autonomous agencies. There are technical and operational challenges, such as agreements on common interface standards, integration of heterogeneous and legacy software systems, and

agreement on system tasking, operations, and maintenance. Resolving these issues will be a challenge that should be addressed in the conceptual design document.

3. **Metadata standards**: The success of the WATERS Network will depend, in part, on the metadata specifications. It could be useful for the WATERS design team to detail the approach to creating and getting consensus on appropriate metadata standards for both deployment details (e.g., sensors, locations, calibration histories) and data products. In addition to the standards, it would be useful to create detailed example scenarios to demonstrate the operational roles of various metadata tagging and processing activities.

4. **Acquisition of cyberinfrastructure components**: An approach to cyberinfrastructure acquisition should be described in the next level of design documents. What approach will the WATERS design team take in identifying and acquiring the cyberinfrastructure? The WATERS team will need a plan for surveying the current portfolio of NSF-sponsored cyberinfrastructure and identifying elements that can be adapted to their needs. They should avoid the temptation to design and build everything from scratch. For adapting cyberinfrastructure from the WATERS prototypes, they will need a plan that transitions the current test-bed or prototype activities into a continental-scale production facility. Practices and policies that are adequate for small-scale independent systems will not suffice for an integrated system of the scale envisioned for WATERS. They should also engage with the other observational MREFCs to explore options for cyberinfrastructure acquisition.

5. **Operations and maintenance**: A detailed projection of the anticipated costs for operations and maintenance should be performed as soon as possible. The number of fielded sensors and their geographical distribution will require considerable maintenance for deployment, cleaning, calibration, rotation, etc. Similarly, the need to maintain decision theaters and modeling clusters will also require administrators, support staff, and managers. An early estimate of the costs of operations and maintenance could perhaps provide useful feedback to determine the scope of cyberinfrastructure services that the WATERS Network will provide.

6. **Phased deployment**: Given the broad distribution of the WATERS cyberinfrastructure and the rapid rate of technology evolution, the WATERS team should consider various deployment schedules. Also, given the loosely coupled nature of many of the cyberinfrastructure components, it will likely be possible to mitigate some development risks by strategically testing and hardening system components on a relatively

small scale (e.g., a watershed). In addition to a phased system deployment, it will be important to have a plan for periodic technology refresh. Given the intended lifespan of the WATERS Network, the cyberinfrastructure will most likely need to support several generations of sensors and instruments.

7. **Management**: The committee recognizes that WATERS is a large and complex system. Although there is a sizeable and qualified project team, it could be useful to hire a full-time systems design engineer who has experience with complex large-scale systems as the WATERS Network moves forward.

CONCLUSIONS AND RECOMMENDATIONS

As noted in the committee's letter report (NRC, 2009), **the Science Plan was intended as a broad vision document, and in this light the document succeeds in communicating a high-level vision for transforming water science and engineering research through establishing an observatory network.** The Plan outlines the opportunity to collect, analyze, and integrate hydrologic, environmental science and engineering, and social sciences data at a level that has not previously been possible. Opportunities for cutting-edge research are envisioned through the collection of data from sensors distributed at sites along gradients or at nested sites that will enable the improvement of the understanding of the complete water balance within a research site. The proposed network also could support research on how better to design and build engineering systems for water management and the collection of social science data from individual sites and on a national scale to better understand human–water resource interactions and impacts. Overall, the committee finds that the presentation of the overarching science question and the three grand challenges in hydrology, engineering, and social sciences provide compelling arguments in support of the WATERS Network. The hypothetical observatory examples illustrate the potential interdisciplinary research that could be undertaken using the WATERS Network, although the linkages between the example observatories that would lead to a national network based on intersite comparison remain poorly defined. **The integration of social sciences with engineering and hydrology is a key benefit of the WATERS Network.** The committee commends the WATERS team for its efforts to bring together this community of researchers, and encourages the team to continue to nurture the integration of multiple disciplines.

Although the committee finds the high-level vision for science to be well done in the Science Plan, as the WATERS Network moves ahead through the conceptual design phase, a much more detailed "science plan" will need to be developed in parallel with the design to make sure that the necessary coordination between the desired science and the feasibility of network construction is accomplished. That is, the natural progression from high-level vision to detailed description of scientific objectives will have to occur.

3

Observational Networks

WATERS is envisioned to be an integrated network of observatories that support hydrologic, engineering, and social sciences research and education on water-related problems. In this chapter, the committee explores the concept of a network and evaluates how well the Science Plan describes the characteristics that define the unique attributes of the proposed WATERS Network. The chapter also includes discussions of challenges that are likely to be faced when developing the WATERS Network.

THE NETWORK IDEA

Networks are needed to collect uniform information across temporal and spatial scales. The word "uniform" is key here because the data need to be comparable in order to facilitate intersite comparisons. Sometimes, when a variable is measured at different sites using different types of sensors, one cannot distinguish if the differences in the measured values are related to spatial and temporal changes in the variable or if they are related to the instruments used to collect the data. For example, if nitrate is measured in one location using an optical sensor and in another location using an electrode, the numbers may not be comparable, and extensive intercalibration, which is costly and time-consuming, would be needed. Quality assurance and quality control are essential for cross-calibration of instrumentation and sensors. Furthermore, to facilitate intersite comparisons, networks need to be based on a common conceptual framework, driven by an encompassing set of conceptual models and hypotheses, so that commonalities in information can be distinguished from information unique to a particular environment.

Networks generally consist of one of two types: (1) an instrument network or (2) a thematic network of research areas. In an instrument network, a single type of instrument is deployed across a variety of environments so that the spatial and temporal distribution of one specific type of information can be collected. The second type of network consists of a group of areas (e.g., watersheds) where research is conducted to address specific questions about how ecosystems function, including the natural, engineered, and human systems.

An example of an instrument network is the National Weather Service's network of precipitation gauges across the United States. These gauges have uniform specifications and operation protocols. Another such network is the stream gauging network operated by the U.S. Geological Survey. The operation of this network requires extensive training of field technicians to use uniform protocols and computation techniques to measure stream velocities and cross-sectional areas under conditions that range from partially frozen rivers in Minnesota to the slow-flowing bayous of Louisiana. The goal is comparable data across the network.

An example of the second type of network, a group of research areas operated under the same theme (or conceptual framework), would be the Experimental Forests operated by the U.S. Forest Service. Research in the Experimental Forests generally has a common theme, such as the effect of weather on forest conditions or the effect of forest-harvesting practices on surface water quantity and quality. Similar to the case of an instrument network, the operation of a network of experimental or research areas requires a substantial amount of time and resources devoted to planning and training. Intersite comparisons are a goal common to both types of networks.

Long-Term Ecological Research (LTER) sites might also be considered a network. However, because of the wide variety of ecosystems being studied, this is a more loosely constrained network in terms of specific questions that are being asked that are uniformly addressed at all sites. LTER sites are each expected to provide comparable data with regard to pattern and control of primary production; spatial and temporal composition of populations selected to represent trophic levels; pattern and control of organic matter in sediments; patterns of inorganic nutrients and their movements through soils and water; and patterns, frequency, and effects of disturbance. The approaches, hypotheses, and experimental design differ by site. Another example might be a a program funded by the National Science Foundation for understanding climate-related decisions under uncertainty,[5] in which five interdisciplinary

---

[5] See *http://www.nsf.gov/news/news_summ.jsp?cntn_id=100447&org=EEC*.

research teams each study different decision makers (e.g., water managers, insurance managers, and electric utility managers) or different aspects of decision making (e.g., group decisions, policy-maker use of information). The potential power of a network, however, is unclear in that climate decisions research program because of divergent research foci, the lack of common research protocol, and little integrating management structure.

The Need for Networks

A thematic network of research areas, as described in the preceding section, may be needed to address questions for which broad coverage is required to understand the functioning of various processes in both comparable and contrasting environments. There are many different natural environments in the United States that are defined by factors that include land-surface topography, soils, geology, climate, water abundance, and chemistry. Furthermore, the natural environments interact in complex ways with different human systems defined by factors such as land use, urbanization, water user types, community organizations, and the institutional structure that governs their use of water.

The Science Plan justifies the need for the WATERS Network in part because of the expected need for rapid policy changes affecting the wide variety of human and natural environments across the country (and the world) as society copes with water scarcity, declining quality, and climate change. Current studies of these issues are limited to short periods and limited locations, and therefore provide insufficient information of appropriate density and duration to adequately inform policymakers coping with these problems. A network of observatories could provide a stronger scientific foundation for research that could be generalized over the major temporal and spatial variations in human and natural systems affecting policy choices. Timely development of a WATERS Network may therefore enhance our ability to adapt to change and cope with foreseeable problems in the coming decades.

It is logistically and financially impossible to study all problems in all areas; therefore, specific areas considered to be representative of particularly challenged or important environments are selected for intense research. If the areas are defined and selected based on a common conceptual framework such that intersite comparisons can be made, the group of areas could be considered to be a network. An example of an intersite comparison might be a project to examine the effects of agricultural practices on water quality in areas having flat land and sandy soils across a gradient of climate, such as comparing parts of Florida, Nebraska, Minnesota, and California's central valley.

Networks also are needed to collect long-term datasets. The variability of climate provides natural variation in both the natural and human environments that allows hypotheses to be tested over a broader range of conditions than can be experienced in a limited time period. The planned spatial variation in network observations becomes even more powerful when supplemented by temporal variation. In addition, collection of long-term records permits evaluation of natural experiments (e.g., floods, droughts) and unplanned man-made experiments (e.g., changes in policies or governing institutions, changes in water users' attitudes and economic status, failed treatment plants, burst pipelines). The impacts of such unplanned experiments can best be evaluated if captured and documented within the broader context of long-term, spatially distributed data that allow temporal comparisons before and after the intervention as well as with other "control" locations not affected by the experiment.

In addition to spatial and temporal observations to support hypothesis testing and modeling of systems, a network can also provide common experimentation facilities across a range of conditions. For example, decision management systems designed to improve policy-making decisions under uncertainty could be "laboratory tested" with policymakers from the diversity of institutional settings selected for observatories in the network. Common experimentation in the natural and human systems across the variation in conditions included in the network provides a much stronger basis for developing knowledge that is applicable on the national scale.

Challenges to Establishing Networks

The committee identified at least three major challenges that networks face in achieving their potential advantage over a less integrated set of observatories: (1) identifying the common bases that facilitate intersite comparisons; (2) matching methodologies with the science questions and developing common protocols; and (3) maintenance, management, and long-term operation.

Identifying Common Bases

One of the first challenges in designing networks is to identify the common bases that facilitate intersite comparisons. Such bases include physical attributes of the land, movement of water through landscapes, water quality, effects of humans on land and water, human attitudes and willingness to pay for high-quality water, and governing institutions. It generally is necessary to construct maps of these attributes so that "representative areas" (example areas made up of particular physical and human attributes) can be selected for long-term monitoring and intensive comparative study. The WATERS Science Plan states that it will base the selection of observatory sites on such a map.

The WATERS Network science team will face at least three challenges when constructing and integrating the required maps. First, attributes need to be selected that are most critical on a nationwide basis to the specific science questions for which the network is developed. Second, adequate national data on each attribute need to be developed to determine categories that provide the variance and "representativeness" that justifies the network concept. Although extensive measures of some potential attributes are readily available on a national scale, as illustrated in the Science Plan, others—particularly those related to users, user groups, and governing institutions—will need to be developed during the planning phase. Third, selection criteria need to be developed for weighting each attribute according to its importance to the central science questions, and this will be particularly challenging given the interdisciplinary foundations of the network. It is difficult to know how successfully the Science Plan's clustering analysis approach can identify convincing bases for comparison without knowing the specific attributes and quality of data available. Decisions on how to construct the mapping need to be revisited in conjunction with the selection and refinement of attributes critical to the science plan.

Matching Methodologies with the Science Questions and Developing Common Protocols

Once representative areas have been identified, a second major challenge is to match the monitoring and experimental methodologies with the science questions and to develop common protocols capable of generating uniform information across a diversity of environments. The many possibilities unique to the particular environment of each observatory site will raise numerous issues involving trade-offs between standardization of data and infrastructure across all observatory platforms versus customized data to take advantage of specific local situations. For example, the involvement of other agencies and organizations in data collection will require various trade-offs. In some cases, agencies are already collecting data on measures to be included in the observatories or are potentially willing to share responsibilities for data collection, but the protocols and site selection for measurements will need to be negotiated to fit the network's need for uniformity. In other cases, local organizations including user groups and regulatory authorities will need to be involved to obtain data about their members and activities. Negotiating common protocols in diverse areas is again necessary for uniform information but may be particularly difficult with local groups and regulatory authorities, which face a diversity of challenges, including many that are unrelated to the network's focal questions. In general, research involving human subjects will require a networkwide institutional review board to develop appropriate protocols capable of addressing national as well as local concerns involving human subjects.

Additional trade-offs will be confronted in developing common "data structures" that would integrate raw measurements into measures of higher order concepts that can be accessed and analyzed by a broad range of users from different disciplines. For example, to develop the means for evaluating the impact of policy or institutional changes on water quality across observatories, a common protocol would be needed for aggregating data from a grid of water quality monitors into meaningful indicators of water quality that would match the area affected by each policy or institution. The trade-off between optimizing the protocol for one observatory's environment versus multiple or all observatory environments will need to be resolved for each data structure developed over the life of the network.

These and other trade-offs complicate the critical task of creating common protocols, particularly in comparison with protocols developed for a single independent observatory. On the other hand, a common network protocol is critical to ensure the uniform information that makes the network so valuable. By adjusting protocols for the expected range of environmental conditions early in the design stage, the network can avoid the costs and problems of trying to retrofit existing protocols developed separately at different independent observatories.

Maintenance, Management, and Operation

Perhaps a more daunting task after establishing networks of representative areas and common protocols is the maintenance, management, and long-term operation of the networks. The networks identified previously (e.g., Experimental Forests) are operated by government agencies that have a mandate to do so. Furthermore, their highly trained employees are at the job for long periods of time, adding stability and continuity to datasets. It is a greater challenge for academic institutions to operate networks because their principal mandates are teaching and research, although they could hire full-time technical staff to oversee maintenance and operation.

Within the management challenge, it is important to ensure continuity of data collection as well as adaptability to changing research concerns and opportunities. Continuity is critical to achieving the benefits associated with consistent longitudinal data. On the other hand, adaptability may be equally critical for ensuring maximal benefits from the network, given the long anticipated life expectancy of observatories, the potential problems in integrating the diverse measures of the human and natural environments, and the likely importance of emerging technologies for addressing critical science questions during the life of the observatories.

As with the previous challenges, the WATERS Network team will face differing perceptions of importance across various scientific disciplines, across the different observatory locations, and over time when balancing the needs for continuity and adaptability. Few examples of long-term facilities management deal with the same degree of potential challenges facing the WATERS Network, since few have attempted the scope of interdisciplinary integration required for this network. Planning the management structure that is capable of addressing these issues will be an important part of the design phase.

EVALUATION OF THE WATERS NETWORK SCIENCE PLAN AGAINST CRITERIA FOR NETWORKS

The WATERS Science Plan recognizes the need for a network of observatories in representative areas using common protocols, as well as the need for effective management and operation of them. It is too early in the development of the WATERS Network to discuss the detailed management and operation of a network of representative areas.

The program has also made a substantial first step in developing a map based on common attributes across the nation that serves as an illustration of how representative areas might be selected (see Figure 3-1). The map shows "human-influenced water environmental classes" (HIWECs), which are based on (1) land slope, (2) bedrock permeability, (3) soil permeability, (4) air temperature, (5) precipitation, (6) land cover, (7) population density, and (8) water use. These factors are a combination of the physical characteristics of the Earth, climate, and humans, including natural water flows, human-engineered flows, and human preferences for land and water use. They are selected primarily to illustrate how HIWECs can be developed from a convenient set of available data. To provide the foundation for developing a network that is based on a common conceptual framework, the specific attributes used to define the HIWECs need to be justified in terms of the focal scientific issue developed in the next phase of the project, and each HIWEC needs to have one or more hypotheses stated that will facilitate intersite comparisons. Potential climate change is one factor, not included in the list above, that would be particularly relevant to the WATERS Network science questions.

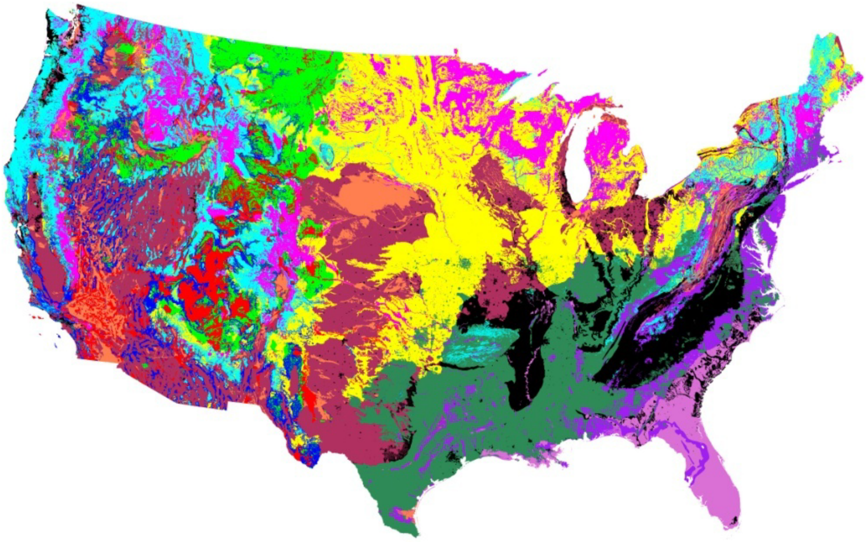

FIGURE 3-1 Human-impacted water environment classes in the continental United States, based on land slope, bedrock permeability, soil permeability, air temperature, precipitation, land cover, population density, and water use.
SOURCE: Dozier et al. (2009).

As noted in Chapter 2, the Science Plan does not clearly articulate compelling questions or hypotheses that require integration across individual observatories at the same time (i.e., that satisfy the strict requirement for a science network). Rather, the proposed network of observatories appears to be a collection of many strong pieces. The science questions posed are excellent at the vision level, and the committee believes that the case for requiring a science-based network to address the questions can indeed be made. It will be essential for the WATERS planning team to build the case for a network and develop the rationale for an integrated spatial and temporal intersite comparison as part of the next conceptual design planning stage. This issue is described in more detail in Chapter 4.

CONCLUSIONS AND RECOMMENDATIONS

Networks are needed to collect uniform information and test hypotheses across temporal and spatial scales. The WATERS Science Plan recognizes the strengths and usefulness of a network of observatories for addressing water issues that relate to the nation as a whole. However, the Science Plan does not clearly articulate specific questions that require a national network. Entering the conceptual design stage, MREFC projects need to articulate plans for a "site-independent description of the research infrastructure and technical requirements needed to meet the science" (NSF, 2007). To meet this requirement, the WATERS team would need to consider the criteria for networked sites and clarify what commonalities link the sites to form a network.

As the WATERS team goes forward, the WATERS team should bolster its case that a national network of observatories is *required* to address the science questions that are posed. Are there national-scale testable hypotheses that only a network of observatories such as the one envisioned by WATERS could address? These testable hypotheses would be intermediate between the three high-level science questions and the specific science cases (exemplified by snow hydrology, eutrophication, and the urban engineered system in the Science Plan; see Chapter 2). Because one of the clear strengths of the WATERS Network is the integration of hydrology, engineering, and aspects of the social sciences, the national-scale testable hypotheses should integrate across these disciplines.

The WATERS Network faces at least three major challenges in future planning to achieve their full advantages over a less integrated set of observatories: (1) identifying the common bases that facilitate intersite comparisons; (2) matching methodologies with the science questions and developing common protocols; and (3) maintenance, management, and long-term operation. With respect to common bases, the Science Plan recognizes that the WATERS observatories need to be selected on the basis of a map uniquely designed for the WATERS program. The factors used to construct the present HIWEC map in the Science Plan may not be the most appropriate. Therefore, the committee recommends that the factors (data layers) that are used to generate the HIWEC map be thoroughly evaluated and debated to ensure that the most appropriate data are used to address the WATERS Network science questions. Developing appropriate methodologies and plans for network operations and maintenance will be critical issues to consider in the conceptual design stage ahead.

4

Major Research Equipment and Facilities Construction

In its statement of task (see Box 1-1), the committee was asked "to assess whether the Science Plan makes a compelling case for establishing the WATERS Network with Major Research Equipment and Facilities Construction (MREFC) funding." The committee addressed this question in its letter report (NRC, 2009; see also Appendix A), and its findings are described below.

DEFINING A FACILITY UNDER MREFC

The National Science Foundation (NSF) defines a facility under MREFC as an essential part of the science and engineering enterprise that will advance science in ways that would not be possible otherwise. The facility can either be centralized or consist of distributed installations. The project "should offer the possibility of transformative knowledge and the potential to shift existing paradigms in scientific understanding and engineering processes and/or infrastructure technology and should serve an urgent contemporary research and education need that will persist for years" (NSF, 2007).

MREFC projects are so large that the total construction costs would be >10 percent of the budget for the sponsoring directorate or office. Thus, funding of the facility would distort the base program of funding in that discipline(s) without MREFC funding. Investments in computing resources and for supporting cyberinfrastructure can be included in the design plan and the construction costs. In most MREFC projects, construction occurs over a relatively limited period of time (approximately 5 years). Within this short construction time line, there is little time for learning and adaptation, given the magnitude of the project and the advanced planning requirements.

Although many funded MREFC facilities are large items such as particle accelerators, telescopes, research vessels, and polar aircraft, several geographically distributed but networked MREFC facilities have been approved and are in various stages of development. Earthscope, a continental-scale seismic and magnetotelluric observatory designed to provide a foundation for integrated studies of continental lithosphere and deep earth structure over a wide range of scales, has completed the construction phase and continues to collect data and address fundamental science questions. The Ocean Observatories Initiative (OOI), a set of ocean observatories designed to encompass nearly every area of ocean science at global, regional, and coastal scales, is a project approved for construction. The National Ecological Observatory Network (NEON), a national network of observatories for continental-scale observations and experiments on ecological systems, has passed the preliminary design review phase of the MREFC process.

CASE FOR ESTABLISHING THE WATERS NETWORK WITH MREFC FUNDING

MREFC is a possible mechanism to fund the infrastructure envisioned for the WATERS Network. One of the major strengths of the WATERS Network is that hydrologic sciences, engineering disciplines, and the social sciences are cooperatively developing the WATERS Network plan with the full support of the three NSF directorates. This would be the first MREFC project to span natural sciences, social sciences, and engineering.

The NSF guidelines (NSF, 2005) state several conditions that a project must meet to qualify for MREFC funding. Among the conditions are the following: "To qualify for MREFC investment, networked infrastructure must exhibit systems characteristics greater than inferred simply by the connectivity of its parts." The understanding also is that the facility would "require large investments for construction/acquisition, over a limited period of time, such that the project cannot be supported within one or more NSF Directorate(s)/Office(s) without severe distortion to the funding of its portfolio of activities." The committee understands that NSF intends these guidelines to mean that a *facility* must satisfy the condition that addressing the proposed science questions would require construction of the network in its entirety over a short period and that pieces of the network (e.g., one or a few of the observatories) could not effectively meet the science objectives. That is, the committee assumes that a proposed network would have to satisfy both the "systems characteristic" and the "large investments over a relatively short period" conditions to qualify for MREFC funding. The Long-Term Ecological Research (LTER) Network and the more recent Critical Zone Observatories, funded under directorate research programs, are examples where individual observatory sites conduct transformative science without meeting the MREFC criteria, even though additional comparative insights are gained by having multiple observatories.

The Science Plan makes a convincing case that the WATERS Network will likely lead to strong, transformative science *in its individual pieces.* The committee, however, was not clearly convinced by the Science Plan that a collection of such pieces will meet the MREFC criterion that the WATERS Network will "exhibit systems characteristics greater than inferred simply by the connectivity of its parts." Each of the three hypothetical examples of regional, theme-based science (snow hydrology, eutrophication of estuaries, and urban water systems) illustrates how our understanding of particular issues could be significantly advanced. However, as noted in Chapter 2, there do not appear to be clearly articulated compelling questions or hypotheses in the Science Plan that require integration across individual observatories at the same time. Rather, the proposed network of observatories appears to be a collection of many strong pieces. Some of the components are new, while others would consist of existing sensors or observatories, operated by mission agencies, that could be shared or repurposed to meet objectives of the WATERS Network.

From a purely scientific view, the Science Plan does not clearly articulate a rationale for why WATERS *as a facility* is required to address the key science questions. That is, the Science Plan does not present a convincing case explaining why the simultaneous construction of the entire infrastructure is essential to answer the science questions, as opposed to phased construction of a few observatories at a time. The document also does not explain clearly why any of the three major questions cannot be approached regionally and, in fact, why some current efforts are not addressing the science questions, at least in part. For example, the first major WATERS question is "how is fresh water availability changing and how can we understand and predict such changes?" (Dozier et al., 2009). The U.S. Climate Change Science Program (CCSP) is carrying out work described as follows:

> FY 2008 activities will focus on a few regional case studies in which both models and measurements will be used to develop

> closure in the terrestrial water cycle budget for those regions. This multiagency CCSP project will use existing regional sites to improve observational capabilities (surface, subsurface, and remote sensing). A range of climate zones will be considered to provide a suitable research framework that concurrently addresses climate/water cycle science and water resource management issues. (USCCSP, 2007)

The WATERS Science Plan does not describe, even conceptually, why efforts such as these are insufficient to address the first grand challenge identified, and thus, why the network as a facility (in the sense of NSF's MREFC program) is needed.

The Science Plan does argue that the accelerating pace of human-induced changes to the environment calls for enhanced knowledge for policy makers and water users to cope with potentially disastrous effects. The committee envisions that policy-relevant social sciences questions could be addressed at a national scale through the WATERS Network, at least for the specific issues developed in the Science Plan. For example, how do incentive- and regulatory-based management approaches differ in their ability to control nutrient loading and hypoxia in rural, suburban, and urban watersheds, and how consistent are these differences across different hydrologic conditions? Important policy-relevant discoveries from one observatory could be cross-checked rapidly at others, providing a national-level knowledge base for policy makers. Thus, if implemented as a facility, the WATERS Network could provide an integrating source of knowledge needed for rapid adaptation in the very fragmented governance system. This is a powerful argument in support of a national network supporting interdisciplinary research in water science, with a strong social sciences component, that is not clearly articulated in the Science Plan. However, the persuasiveness of the argument for WATERS as a unified facility also requires a strong case for the scientific and engineering knowledge to be gained from a national network.

As the WATERS team goes forward, there are two possible options that the committee sees. First, the WATERS team could bolster its case that a national network of observatories is required to address the science questions that are posed. Second, an alternative funding procedure under the MREFC or some other mechanism within NSF might be considered, if feasible, for establishing a phased network of observatories such as envisioned in the WATERS Science Plan. It may not be best for advancing water science to demand that spatially distributed and temporally extensive measurements at a set of observatories pass a "facility" test.

Rather than emplace a network of sensors that is based on a fixed initial design (or an initial set of hypotheses), it may be more efficient to build out a field design as one learns how the hydrologic–human systems operate at a site, provided that there is a long-term commitment to the program. If the entire network is not simultaneously required to address the science questions, it is probably more sensible to build the network incrementally and let the questions and experiments evolve in an adaptive framework. This approach, which is not constrained by MREFC time lines for design and construction phases, could take better advantage of advances in technology over time, such as for sensors and components of the cyberinfrastructure. Also, capital costs would be lower initially and would be spread out over a longer period of time. Downsides of this phased approach are that the delivery of data from the network as a whole would be substantially delayed, and it is possible that observatories in the network would be based on different technology and even different science questions. Given the current vision for WATERS as outlined in the Science Plan, the potential benefits of a phased approach appear to outweigh these drawbacks, assuming that long-term funding support for phased implementation can be found within NSF.

CONCLUSIONS AND RECOMMENDATIONS

To qualify for MREFC funding, NSF requires that facilities "must exhibit systems characteristics greater than inferred simply by the connectivity of its parts" (NSF, 2005). The proposed network of observatories appears to be a collection of many strong pieces, but the Science Plan does not explain clearly why any of the three major questions cannot be approached regionally and, in fact, why some current efforts are not addressing the science questions, at least in part. **As the WATERS team goes forward, it should bolster its case that a national network of observatories is *required* to address the science questions that are posed.** The committee believes that such a case can be made, especially with a strong social sciences component as part of the interdisciplinary water science network. However, the persuasiveness of the argument for WATERS as a unified facility also requires a strong case for the scientific and engineering knowledge to be gained from a national network. **Alternatively, a different funding mechanism within NSF might be considered, if feasible, for establishing a phased network of observatories that could address the questions posed in the WATERS Sci-**

ence Plan while taking better advantage of advances in technology over time.

5

Integration and Coordination with Existing Networks

The WATERS Science Plan (Dozier et al., 2009) envisions a set of activities and observatories that could transform the nation's capabilities in water research and the way in which science is used in water resource management decisions. While transforming water research within the academic community is a primary goal of the National Science Foundation (NSF) for WATERS, the project also needs to involve other agencies to build on the existing foundation of hydrologic data and to ensure a more lasting implementation. A requirement of Major Research Equipment and Facilities Construction (MREFC) funding is the "coordination with other organizations, agencies and countries to ensure complementarity and integration of objectives and potential opportunities for collaboration and sharing of costs" (NSF, 2007). The WATERS Science Plan lists programs in other agencies, but much remains to be done in the conceptual design phase to describe well-defined partnerships with agencies that have water programs.

This chapter describes ways in which the WATERS Network can improve the coordination and integration with federal, state, and local agencies and international organizations. For decades, government agencies have been the collectors of water-related data for both management and scientific purposes. The academic community has relied upon these long-term datasets but has less experience contributing to and managing data collection at these scales. Interagency collaboration could entail at least four possible levels of coordination:

1. Interaction among researchers so that the WATERS Network team stays abreast of the objectives and findings of related programs and can learn from the experience of agency staff working with similar large-scale data collection and management projects;

2. Development of policies for sharing data collected through independent initiatives;
3. Coordination of future data acquisition plans, possibly including agreements between agencies to avoid redundancy and ensure coverage, to improve consistency across datasets based on sampling protocol, or to simplify the sharing of metadata; and
4. Development of cyberinfrastructure for data sharing and other collaborative activities.

This chapter outlines the specific linkages and activities that WATERS could nurture to build appropriate alliances and to help secure the full benefits of the program. The degree of optimal coordination, however, may ultimately depend on the data sharing and cyberinfrastructure challenges encountered, as discussed in Chapter 2.

FEDERAL AGENCIES

WATERS can benefit from and build on the numerous existing hydrologic data networks already in operation through federal agencies. Furthermore, the involvement of federal agencies with program responsibilities in the water sector could strengthen the implementation and quality control of the data collection and management aspects of the program.

Areas and agencies where WATERS has established links or anticipates establishing them include:

- National Oceanic and Atmospheric Administration (NOAA) efforts related to Integrated Water Resources Science and Services,
- National Water Quality Monitoring Council recommendation for a National Water Quality Monitoring Network,
- The U.S. Geological Survey (USGS) National Water Availability and Use Assessment,
- Federal interagency studies on climate change,
- National Research Council (NRC) decadal survey study to guide federal satellite missions,
- U.S. Environmental Protection Agency (EPA) experimental engineering facilities, and
- The U.S. Department of Agriculture (USDA) snow measurements.

The committee agrees with the importance of these programs and initiatives and suggests others that should be included in the planning for WATERS. In addition, WATERS would benefit by having some of their sites colocated with sites maintained by federal agencies to take advantage of the long-term datasets to ground-truth remotely sensed data as well as the data management capabilities developed within these agencies. The federal agencies would benefit by being able to collect data that, in the future, require less onsite human labor. Some of the linkages that the committee thinks will be keys to success are discussed below.

USGS

The USGS is responsible for the operation of the national surface water and groundwater observational networks for water quantity and quality and the collection, quality control, and analysis of these data for water managers across the country. In addition, they are responsible for geologic, biogeochemical, and biodiversity data and a mapping service. These long-term datasets will provide a baseline and context for many WATERS studies. Some level of interoperability of data systems will need to be maintained between the USGS and WATERS to ensure that WATERS can build on and contribute to the national data systems and ensure that the users derive the benefits of the synergies that exist between the USGS and WATERS.

Within the USGS, the WATERS team would benefit from interacting with the USGS National Water Quality Assessment Program (NAWQA). The program addresses questions that are central to the WATERS science agenda, including: (1) What is the condition of our nation’s streams and groundwater; (2) how is water quality changing over time; and (3) how do natural features and human activities affect the quality of streams and groundwater? The USGS also can support the data-gathering and management activities of WATERS. Among other things, NAWQA provides comparison of data across sites in 42 of the nation’s most important river basins and aquifer systems by using some of the same analytical measurements. Other USGS data programs of relevance to WATERS include the National Streamflow Information Program, the USGS stream-gauging program long-term datasets of the small watershed program (Water, Energy, Biochemical Budgets; WEBB), research sites supported by the National Research Program, and Water Science Centers study sites. In addition to the national programs, the USGS has field units in every state that could be helpful in consideration for colocation of field sites.

The new instrumentation and data acquisition and handling techniques that will emerge from WATERS could also help to maintain and improve the efficiency and scope of USGS measurement programs.

National Aeronautics and Space Administration (NASA)

The WATERS program will rely upon new and existing remote sensing data provided by NASA. Some of the existing missions, however, may not yet be operational when WATERS is implemented. New missions that will provide clear benefits to WATERS include Soil Moisture and Freeze/Thaw for Weather and Water Cycle Processes; Ice, Cloud, and Land Elevation Satellite II; Geostationary Coastal and Air Pollution Events; LIDAR Surface Topography; and Gravity Recovery and Climate Experiment II, among others. In addition, WATERS researchers would have access to additional research support through the NASA earth science research program. Many of NASA's field campaigns could be carried out in collaboration with WATERS, providing new datasets not yet possible to fully envision in the WATERS science plan. For example, NASA operates research aircraft that could be used to supplement some of the surface measurement programs envisioned by WATERS. However, it is unlikely that NASA could provide long-term support for the operation of a regional network unless it was tied to an evolving research project that had gained a long-term NASA funding commitment (such as the Large-Scale Biosphere-Atmosphere project).

The potential for loss of critical satellite remote sensing capabilities has been identified as a key risk for the National Ecological Observatory Network (NEON),[6] and it is likely that this will be a consideration for WATERS. In working with NASA, it is important to realize that the agency may have different or shifting priorities associated with the missions that it plans and launches. For example, the NASA program underwent significant adjustments as a result of the recent NRC review (NRC, 2007). Thus, building and maintaining links between WATERS and NASA will be an ongoing effort as the program proceeds. The committee judges that, at the program manager level in NASA, there is support for WATERS developing a sophisticated hydrologic observational capability and an interest in working with WATERS to build the hydrol-

---

[6] See http://www.nsf.gov/bio/budget/fy10/neon10.pdf.

ogy program that would result from this capability, and so there is reason for optimism regarding collaboration.

NASA could benefit from the WATERS Network by using the results of the research in its scientific program and by building stronger collaborations with its observational activities. The science and data that will be delivered by the WATERS Network could be of great value to planning and developing future water-related earth science missions. Currently, NASA has a need for soil moisture measurements that could support its Soil Moisture and Freeze/Thaw for Weather and Water Cycle Processes mission and the development of algorithms for water-related variables and calibration of space-based sensors (as outlined in NRC, 2007). WATERS data and associated research could be of particular importance in addressing scaling issues that are so critical to understanding and interpreting satellite measurements.

NOAA

NOAA has a mandate to improve forecast capabilities and information services for weather, water, and climate, and a responsibility for national stewardship of marine resources. The research program being proposed by WATERS touches upon a number of the issues of concern to NOAA, creating many potential synergies and opportunities for collaboration. Areas of specific responsibility that will have links with WATERS include the Great Lakes, coastal zones, and NOAA's nationwide hydrologic and forecast services. WATERS could work with NOAA to take advantage of NOAA's research platforms.

NOAA will also be a client for WATERS research results. For example, NOAA's hydrologic services presently do not consider soil moisture and vegetation in a sophisticated way. NOAA would welcome efforts that would facilitate the more effective use of soil moisture and vegetation and evaporation information in hydrologic prediction models. Although the oceanic and atmospheric components of the global observation systems are well coordinated, there is considerable room for improvement in the coordination of terrestrial measurements among the federal agencies. NOAA would be particularly interested in efforts that could lead to more comprehensive information on river and lake levels and discharge measurements.

EPA

WATERS has potential to benefit from interactions with EPA in the physical sciences, engineering, and policy domains. Some interactions will require little coordination, as in the use of effluent reporting data from the National Pollutant Discharge Elimination System (NPDES). The WATERS Network has already actively pursued cooperative relationships with EPA at the laboratory level. For example, there is an informal cooperative agreement between WATERS and EPA's Breidenbach Environmental Research Center in Cincinnati, Ohio, where the center's nested sampling sites in the Little Miami River watershed could serve as a prototype sensor network for WATERS. In addition, EPA has an artificial stream facility in Cincinnati, Ohio, that could conceivably be a prototype for the "built environment" concept. WATERS could also benefit from the use of EPA's technologies such as the standard water quality sondes being deployed to measure standard water quality parameters (e.g., pH, dissolved oxygen, temperature) and biomonitors used to assess stress levels resulting from contaminated water. WATERS could also benefit from EPA expertise and facilities for developing and testing new sampling techniques and advanced laboratory procedures. In turn, EPA could learn a great deal from WATERS, especially where cyberinfrastructure and the cost-effective wireless acquisition of data are involved.

Examples of collaborative studies between WATERS and EPA scientists are occurring in a number of locations including Cincinnati and the Little Miami River site and the water treatment facility on East Fork Lake. Several memoranda of understanding (MOUs) are under development between WATERS and EPA to formalize EPA's commitment to the WATERS Network.

USDA

USDA has a mission to support the development of the agricultural sector in the United States. To accomplish this objective, it maintains data-gathering networks for a wide range of physical and economic variables that will be of interest to WATERS scientists. A critical point of contact for WATERS will be the National Water Management Center which provides assistance, information, and technology on water-related efforts with a view to improving water conservation. This support includes the collection of data through snow and soil moisture networks, the development of inventories of soil and crop types, groundwater quality and quantity information, and a substantive assessment capability that relies on models. On the economic side, USDA maintains records of crop production and keeps an overview on water usage for agriculture. The USDA mandate also covers the forestry sector, and similar hydrometeorological datasets are gathered in support of forestry operations. USDA also has strong links to agricultural policy and farm aid programs. USDA's Agricultural Research Service supports research at approximately 100 sites across the country, and these research sites and laboratories may offer additional opportunities for useful collaborations with WATERS.

Other Mission-Oriented Federal Agencies

This report does not attempt to recount exhaustively the wide variety of relevant data networks, laboratories, and research activities that would support WATERS. The agencies and departments discussed here provide a sampling of some of the major interactions based on the Science Plan that was presented. Depending on the specific scientific priorities determined in the future conceptual design, the WATERS Network may also benefit from interactions with agencies such as the Department of Health and Human Services (for issues related to pathogens and disease), with the Department of Energy (on issues related to the nexus between water and energy), with the U.S. Army Corps of Engineers (regarding design criteria and system simulations), with the Department of Homeland Security (on issues related to extreme events and security), and with the U. S. Census Bureau (on issues related to population growth, shifts in employment, socioeconomic conditions, and local governmental institutions).

STATE AND LOCAL AGENCIES

As with WATERS interactions with federal agencies, combining forces with state and local agencies with jurisdiction in various observatory areas could provide WATERS with efficient means of gathering data on the natural, engineered, and human systems affecting water. The WATERS Network will benefit from relevant state and local agencies as well as voluntary organizations that collect data that bear on the engineered and human systems.

There are a number of data-sharing possibilities with state and local governments, utilities, and local organizations, including:

- **Hydrologic data**. State agencies collaborate with federal agencies to maintain hydrologic and water quality monitoring networks. In addition, local agencies may collect more detailed data related to local issues that are not available in national archives.
- **Water supply and usage data**. Many local utilities have water use data at different levels of aggregation that could be made available for research. There may be opportunities to collaborate with local agencies to extend water use monitoring through more extensive surveys.
- **Water quality and habitat data**. State and local agencies may be able to provide estimates of effluent discharges, water quality measurements, and impacts on biological systems for assessing pollution sources.
- **Water user information**. Local groups such as cooperatives and nongovernmental organizations can assist in gathering annual data from their members related directly to water usage and help with studies of public attitudes toward current regulations and perceptions of water-related issues.
- **Water-related policy information**. State and local agencies with jurisdictions within the study areas of WATERS observatories could provide information on ongoing rulemaking and permitting decisions required to assess the impact of policies on hydrologic observations and of hydrologic observations on policy processes.

Given that the state and local levels will have much greater diversity in the formats and procedures for collecting and archiving data, WATERS will have to consider several issues when dealing with the state and local levels. First, the complex effort to develop and implement shared data objectives in a system with multiple groups with vested interests and historical procedures for data collection, management, and analysis will require considerable time and effort at each observatory site. Indeed, assessment of the potential for collaboration will need to be incorporated in the site selection process. In addition, standards for human subject reviews, data collection, and data storage will need to be agreed upon and implemented to allow interoperability and convergence among diverse data systems used by states and local facilities. These standards need to be planned in a way that will balance research needs with the requirements of participating agencies. Finally, instruments will need to be developed to measure the human system, and the WATERS

Network will need to plan for the integration of these measurements into a consistent data structure. If WATERS could facilitate the development of a national data framework involving state and local governments as well as the federal government, it would be performing a major service to the nation.

Given the complexity and diversity of relationships at the state and local levels, these challenges require a well-conceived strategy and possibly more effort and resources than the effort to coordinate with national agencies. Preliminary investigation and negotiations involving candidate sites will be necessary to evaluate the opportunities and obstacles for cooperation at each site before specific sites are selected. The procedures and decision process for developing common data objectives, human subject approval standards, and instrumentation need to be developed in conjunction with the site selection process, because early participation of at least some critical local agencies is more likely to secure the broader participation of similar agencies. The theoretical and practical trade-offs between the required uniformity of core networkwide data and the potential richness of site-specific data beyond this core will require an ongoing assessment procedure, and the data storage and retrieval system must be planned with these trade-offs in mind.

INTERNATIONAL

There are many programs that involve water research in countries outside the United States. WATERS would need to keep abreast of international developments and organize collaborations as appropriate to achieving the network's science goals. Listed below are some key international programs with the committee's suggestions on themes of joint interest:

- **World Climate Research Programme's Global Energy and Water Cycle Experiment (GEWEX)**[7] is an integrated program of observations, modeling, field campaigns, and applied research in water cycle sciences with an aim to improve prediction capabilities. WATERS work on hydrologic modeling, closing water budgets, and placing regional water issues in a global context are complementary to this program.

---

[7] See *http://www.gewex.org*.

- **Group on Earth Observations**[8] is coordinating international efforts to build a Global Earth Observation System of Systems. This emerging public infrastructure is bringing together observational systems for monitoring and forecasting changes in the global environment. The development of standards and protocols for measurement and prototype systems for data handling, analysis, and integration will be important for WATERS.
- **The Global Water System Project** addresses research questions regarding impacts of integrated global environmental change on water, themes that are clearly consistent with those of WATERS.

There are a number of other international science and engineering programs that could also be useful points of contact for WATERS internationally. Programs administered through the United Nations, including the World Meteorological Organization and its Climate and Hydrology division, the United Nations Environmental Programme and the United Nations Education, Scientific and Cultural Organization's International Hydrology Programme are examples. The International Geosphere-Biosphere Programme's Integrated Land Ecosystem-Atmosphere Processes Study, which deals with the role of water on the land surface and its interactions with the atmosphere, and the International Human Dimensions Programme, which has a number of projects looking at the effects of management policies and practices on water, are among other possible international efforts that are pertinent to WATERS.

CONCLUSIONS AND RECOMMENDATIONS

Descriptions of federal and state agency water-related activities tend to provide a picture of programs that are compartmentalized and directed by agency mandates and authorities through appropriations by Congress. Given the breadth of the WATERS agenda, the program will gain from interactions with all of these diverse agency programs. Many of the benefits for WATERS of improved coordination and collaboration have been summarized in this chapter. Although integration across agencies and even within agencies (including within NSF) in the area of water is often recognized as a desirable goal, this is difficult to achieve within the existing institutional framework without a catalyst. **WATERS could serve as a catalyst for bringing agencies together to support a com-**

---

[8] See *http://www.earthobservations.org*.

mon agenda that transcends normal agency activities and provides opportunities to contribute to a broader integrated agenda. **To achieve this goal, the WATERS team should involve appropriate federal agencies, state and local governments, organizations, and international programs at an early stage.** Interactions and relationships that are developed in a coordinated and planned way will have more impact than ad hoc opportunism by individual scientists. The degree of coordination that can reasonably be achieved, however, may depend upon the data-sharing and cyberinfrastructure challenges encountered, as discussed in Chapter 2.

References

Barnett, T. P., J. C. Adam, and D. P. Lettenmaier. 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438:303-309.

Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. Science 319(5866): 1080; doi:10.1126/science.1152538.

Dozier, J., J. B. Braden, R. P. Hooper, B. S. Minsker, J. L. Schnoor, R. C. Bales, M. H. Conklin, L. A. Derry, T. Harmon, A. Michalak, J. R. Mihelcic, J. Myers, S. L. Schneider, D. Tarboton, J. M. VanBriesen, and P. R. Wilcock. 2009. Living in the water environment: The WATERS Network Science Plan, *Report for Cooperative Agreement CBET-0838607*. Arlington VA; National Science Foundation; doi:10.4211/sciplan.waters.20090515.

Hutson, S., S. Nancy, L. Barber, J. F. Kenny, K. S. Linsey, D. S. Lumia, and M. A. Maupin. 2004. Estimated Use of Water in the United States in 2000, USGS Circular 1268. Reston, VA: USGS. Available online at: http://pubs.usgs.gov/circ/2004/circ1268/.

NRC (National Research Council). 2001. Envisioning the Agenda for Water Resources Research in the Twenty-First Century. Washington, DC: National Academy Press.

NRC. 2006. CLEANER and NSF's Environmental Observatories. Washington, DC: The National Academies Press.

NRC. 2007. Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. Washington, DC: The National Academies Press.

NRC. 2008. Preliminary Review of the Draft Science, Education, and Design Strategy for the Water and Environmental Research Systems

(WATERS) Network. Washington, DC: The National Academies Press.

NRC. 2009. Letter Report Assessing the WATERS Network Science Plan. Washington, DC: The National Academies Press.

NSF (National Science Foundation). 2005. Guidelines for Planning and Managing the Major Research Equipment and Facilities Construction (MREFC) Account. Arlington, VA: NSF. Available online at: http://www.nsf.gov/bfa/docs/mrefcguidelines1206.pdf. Accessed September 30, 2009.

NSF. 2007. Large Facilities Manual, NSF07-38. Arlington, VA: NSF. Available online at: http://www.docstoc.com/docs/7312147/Large-Facilities-Manual. Accessed September 30, 2009.

Pierce, D. W., T. P. Barnett, H. G. Hidalgo, T. Das, C. Bonfils, B. D. Santer, G. Bala, M. D. Dettinger, D. R. Cayan, A. Mirin, A. W. Wood, and T. Nozawa. 2008. Attribution of declining western US snowpack to human effects. Journal of Climate 21:6425-6444.

Slaymaker, O., and R. Kelly. 2007. The Cryosphere and Global Environmental Change. Malden, MA: Blackwell.

USCCSP (U.S. Climate Change Science Program). 2007. Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Year 2008. Washington, DC: USCCSP. Available online at: http://www.usgcrp.gov/usgcrp/Library/ocp2008/ocp2008.pdf. Accessed September 29, 2009.

Vollenweider, R. A. 1971. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Paris, FR: Organisation for Economic Co-operation and Development.

WNPO (WATERS Network Project Office). 2008. Draft Science, Education, and Design Strategy for the WATer and Environmental Research Systems Network, February 27, 2008. Arlington, VA: WNPO.

Appendix A

Letter Report Reviewing the WATERS Network Science Plan

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Water Science and Technology Board
500 Fifth Street, NW
Washington, DC 20001
Phone: 202 334 3422
Fax: 202 334 1961
www.nationalacademies.org/wstb

July 7, 2009

Dr. Timothy Killeen
Assistant Director for Geosciences
Dr. David Lightfoot
Assistant Director of Social, Behavioral and Economic Sciences
Dr. Thomas Peterson
Assistant Director for Engineering
National Science Foundation
4201 Wilson Boulevard
Arlington, Virginia 22230

Dear, Dr. Killeen, Dr. Lightfoot, and Dr. Peterson:

In 2006, the National Science Foundation (NSF) requested that the National Research Council's (NRC's) Water Science and Technology Board review and assess the adequacy of the conceptual design and planning process for NSF's proposed Water and Environmental Research Systems (WATERS) Network. In response, the NRC formed a committee (see Attachment B for committee membership) that first issued an interim report evaluating the Draft Science, Education, and Design Strategy for the WATERS Network (NRC, 2008). Subsequently, in response to requests from NSF, the statement of task for the committee was modified towards reviewing a vision-level Science Plan, and the NRC and committee agreed to provide quick advice on part two of the statement of task (see Attachment C). This letter report summarizes the committee's assessment of whether the Science Plan "sets forth a vision of what could be accomplished with an observing network to transform water science and engineering research and education" and "whether the Science Plan makes a compelling case for establishing the WATERS Network with Major Research and Facilities Construction (MREFC) funding." We address these two questions individually below and offer an overall assessment as well. The committee's final report, which is anticipated to be completed in fall 2009, will address the third part of the statement of task, along with a more detailed review of the Science Plan (task #2).

Vision for Science and Engineering Research

The WATERS Network Science Plan identifies many of the important questions and research issues that need to be addressed if we as a nation are to meet the water management challenges facing society today and in the future.[1] The world and our nation face pressing and, in some places, urgent water problems stemming from a changing and uncertain climate, coupled with varying and uncertain demands for water over time and space. In addition, human behavior impacts the use and management of water and the condition of the resource itself, and these impacts need to be better understood if this resource is to be sustainably managed. The Science Plan envisions an integrated approach involving the natural, engineering, and social sciences with potential to help address these issues through a network of hydrologic observatories in the United States.

The Plan outlines the opportunity to collect, analyze, and integrate hydrological, environmental science and engineering, and social science data at a level that has not been possible before. Opportunities for cutting-edge research are envisioned through the collection of data from sensors distributed at sites along gradients or at nested sites that will enable the improvement of the understanding of the complete water balance within a research site. The proposed network also could support research on how better to design and build engineering systems for water management and the collection of social science data from individual sites and on a national scale to better understand human-water resource interactions and impacts. The Network's support of cyberinfrastructure to store, manage, and provide access to data is key to the success of the project, as it will be used by researchers throughout the nation, via analysis and modeling, to examine questions related to a diverse set of water environments and to better understand complex processes.

The Science Plan was intended as a broad vision document, and our assessment of it in this light is that the document succeeds in communicating a high-level vision for transforming water science and engineering research through establishing an observatory network. The educational impacts of the WATERS Network could also be transformative.

The Committee believes it is important to continue to improve the Science Plan as the program moves ahead through more detailed planning in the conceptual design stage, which is the next stage of the process on the way toward construction, if approved. The committee envisions potential contributions of the WATERS Network to our understanding of water and human health, water-energy linkages, water economics, and international water issues, and these contributions should be described more fully in the future as the Science Plan evolves. With respect to international issues, the Science Plan describes a number of objectives that link with the goals of international programs. As one example, WATERS could make major contributions on behalf of the United States to the Global Water System Project (GWSP), which is addressing human interactions with the hydrological cycle in terms of natural and built environments. The WATERS research findings also could become an important US contribution to international development programs, particularly for those countries where water issues are most critical.

The Science Plan was conceived as a high-level vision statement and not as a design document. The committee wants to stress, however, that careful attention to developing a clear and complete plan for cyberinfrastructure will be critical in the future. The challenges of building

---

[1] The overarching science question for the WATERS Network is: "How can we protect ecosystems and better manage and predict water availability and quality for future generations, given changes to the water cycle caused by human activities and climate trends?" Three second-level research questions posed in the Science Plan are: 1) how is fresh water availability changing and how can we understand and predict these changes; 2) how can we engineer water infrastructure to be reliable, resilient, and sustainable; and 3) how will human behavior, policy design, and institutional decisions affect and be affected by changes in water? (NSF, 2009)

the cyberinfrastructure network are indeed formidable. The WATERS vision of having observing system cyberinfrastructure across the natural, social, and built environments and the need to share infrastructure with existing agencies and organizations goes beyond anything that has been accomplished in the past. Consequently, the planning will be correspondingly challenging and many open issues remain.

Case for Establishing the WATERS Network with MREFC Funding

MREFC is a possible mechanism to provide the infrastructure for the WATERS Network. One of the major strengths of the WATERS Network is that hydrologic sciences, engineering disciplines, and the social sciences are cooperatively developing the Network plan with the full support of the three NSF directorates. This would be the first MREFC project to span natural sciences, social sciences, and engineering, and, thus, WATERS would become a model for conducting interdisciplinary research within NSF and the MREFC program. The integration of the social sciences with the natural and engineering sciences has been a long-standing challenge, and the integrated WATERS Network would provide a unique opportunity to integrate the social sciences into water science. The committee does not have knowledge of whether this type of multi-disciplinary, large infrastructure project could move forward within other existing (non-MREFC) mechanisms at NSF.

The NSF guidelines[2] state several conditions that a project must meet to qualify for MREFC funding. Among the conditions are the following: “To qualify for MREFC investment, networked infrastructure must exhibit systems characteristics greater than inferred simply by the connectivity of its parts.” The understanding also is that the facility would “require large investments for construction/acquisition, over a limited period of time, such that the project cannot be supported within one or more NSF Directorate(s)/Office(s) without severe distortion to the funding of its portfolio of activities.” The committee understands that NSF intends these guidelines to mean that a *facility* must satisfy the condition that addressing the proposed science questions would require construction of the network in its entirety over a short period and that pieces of the network (e.g., one or a few of the observatories) could not effectively meet the science objectives. That is, we assume that a proposed network would have to satisfy both the “systems characteristic” and the “large investments over a relatively short period” conditions to qualify for MREFC funding. The LTER network and the more recent Critical Zone Observatories, funded under directorate research programs, are examples where individual observatory sites conduct transformative science without meeting the MREFC criteria, even though additional comparative insights are gained by having multiple observatories.

As currently described in the Science Plan, the proposed network of observatories appears to be a collection of many pieces. Some of the components are new, while others would consist of existing sensors or observatories operated by mission agencies that could be shared or repurposed to meet objectives of the WATERS Network. According to the committee’s understanding, construction of all of the pieces over a relatively short (5-year) period is envisioned, consistent with typical MREFC facility requirements. The Science Plan does not clearly articulate a rationale for why WATERS *as a facility* is required to address the key science questions. That is, the Science Plan does not present a convincing case explaining why the simultaneous construction of the entire infrastructure is essential to answer the science questions,

---

[2] http://www.nsf.gov/bfa/docs/mrefcguidelines1206.pdf

as opposed to phased construction of a few observatories at a time. The document does not explain clearly why any of the three major questions cannot be approached regionally and, in fact, why some current efforts are not addressing the science questions, at least in part. For example, the first major WATERS question is "how is fresh water availability changing and how can we understand and predict such changes?" The US Climate Change Science Program is carrying out work described as follows: "FY 2008 activities will focus on a few regional case studies in which both models and measurements will be used to develop closure in the terrestrial water cycle budget for those regions. This multi-agency CCSP project will utilize existing regional sites to improve observational capabilities (surface, subsurface, and remote sensing). A range of climate zones will be considered to provide a suitable research framework that concurrently addresses climate/water cycle science and water resource management issues."[3] The WATERS Science Plan does not describe, even conceptually, why efforts such as these are insufficient to address the first major question[1] and, thus, why the network as a facility (in the sense of NSF's MREFC program) is needed.

As the WATERS team goes forward, there are two possible options that the committee sees. First, the WATERS team could bolster its case that a national network of observatories is required to address the science questions that are posed. Are there national-scale testable hypotheses that only a network of observatories such as the one envisioned by WATERS could address? These testable hypotheses would be intermediate between the three high-level science questions[1] and the specific science cases (exemplified by snow hydrology, hypoxia, and the engineered system in the Science Plan). Because one of the clear strengths of the WATERS Network is the integration of hydrology, engineering, and aspects of the social sciences, the national-scale testable hypotheses should integrate across these disciplines.

Second, an alternative funding procedure under the MREFC or some other mechanism within NSF might be considered, if feasible, for establishing a phased network of observatories such as envisioned in the WATERS Science Plan. It may not be best for advancing water science to demand that spatially distributed and temporally extensive measurements at a set of observatories pass a "facility" test. Rather than emplace a network of sensors that is based on a fixed initial design (or an initial set of hypotheses), it may be far more efficient to build out a field design as one learns how the hydrologic-human systems operate at a site. If the entire network is not simultaneously required to address the science questions, it is probably more sensible to build the network incrementally and let the questions and experiments evolve in an adaptive framework. This approach, which is not constrained by MREFC timelines for design and construction phases, could take better advantage of advances in technology over time, such as for sensors and components of the cyberinfrastructure. Also, capital costs are lower initially and are spread out over a longer period of time.

Summary

In summary, the committee is very favorably impressed by the progress that has been made by the WATERS team over the past year. We think that they have identified an overarching theme and a set of high-level research questions that can be used as a foundation for formulation of second-level science questions. The three examples of hypothetical nodes in the proposed network demonstrate clearly that fundamental, transformative research is likely to stem

---

[3] http://www.usgcrp.gov/usgcrp/Library/ocp2008/ocp2008-focus.htm

from the project. We find the collaboration among three directorates at the NSF to be a refreshingly positive step. There are improvements that can be made to the Science Plan in the future that would make it even stronger and the committee believes that the document should evolve as the project proceeds.

The Science Plan presents a compelling case for the need for new work in natural science, social science, and engineering, but the committee found the question of whether the project should be established within the MREFC framework to be less clearly answered by the Science Plan. That is, assuming that the current MREFC guidelines require that the WATERS Network be a *facility*, the Science Plan does not present a cogently argued rationale in support of the claim. The data products and cyberinfrastructure elements envisioned would benefit from the full network of observatories, but the case for the need of a facility in terms of accomplishing new science is not fully developed. Thus, the WATERS team should focus on clearly articulating the case for why the network of observatories as a whole is needed to address both the high level science questions and the second level science questions that will be developed as the project proceeds.

Sincerely,

George Hornberger

George Hornberger, Chair
Committee on the Review of
the Water and Environmental
Research Systems (WATERS)
Network

Attachment A: References
Attachment B: Committee membership
Attachment C: Statement of task
Attachment D: Acknowledgement of reviewers

cc:
Paul Bishop, NSF, ENG
Harold Clark, NSF, SBE Division Director
Richard Cuenca, NSF, GEO
Robert Detrick, NSF, GEO Division Director
Cheryl Eavey, NSF, SBE
Bruce Hamilton, NSF, ENG
Doug James, NSF, GEO
John McGrath, NSF, ENG Division Director
Robert O'Connor, NSF, SBE

Appendix B

Committee and Staff Biographical Sketches

George M. Hornberger (NAE), *Chair,* is Distinguished University Professor at Vanderbilt University, where he is the director of the Vanderbilt Institute for Energy and Environment. He is the Craig E. Phillip Professor of Engineering and Professor of Earth and Environmental Sciences there. His research interests are in catchment hydrology and hydrochemistry, the transport of solutes and colloids in geologic media, and energy-water interrelationships. Dr. Hornberger is a fellow of the American Geophysical Union, the Geological Society of America, and the Association for Women in Science. He has served on numerous National Research Council boards and committees and is currently a member of the Research Panel of the Committee on America's Climate Choices and the Report Review Committee, is the chair of the Committee on Opportunities and Challenges in the Hydrologic Sciences, and was the chair of the Board on Earth Sciences and Resources from 2003 to 2009. 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 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 (NRC) Water Science and Technology Board and has served on several NRC committees including the Committee on Ground Water Cleanup Alternatives and the Committee on Source Removal of Contaminants in the Subsurface, and most recently was a member of the committee that reviewed CLEANER and the National Science Foundation 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 School of Earth Sciences at Ohio State University, where he has been on the faculty for more than 15 years. Prior to joining 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. His current research interests include the role of dissolved organic matter in mediating environmental and biogeochemical reactions. Dr. Chin's work has been published in over 60 peer-reviewed articles, and he has served as a panelist 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 have 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 National Research Council 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 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 sensor-net 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 (NEON) Facilities and Infrastructure Committee and advises on the development of NEON's communication and information technology. He was a member of the National Research Council 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 Long-Term Ecological Research (LTER) network and has served on the LTER Executive Committee. He serves on the steering committee of the Global Lakes Ecological Observatory Network. He has participated on the National Research Council (NRC) 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 Global Energy and Water Cycle Experiment (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 Group on Earth Observations tasks. Prior to occupying these positions, he worked with the University

Corporation for Atmospheric Research as a National Oceanic and Atmospheric Administration program manager for the GEWEX Continental Scale International Project and then the GEWEX Americas Prediction Project. He cochaired the Climate Change Science Program (CCSP)/ U.S. Global Change Research Program 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 research management and coordination, policy development, program evaluation, and planning for Science and Technology and for the federal Inland Waters Directorate and applied climate research. 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 National Research Council, 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 in the Department of Geography and Environmental Engineering at 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 Water Science and Technology Board and the Board on Environmental Studies and Toxicology. He has served on numerous National Research Council 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 to 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 fellow of the American Association for the Advancement of Science, an Aldo Leopold Leadership Program fellow, past president of the Estuarine Research Federation, a national associate of the National Academy of Science, a member of the Scientific Steering Committee of Land-Ocean Interactions in the Coastal Zone/International Geosphere-Biosphere Programme, and past chair of the National Research Council 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), National Oceanic and Atmospheric Administration 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.

John T. Scholz is the Francis Eppes Distinguished Professor of Political Science and Courtesy Professor of Law at Florida State University. His major research interests include public policy, public administration, political economy, and institutional collective action. Dr. Scholz has analyzed government regulatory policies from the federal to the local level involving issues of occupational safety and health, water pollution, and taxation, focusing in particular on enforcement and compliance issues. His current research analyzes the problems of developing and maintaining cooperative solutions to collective-action problems, emphasizing the role of policy networks, private partnerships, and collaborative government programs in resolving collective problems involved in resource management. He received his B.A. from Harvard University and his M.S. in resource economics and Ph.D. in political science from the University of California at Berkeley.

Thomas C. Winter is a senior research hydrologist emeritus with the U.S. Geological Survey (USGS) in Denver, Colorado. From 1961 to 1972, he conducted geological and water-resource studies in Minnesota, and was in charge of USGS groundwater 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 groundwater 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.

NRC Staff

Stephanie E. Johnson is a Senior Program Officer with the Water Science and Technology Board. Since joining the NRC in 2002, she has served as study director for ten committees, including the Committee on Advancing Desalination Technology and the Committee on Water Reuse. She has also worked on NRC studies on contaminant source remediation, the disposal of coal combustion wastes, Everglades restoration, and water security. Dr. Johnson received her B.A. from Vanderbilt University in chemistry and geology, and her M.S. and Ph.D. in environmental sciences from the University of Virginia on the subject of pesticide transport and microbial bioavailability in soils.

Michael J. Stoever is a research associate with the Water Science and Technology Board. He has worked on a number of studies including Desalination: A National Perspective, the Water Implications of Biofuels Production in the United States, and the Committee on Independent Scientific Review of Everglades Restoration Progress. He has also worked on NRC studies on Louisiana coastal restoration, the effect of water withdrawals on the St. Johns River, and Chesapeake Bay restoration. Mr. Stoever received his B.A. degree in political science from The Richard Stockton College of New Jersey in Pomona, New Jersey.