Integrating Social Science Research into the WATERS Network

The WATERS Network Project Office Social Science Committee

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[1] Full committee membership is listed in Appendix A

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Executive Summary

This report provides the findings and recommendations of the Social Science and Economics Committee of the WATERS Network Project Office. The committee began by reviewing efforts to integrate studies of the social dimensions of environmental systems into the research agenda of other recent NSF environmental initiatives, including the NEON and ORION observatories and the existing LTER network. To better understand these efforts and to facilitate better coordination across the NSF initiatives our committee helped organize and conduct a workshop on “Integrating Social Sciences at NSF Observatories,” held January 24-26, 2007, in Arlington, Virginia. Working together with the leadership of multiple NSF Directorates, the workshop participants identified a number of opportunities for social science data collection, integration, model development, and cybercollaboration in the observatory programs.

The WATERS Network is especially well-positioned to pursue a highly integrated agenda of biophysical, engineering, and social science research. Social scientists have a key role to play in the earliest stages of research planning, where problems are framed and study boundaries defined. These contributions should include the formulation of monitoring and modeling objectives for WATERS sites and research to ensure effective use of WATERS results by policy makers and other stakeholders.

The committee identified a number of topics at the frontier of environmental social science research that would be strengthened by inclusion in the WATERS Network program, including: 1) Decision analysis for multi-attribute/multi-stakeholder problems; 2) Development of national accounts that consider environmental quality and ecosystem services; 3) Market-based regulation of water pollution; 4) Mechanisms for adaptive environmental management; and, 5) Future design of water supply and treatment systems.

Infrastructure investments to support social science in the WATERS Network should include extensions of physical science sensor networks to observe human behavior and enhancements of existing social science data collection tools and community data structures. Improved understanding of changes in water budgets and environmental quality will be possible through integration of satellite data, as well as intensive sensing of farms, industrial sites, and households. Advanced monitoring systems can likewise help strengthen the link between water quality data and the revealed and stated preferences of people regarding swimability, fishability, and other beneficial uses of waterways. Such results can have a profound impact on decision support for multi-stakeholder deliberations for complex water resource and environmental quality decisions, using tools such as decision theaters and Internet collaboratories. To ensure that this vision is achieved, social scientists must continue to be involved in the conceptual design for WATERS Network field sites and its centralized cyberinfrastructure. In addition, solicitations for WATERS Network projects should include exploratory test-bedding of social science hypotheses, modeling, and decision-support tools. WATERS Network initiatives involving joint efforts by biophysical and social scientists, with support from a range of appropriate NSF Directorates, can lead to new fundamental knowledge on human environmental systems that could not be achieved by any single discipline alone.

I. Background

The National Science Foundation (NSF) is currently undertaking several large-scale environmental observatory initiatives (e.g., WATERS Network, NEON, and ORION), as well as LTER, and each was specifically designed to include a social science research agenda. Elements of these research designs are briefly reviewed in the following section. As indicated there, research on the social dimensions of environmental systems has been successfully integrated with physical science and engineering studies at a number of the Long Term Ecological Research (LTER) Network sites and promising plans have been developed for including social science research in the other NSF Observatory programs. Nonetheless, despite these efforts, the dialog between physical or biological sciences and the social sciences in large-scale environmental studies remains largely underdeveloped. In particular, there is no clearly-established long-term framework for this dialog to occur.

As a concrete step to address this need, our committee helped to coordinate the Workshop on "Integrating Social Sciences at NSF Observatories," held January 24-26, 2007, in Arlington, Virginia. The workshop brought together a broad spectrum of physical and social scientists to explore opportunities for enhancing multidisciplinary research on interrelated human-environmental systems, with many of the participants involved in the WATERS Network, NEON, ORION, or LTER projects and programs. Ideas were shared with the leadership of NSF Directorates in the physical sciences, engineering, and the social behavioral and economic sciences. The workshop helped to identify a number of important research questions where social scientists, using opportunities for data collection, integration, and cybercollaboration that become possible with the new NSF environmental observatories, can make transformative advancements in our understanding of social, behavioral and economic processes that affect, and are affected by, environmental quality and sustainability.

The WATERS Network is especially well-positioned to pursue a highly integrated agenda of biophysical, engineering, and social science research. Water has an intrinsic social dimension that includes economic, cultural, and moral considerations. For the WATERS Network to achieve its full potential, social science must be integrated into the design from the beginning. This integration is, perhaps, more natural with environmental engineering and hydrologic science than other science disciplines because economic development of water resources has long been a driver of these fields. The multi-faceted nature of water offers great potential for interdisciplinary research spanning the natural sciences, engineering, and social sciences that the WATERS network can both foster and use. To determine the impact of the information generated by WATERS, social science research is needed to better understand the beneficial uses of environmental resources and the way in which improved knowledge and data enable more effective resource management and stewardship. This research can provide the basis for methods that support the allocation of limited resources for physical, chemical and biological data collection in observatories by developing scenarios to determine the context-dependent value of information.

Beyond the WATERS Network, we believe that a dialog among the social scientists and science leaders representing each of the NSF observatory initiatives would help generalize the programmatic integration of social sciences with the various biological and physical science domains. Representatives of these science domains are currently defining the programmatic goals and infrastructure requirements for each observatory initiative. Therefore, it is essential that a dialog begin very soon on 1) determining how to integrate the social sciences more effectively into the observatory programs, 2) defining social science infrastructure needs to incorporate into the WATERS MREFC planning effort, 3) defining a social science research agenda that complements the related biological and physical science research agendas that the infrastructure will support, and 4) developing a funding strategy for supporting the implementation of the research agenda.

The principal motivation for developing this document is our belief that in order to facilitate better decision-making on environmental issues, new social science research is needed to support:

i) evidence-based design, enforcement and evaluation of policy;

ii) assessment of human impact on the societal or economic value of natural and engineered environmental systems;

iii) assessment of the impacts of environmental modifications or remediation on social, biological and economic systems; and

iv) the use of advanced information systems to improve policy-based decisions and outcomes while protecting fundamental civil rights and privacy.

For the WATERS Network initiative, this research agenda must recognize the full hydrologic cycle, including water use by humans, its collection, treatment, consumptive and non-consumptive uses, and wastewater treatment, plus modifications of waterways, aquifers, and wetlands. At the present time, decisions that determine these uses and establish management priorities are typically informed by incomplete scientific knowledge. However, these decisions also occur within social, economic, and political contexts that are likewise poorly understood. Thus, an objective of the research agenda will be to address the need to improve the knowledge base that determines environmental conditions, impacts and responses in the context of potential tension and feedback among the participating social, biological and economic systems. This knowledge base naturally exists at the intersection between the social sciences and the physical sciences. For water systems, some experience has been gained in integrating knowledge across these domains through recent projects such as the Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) Center, an NSF Science and Technology Center. The insights from this and related research will be directly relevant to the WATERS Network.

There are a number of challenges involved in bringing increased participation by social scientists in the WATERS program. There are many cultural differences between how social scientists view research and information infrastructure requirements and how their counterparts view them (see, for example, Schutz, 1954; Harrington, 2000; Orlikowski and Barley, 2001). Since the observatory initiatives are integrating these research domains to address new grand challenge research objectives, it is essential that the discussion on cyberinfrastructure take into account these cultural differences as well as the unforeseen requirements that emerge precisely because the research paradigm is changing to a more integrated model.

A. Current Efforts at Integrating the Social Sciences in Other NSF Observatory Programs

Before outlining the role that the social sciences should play in the WATERS program, a brief overview is provided of current efforts to include social and behavioral sciences as part of related NSF programs, including LTER, NEON, and ORION. **The Long Term Ecological Research (LTER)** Network is the oldest of these efforts, involving a multisite program to study ecological processes across the United States over long temporal and broad spatial scales. The NSF established the LTER program in 1980 and the Network currently includes 26 LTER sites representing diverse locations and ecosystem types (http://www.lternet.edu/). Social science research has occurred principally at four of these sites (Gragson and Grove, 2006):

i) the Northern Temperate Lakes LTER research program, which focuses on the effects of human-dominated landscapes on watersheds in the Southern and Northern Highlands Lake Districts of Wisconsin, including social-behavioral research on the relationship between measured and perceived water quality and the variation of individual behaviors with respect to nutrient management (http://lter.limnology.wisc.edu);
ii) the Coweeta LTER which seeks to advance scientific understanding of the spatial, temporal, and decision-making components of land-use change in southern Appalachia, including future forecasts of land-use (http://coweeta.ecology.uga.edu);
iii) the Baltimore Ecosystem Study LTER which examines the relationships among socioeconomic, ecological, and physical factors that affect environmental quality in an urban area, including the development and use of residents' understanding of the metropolis as an ecological system to better control pollution loadings (http://beslter.org); and
iv) the Central Arizona-Phoenix LTER which studies how patterns and processes of urbanization alter the environment of Phoenix and surrounding areas, feeding back to the social system and generating future change (http://caplter.asu.edu).

A number of other LTER sites also include consideration of interactions between humans and the environment, such as the Bonanza Creek (Alaska) LTER site where the Alaskan Native community and the boreal forest are studied as a coupled social-ecological system that responds to changes in climate and socioeconomic forces (http://www.lter.uaf.edu/).

The NSF **National Ecological Observatory Network (NEON)** is planned to provide an ecological measurement and observation system designed "to answer regional- to continental-scale scientific questions" and "to achieve credible ecological forecasting and prediction." The program description indicates that "social scientists and educators will join ecologists and physical scientists in NEON planning and design and participate as observatory users, recognizing that we live on landscapes that are, to varying degrees, human-dominated ecosystems." (http://www.neoninc.org/about/). The NEON program thus plans a particular focus on characterizing and forecasting changes in land-use and land cover, along with other "important reciprocal or feedback relationships between human systems and environmental systems *that* require a strong and focused social science component." (http://harvardforest.fas.harvard.edu/neon/NEON_SSI.pdf)

The **Ocean Research Interactive Observatory Networks (ORION)** is a program that "focuses the science, technology, education and outreach of an emerging network of science driven ocean observing systems." The program seeks to support research that resolves "the full range of episodicity and temporal change central to . . . ocean processes that directly impact human society, our climate and the incredible range of natural phenomena found in the largest ecosystem of the planet." (http://www.orionprogram.org/) The principal social science dimensions of the ORION program are included under a research theme on Ocean Hazards, addressing harmful algal blooms, spills, hypoxia, overfishing, invasive species, rip currents, beach erosion, hurricanes, tsunami events, and sea-level rise, all of which include important human elements that affect their causes, effects, and mitigation (the ORION Science Plan is available at http://www.orionprogram.org/documents/default.html). ORION also includes an Education and Public Awareness Committee (EPAC), though this effort is most-closely aligned with the WATERS Network activities in education and outreach (http://www.orionprogram.org/organization/committees/education.html).

With this introduction to the role envisioned for the social sciences in other NSF observatory programs, we now take a broad view of its potential contribution to the WATERS Network. In particular, we focus on the role of the social sciences in helping to formulate the overall WATERS research agenda and specific social science research and data collection efforts that would transform the types of environmental problems that we are able to address, and the modes of research collaboration used to address them.

II. Critical Role in Providing Inputs to Science Plan

Social scientists have a key role to play at the earliest stages of research planning. It is here where problems are framed and study boundaries formulated. Failure to consider key regulatory constraints and economic and social forces can lead to a study plan that answers the wrong questions (NRC, 1996). Furthermore, understanding how data and scientific results are used is critical to effective research planning. Even the "best" scientific information may have little practical value if it is ignored, misused or misunderstood. In addition, particularly in times of constrained funding, it is important to learn how to do more with less – to get the maximum policy payoff for each dollar invested in scientific research.

For the needed improvement to be achieved there will be a need for systematic attention to the factors that lead to higher or lower levels of success in the making of decisions that reflect the best available science. The studies are likely to show that successful outcomes depend in part on the nature of the scientific work being done, in part on the ways in which the scientific results are communicated, and in part on the ways in which agencies are structured and managed. What is vital, however, is that the factors influencing successful organizational performance be subject to the same kinds of thorough, systematic, long-term research as is devoted to the understanding of physical systems. Indeed, studies of this type should be applied to the WATERS Network and the other observatory organizations to assess their success at linking researchers, providing needed data and knowledge for decision support, and involving various stakeholders in critical planning and assessment activities.

A. Formulation of Monitoring and Modeling Objectives

Engineering and science analysis networks can be designed to ensure that information necessary for social science questions to be answered is included in their design criteria. This can be accomplished by collecting data through existing systems; by extending new networks for data collection; and by ensuring that the data that are collected are effectively packaged for use by policy makers and other stakeholders.

Data Collection from Current Engineered Systems

There are a wide variety of engineered systems that are underutilized as social science data gathering networks. Some systems are difficult to access, or fully inaccessible, due to privacy concerns (e.g., household water consumption, hospital asthma admissions). Others data sets are hidden for public perception regions (e.g., rat eradication efforts). Still others are simply not used due to the lack of interaction between academic scientists and city utilities (e.g., spatial patterns of condemned property).

While the simple integration of physical and social sciences should begin to generate solutions to some of these challenges, expenditures on specific infrastructure can facilitate social science leveraging of these networks. In particular:

- Any centralized informatics office should include expertise in privacy issues, to allow both cultures (physical and social) access to expert advice on ethically and legally correct human data collection.
- In planning processes for any initial network establishment, a wide net must be cast in discussions with local officials. In addition to city engineers and treatment plant operators, others should be included in the planning: e.g. public health officials, housing officials, transportation planners, police spatial data managers, and zoning and planning officials. This will facilitate the collection of community data in the long term.
- Access to current engineered systems may require specialized equipment. For example, development of handheld/remote devices to read radio tags may provide insight into catchment litter sources by recording information on litter conveyed by fluvial systems. Further, cheap, remote traffic counters may transform our understanding of traffic patterns and our quantification of vehicle miles traveled. The convergence of three trends—low cost instrumentation, ubiquitous Internet access, and a large pool of active retirees and other potential citizen scientists—make additional data collection more feasible now than ever before.

Extension of New Analysis Networks

Physical science analysis networks tend to examine how contaminants behave after they are released, relying on government agencies and private industry to control releases and develop release abatement strategies. However, many of the most interesting social science questions rely on release behavior, often through distributed decision making. Examples include the use of garden fertilizers, herbicides, and pesticides by homeowners; use and disposal of pharmaceuticals and personal care products; manure and fertilizer application schedules adopted by farmers; the use of green roofs, pervious pavement, or rain collection barrels to mitigate peak storm runoff rates; decisions by consumers to recycle old batteries or dispose of them with municipal waste in a landfill; and procedures for disposing of used motor oil by shops or individuals following an oil change. Furthermore, the lack of such data can compromise the results of scientific studies because transport and fate predictions benefit from precise knowledge of spatial and temporal release patterns.

Engineering analysis networks developed as part of the WATERS Network would be able to address social science questions more effectively by extension of these physical science analysis networks. For example, in addition to dense sampling of natural systems, releases must be carefully quantified. Not only does this increase the size and costs of proposed networks, this type of sampling creates the need for specialized information on privacy and access, most likely as part of an informatics center. However, successful integration of social science requires such an extension of these networks.

Packaging of WATERS Network data for policy makers and stakeholders

Ideally, WATERS Network results should be used by regulatory agencies and other stakeholders. Unfortunately, many important tools are abandoned due to improper packaging. Expecting local practitioners to want to understand model parameterization is not realistic. However, with careful effort, tools can be developed to ensure ease of use. We suggest as a model of the scenario planning process, the Wisconsin Northern Highlands Assessment. In addition, tools for TMDL and other basin planning efforts must be packaged in an end-user friendly package. One important model in this effort is the Connecticut Nonpoint Education for Municipal Officials program. There have been many efforts to facilitate this sort of technology transfer. The WATERS Network will be most effective if it examines earlier efforts and attempts to do better.

The public release of data also raises important issues of risk perception and risk communication. For example, a portion of the WATERS Network research effort is likely to address real-time monitoring and modeling of public water distribution systems. This raises a range of issues regarding the security of the data, the interpretation of extreme events, and the sharing of information. How would the public respond to real-time information on concentrations of disinfection byproducts or other contaminants? How should this information be packaged to ensure that it is understandable and useful to those needing to make decisions, including those who may not be fully informed about how to interpret such data?

III. Social Science Research that Could be Enabled by WATERS Network

There are a number of key questions facing the WATERS Network program where social science research will be an integral component of the problem resolution. Examples include:

- Which human actions influence the availability of resources and disturbance regimes across aquatic and associated ecosystems?
- How do human-induced alterations to the environment lead to changes in ecosystems services?
- How do those changes in ecosystem services then affect humans and what we value?

To answer these questions, a broad range of social science expertise will be needed, including geography, sociology, history, law, economics, and behavioral and decision sciences.

Likewise, there are a number of active areas of social science research that could be strengthened by inclusion within the WATERS Network program. By way of illustration, we consider the following:

1. Decision analysis for multi-attribute/multi-stakeholder problems
2. Development of national accounts that consider environmental quality and the valuation of ecosystem services
3. The formulation and support of market-based regulation for water pollution
4. Development of mechanisms for adaptive management.

5. The formulation of future institutional and design strategies for water systems

Each of these topics within the WATERS context is briefly discussed below.

Topic 1. Decision Analysis Methods for Multiattribute/Multistakeholder Problems

Significant progress has been made in recent years in the development of analytical methods to support decision making for complex problems where multiple objectives must be considered and where different parties to the decision place different relative value on these competing objectives (e.g., Marttunen and Hamalainen, 1995; Lahdelma et al., 2000; Hobbs and Meier, 2000; Ananda and Herath, 2003; Greening and Bernow, 2004; Hostmann et al., 2005). Methods range from simple weighting or ranking schemes that produce a single score for different decision options to sophisticated multi-objective optimization methods that consider uncertainty in the outcomes associated with each decision option and produce a risk-based Pareto optimal frontier that enables stakeholders to negotiate among options with the assurance that all win-win gains have already been extracted (Cohon, 2003). Research in this field of decision and behavioral sciences considers not only the mathematical methods for decision support, but also the human behavioral factors that determine: 1) relationships between peoples' disaggregate and holistic valuations of decision options and outcomes (Willis et al., 2004); 2) trust in the competency and impartiality of the information that is used to support the decision (McComas and Trumbo, 2001; Poortinga and Pidgeon, 2003); and, 3) the evolution, convergence, or divergence of beliefs and preferences among individuals or groups involved in an analytic or deliberative decision-making process (Renn, 1999; Gregory and Wellman, 2001).

The environmental problems that will be addressed in the WATERS Network research program provide an excellent test bed for the application and advancement of these methods. Multiple water uses, including agriculture, municipal water supply, recreation, support of aquatic ecosystems, flood control, and power generation dictate that tradeoffs will need to be made among these (often) conflicting objectives. Different groups, including farmers, those living in growing urban areas, boaters, and conservationists, will want to see management options that maximize, or at least suffice, their needs and objectives. WATERS Network data and models will help to establish the relationships between management options and outcomes for these stakeholders with reduced (and properly characterized) uncertainty. Integrating these results into decision-support tools and studying how multiple stakeholder groups use (or do not use) the information in establishing their preferences and conducting their negotiations will provide an excellent laboratory for integrated studies of the physical, cyber-informational, and social-behavioral elements of environmental decision making. Decision analysis can also help to identify the value-of-information for WATERS Network data and scientific advancements that are used for decision support (Yokota and Thompson, 2004).

Topic 2. Valuation of Environmental Quality, Ecosystem Services, and the Development of National Environmental Accounts

Estimates of the economic value of environmental quality are now used in a growing number of policy applications, including cost-benefit studies of environmental regulations or projects, the assignment of externality costs to different sources of pollution, comparative life-cycle assessment for alternative industrial processes and products, and the assignment of natural resource damage costs for polluting activities or events (Matthews and Lave, 2000; Pearce and Seccombe-Hett, 2000; Faure and McCloskey, 2003). A number of approaches are used for economic valuation, including (Farrow et al., 2000; Bockstael et al., 2000; Carson, 2000):

- Estimating the monetary value of ecosystem services, such as the support of aquatic life, climate regulation, nutrient cycling, and the maintenance of genetic resources;
- The use of revealed preference, where the willingness to pay is derived from observed consumer behavior, such as the willingness to spend time and money traveling to recreational areas of high environmental quality; and
- The use of stated preference or “contingent valuation”, where people are asked how much they would be willing to pay to preserve an environmental resource.

A particular application for environmental valuation is in the development of national income measures that consider not only goods and services produced by the economy, but also environmental resources preserved or degraded. The U.S. Congress has sought to improve the National Income and Product Accounts (NIPA) by including measures relating to the interaction of human activity – market and non-market – and the natural environment. The Panel on Integrated Environmental and Economic Accounting, after extensive analysis (detailed in National Research Council, 1999) recommends including a broad array of measures in satellite accounts, in particular, measures of air and water pollution across the country. Some of these measures – particularly pollutant flow accounts – are already established in the European nations as well as an increasing number of developing countries, and comparisons of how these vary across countries are important for assessing the environmental implications of trade patterns (Lange, 2003) as well as domestic economic activity. These enhancements to the NIPA will require comprehensive, consistent data from across the country such as the WATERS sensor network will provide.

To understand and evaluate changes in natural capital – the environmental characteristics that enable life and productive human activity - we require measures not just of commercial natural stocks like coal and timber, but also of the capacity of the ecology as a whole (Lange, 2003; Vincent, 2000). We need to know what comes into the environment, from where, how it interacts with the environment and humans, how effective efforts at remediation are (and where they are best applied), what the returns on remediation expenditures are, and what levels of inputs into ecosystems can be sustained at an acceptable steady-state.

This information allows economists to begin to address important empirical questions about human-environment interactions (where are resource rents being generated, and to whom are they accruing?), and to consider the implications for economic theory, e.g., of the degree to which manufactured or social capital can substitute for natural capital (Harris and Fraser, 2002).

Data allowing scientists to trace and understand interactions between human activities and environmental impacts and outcomes can enhance real productivity, improve regulatory design and enforcement, and identify areas of comparative advantage in the use of natural endowments. Improved knowledge of the source, transport and fate of sediment, pollution and other contaminants associated with human activities allows us to weigh the economic costs and benefits of industry, land-use and land conversion, and other human-environment interactions in an informed way. In particular, as human morbidity and mortality is generally a large part of estimates of externalities, showing the links between pollution outputs and human exposure and health effects is critical for better valuation of costs and benefits (Hofstetter and Hammitt, 2002).

While many aspects of natural capital and services can be monetized, a system of satellite accounts would allow for those that cannot easily be denominated in dollar terms to be considered in physical units. When there are no near-market substitutes for the resource stock or flow in question to estimate a credible price, this is a significant benefit. The physical accounts remain relevant to economists, particularly those engaged in input-output analysis using material flow methods. These approaches allow the estimation of the total material requirements of a given process over its lifetime, including market and non-market flows, and thus comparison of the environmental burden of different proposed activities in a given location. Combined with the earth-sciences based understanding of differential impacts of outputs that the sensor network promises, this can be a powerful tool for economic and systems decision-making.

Topic 3. Market-Based Regulation

A key area where the WATERS Network's monitoring and data processing capabilities could contribute to the development and implementation of economic strategies is in support of market-based regulation for aquatic systems. The lack of consistent water quality data and models at various scales, and the lack of engineering and social science data that integrate seamlessly with those data, currently inhibit this type of socioeconomic analysis of water quality and quantity problems. Examples are related to the potential for water quality and quantity trading as part of Total Maximum Daily Load regulation, the regulation of various types of sewer overflows, and the management of water flows to support multiple uses including ecosystem services.

The use of continuous emission monitors and sufficient support for universal mixing has supported an air emissions trading program that is widely viewed as reducing pollution at a substantially reduced cost (Burtraw and Mansur, 1999; Carlson et al., 2000; Newell and Stavins, 2003). In contrast, the local hydrological mixing conditions and more complex socio-economic links to water quality have made the development of emissions trading programs for water systems more difficult (Shabman et al., 2002; Woodward et al., 2002; Schary and Fisher-Vanden, 2004). Nevertheless, with sufficient data and modeling capabilities, effluent trading programs may eventually support the reduction of water pollution at a net savings. Furthermore, in the arid west, effluent is a valuable asset used for maintaining riparian vegetation and in-stream flow standards. The USEPA has constructed a nation-wide water quality model that illustrates some of the challenges (Miles and Bondelid, 2004). In particular, much of the data for effluent discharges on a high frequency basis are weak and important elements, such as non-point pollution run-off, could be substantially improved.

Topic 4. Mechanisms for Adaptive Management and Risk Assessment

Data to support ecosystem services and the monitoring of water quantity and quality can potentially improve the adaptive management of watersheds. This approach to system management is especially important in multi-use watersheds, such as the Klamath River Basin in northern California and Oregon, where trade-offs involve maintaining water flow for ecosystem purposes with water use for agricultural and other uses (http://www.nrcs.usda.gov/feature/klamath/). The integrated design of science and engineering data and social science data related to determinants of use and water quality could also improve the relevance of basic data to decision makers.

Fundamentally, WATERS Network data and modeling are expected to generate new information. In a social science framework, new information is valuable only to the extent that it can, now or in the future, potentially alter some decision. The social science of even basic research suggests that informing research directions by potential payoff is useful. In areas of the standard economy and for longitudinal studies of social behavior, there is a large data gathering infrastructure and system to monitor the physical, social, and economic activity of firms, consumers, and governments. Environmental data, including water based data, are only indirectly addressed in those data systems. Consequently there is little baseline information about current activity given the regulatory and other management systems in place, and consequent difficulty in determining the effects of management changes.

A data and modeling based infrastructure to assess the current state of "residual" social risks and its ongoing operation to inform data collection and adaptive management decisions would be a significant contribution. This could provide consistent estimates of water based risks related to health, commercial economic activity, and recreational resources. Objective research on the information that alters decisions at various levels of government is also needed. The following matrix illustrates areas where the social and physical sciences overlap naturally in questions of water and environmental quality, and where the WATERS Network could contribute to adaptive management, risk assessment, and related physical-social science analyses.

	Social Science Perspectives					
Natural Science Committee Topics	*Demographic Change*	*Equity*	*Risk Assessment*	*Organizational Dynamics*	*Adaptive Management*	*Market Behavior*
land-use Change	Changes in household and family size driving suburbanization	Blockbusting and Redlining as drivers of suburbanization	Relative risk of daily commute vs. living in urban center	Tax base sharing in metropolitan systems	Metropolitan planning (avoiding balkanization)	Removal of Street Car Networks
Nutrient Loading	Future trends in PCPP's via demographic change?	CAFO's vs. small farm nutrient regulation	Human exposure to toxic materials via biomagnification	How to make TMDLs accessible to local decision makers		How can we develop emission—discharge cap-trading markets for improving water quality?
Water Quality	Suburban environments as non-point sources	Upstream vs. Downstream conflicts	Proper targets for MCLs—immuno-compromised, in utero, etc.?	Challenges reconciling hydrologic and jurisdictional boundaries	Are cap-trading schemes appropriate for toxic materials (e.g., Hg)?	
Water Quantity/ Distribution	Water Recycling—technical and cultural constraints	Water Supply Privatization	Drought risk in limited water supplies? (e.g., Delaware Basin)	Wildlife vs. Navigation: Missouri River organizational conflicts	Are large, adaptively managed projects (e.g. CALFED) failing?	Demand side vs. supply side conservation effectiveness

Climate Change	Flashy hydrographs = more, bigger dams?	Shifts in water availability could adversely affect vulnerable subpopulations	Flashy hydrographs and flood risk	Public Health surveillance and climate change	Credibility of mgmt strategy under variable conditions	Market responses to threshold events

Topic 5. Formulation of Future Institutional and Design Strategies for Water Systems

Current embedded design philosophies have a significant impact on both water quality and the economics of water treatment and delivery in the United States. Along many rivers in the United States and elsewhere water is reused multiple times as it is withdrawn for municipal or industrial supply, treated to enable these uses, polluted with the byproducts of human or industrial waste, and then treated again as it is returned to the stream for eventual reuse downstream. With many water and wastewater treatment jurisdictions defined along political boundaries, and many water supply and wastewater treatment operations under separate management, it is difficult to achieve the type of integrated management necessary to ensure the best overall water quality with limited resources (Levin, et al., 2002). Research on alternative institutional structures for community or regional water authorities and the factors that constrain or enhance their performance is needed to help guide future organizational choices (Lundie et al., 2004; Lienert et al., 2006). As WATERS Network data and models are generated, knowledge of how agencies can best use this information will be important in ensuring that these data have a maximum beneficial impact.

Basic design strategies for our water systems also can have important implications for water quality. While we have done a very good job of using advanced drinking water treatment to eliminate major acute water borne disease in the U.S., there is growing concern that our design philosophies may contribute to other drinking water problems, including increased endemic disease problems (NRC, 2005). We have tended to design water systems in the U.S. to be multipurpose in nature, particularly for fire protection which has led to a tremendous amount of “over capacity” under normal demand conditions. This in turn has lead to systems with very long water residence times and the requirement to move large quantities of water in a short period of time. Long residence times can lead to the formation of disinfection byproducts, loss of disinfection residuals, the formation of biofilms and the potential for regrowth of microorganisms. Movement of large quantities of water can lead to hydraulic surges which stress joints and connections in drinking water piping systems, which in turn may increase the potential for backflow of contaminants and cross connections. The types of diseases associated with these kinds of problems are unfortunately very difficult to identify and quantify.

Despite the fact that the spatial and temporal characteristics of water use “drive” the provision of water to urban areas little is known about the specific details of this use. New real time water meters have the potential for providing a rich data source for increasing our understanding of water use in urban areas and for tying together water usage patterns with other variables such as land-use, housing patterns, human activity patterns and the socio-economic characteristics of consumers.

Increasing regulatory costs and concerns over the availability of adequate water resources have heightened interest in non-traditional drinking water systems. Distributed or decentralized treatment systems use both centralized and distributed technologies to meet water quality and quantity requirements at consumer end points. Under this concept centralized treatment meets basic water quality goals, which might be water safe for human contact, while the distributed units provide advanced treatment to meet stringent water quality requirements. Distributed units would be located either at the point-of-use/point-of-entry (POU/POE) of households, for example, or at a location from which aggregates of uses could be served. This might be at the neighborhood or district level, depending on technological and financial requirements. The principal trade-off associated with using such systems is the alternative cost associated with upgrading large centralized treatment facilities and distribution networks to provide water of a quality that consistently meets increasingly stringent drinking water standards at all points of use. Field and theoretical research is needed to study how decentralized treatment and dual water systems might be best implemented in U.S. water systems. Concomitantly, economics research will be needed to determine the costs and their appropriate allocation for new system designs, as well as behavioral research to determine the public acceptance and likely modes of use (or misuse) of these designs.

In May 1998 the President’s Commission on Critical Infrastructure Protection concluded that the nation’s waste water and water supply systems might be vulnerable to attack and declared these systems as critical infrastructure. As a response to this concern the USEPA and the Department of Homeland Security have launched a number of research efforts that involve real-time monitoring and the use of hydraulic and water quality models for identifying the movement of contaminants within distribution systems. These tools will be useful in identifying the vulnerabilities of drinking water systems to specific threats (e.g., Nilsson et al., 2005). Much of this research is being directed toward measuring the public health and economic impacts and the risks associated with drinking water distribution system vulnerabilities. Social and behavioral research will also be needed to gauge how consumers might respond to water quality alerts from sensing systems, some of which could be prone to false positives (Atwood and Major, 1998). New organizational networks and modes of operation may also be necessary to enable the continual inquiry, informed action, and adaptive learning necessary to effectively respond to future threats (Comfort, 2005). This research will be important to protecting water and waste water systems and will also assist drinking water systems in the U.S. in complying with the increasingly rigorous requirements of the U.S. Safe Drinking Water Act. These tools and research may thus improve our understanding of endemic disease among drinking water consumers and its relationship to deteriorating water infrastructure.

IV. Required Social Science Infrastructure and Data Sources

Successful integration of social science into WATERS Network efforts cannot rely solely on leveraging of research funding from planned natural science and engineering efforts. Transformation of social environmental science requires a commitment of long-term funding and planning to develop a parallel, integrated social science observatory. The necessary capital expenditures can be divided into three categories:

- Extending physical science sensor networks to observe human behavior.
- Using physical science sensor networks to observe human behavior and the aggregate environmental consequences of individual decisions.
- Enhancing traditional social science data collection tools and social science community

data structures.

Integration of significant social science capital costs into development of WATERS Network sensor and cyber- infrastructure will allow successful integration of social science information into hypothesis driven research and ultimately improve management of human dominated ecosystems. While superficial examination of the social sciences might suggest that data sources are abundant, with strong institutional support from governmental agencies including the Census Bureau, the Bureau of Labor Statistics, and the Federal Reserves, these data sources can be temporally sparse, recorded with limited spatial reference, and collected to answer questions isolated from environmental management. In addition, historic volumes in these data series often remain in manuscript form. Therefore, while abundant, these data are not necessarily sufficient to allow hypothesis testing of relevant environmental management questions, particularly using an approach requiring the coupling of natural, engineering, and social science.

Regarding field data collection, social scientists measure and monitor the human behavior that causes pollutant loadings and the human response to and valuation of those loadings. Hence social scientists are concerned about data at the point of environmental concern, spatially distributed data, including human drivers causing the impact and contributing to impact mitigation and management. Social scientists use data infrastructure that spans data of interest to natural and social scientists and engineers and data infrastructure developed to measure parameters of unique interest to social science. We begin with a discussion of data infrastructure designed to meet interdisciplinary needs.

Basin-scale water quality management is emerging as an important tool for achieving water quality goals, as it requires management schemes to address classic societal conflicts (e.g., upland vs. valley use) using powerful management tools (e.g., cap and trade schemes). One of the primary approaches in basin-scale management is development and manipulation of material budgets. Simply put, if we begin by enhancing (e.g., dissolved oxygen) or diminishing (e.g., chemical oxygen demand) the most important sources of these materials, we often reach management goals more quickly.

As a first step in assessing water and pollutant budgets for a watershed, satellite data can provide critical information for characterizing spatial and temporal patterns of land surface and surface water resources, and thereby inform the estimation of parameters for hydrologic and water quality models. Satellite data can be used to assess land-use and land cover, vegetation type, and surface water concentrations of suspended solids, algae, and other water quality constituents (Shafique, et al., 2001; Brezonik et al., 2002; Mertes, 2002). In addition, recent advances in understanding subsurface-ground surface interactions have enabled use of satellite data for the assessment of ground water resources (Becker, 2006). Effective use of satellite data is likely to be an important component of the WATERS Network; determining how this information can be used to enhance understanding of behavioral, land-use, and water quality relationships can help link social science studies to these related physical science assessments.

While broad scale data of the type used for basin-wide assessment of land-use and land cover is important, accurate measurement of material budgets, particularly in material cycles coupled to human activity often requires finer resolution. Absent this, critical water quality relationships are generally modeled under a cloud of assumptions (e.g., what is the "average" human waste nitrogen output? What percentage of this nitrogen makes it through a septic system? What are the uncertainties in these measurements?). Therefore sensor networks designed to clarify material budgets across scales must do so from a fundamentally interdisciplinary framework. We use the basin scale water quality management approach to illustrate the interdisciplinary design necessary for successful and effective observation networks:

1. Continuous monitors for loadings from point sources

While there are multiple programs monitoring and tracking point source emissions including the USEPA's National Pollutant Discharge Elimination System (NPDES) and Toxic Release Inventory (TRI), the regulatory culture of these programs precludes investigations of social science outcomes and factors. Sensor technology allowing verification of quantities discharged exists or is in development. However, the design of sensor deployment is where socioeconomic factors can be considered. For example, deployment should stratify across firm size, as larger firms may be better able to control discharges across multiple units and treatment facilities. Larger firms may also be able to be more precise in measurements due to their access to higher levels of technical expertise. On the other hand, small firms may be more meticulous in self-reporting systems (such as the TRI) as they depend more on local economies and the trust of this consumer base. We might seek to determine whether self reporting systems tend to underestimate emissions or releases. Efforts to accurately measure point sources in cap and trade systems can be used to investigate fundamental questions about firm behavior and producer-consumer relations in local economies. Moreover, this knowledge will in turn improve management effectiveness.

2. Monitoring of loadings from non-point and intermittent sources such as agriculture, construction site runoff, septic systems, and combined sewer systems.

The elimination of point source discharges, while complicated, remains relatively simple when compared to the elimination of non-point sources of contamination. Policy makers have achieved remarkable success in programs designed to ameliorate non-point source pollution through individual management decisions ranging from the planting of riparian buffer strips to the adoption of contour plowing. However, true success in these programs remains elusive as it is exceedingly difficult to measure actual reductions associated with particular behaviors, evaluate programmatic efforts, and adapt management efforts. The introduction of convenient, ubiquitous sensing will transform the policy-based management of basin scale water quality. For example, in watersheds covered by a mixture of low-density residential and agricultural land-use, it is difficult to partition observed bacterial loadings between animal and human sources. The deployment of sensor networks in these areas can potentially have a great impact. The measurement of household wastewater composition via small sensors deployed within residences can allow us to divide use and discharge quantities into shower water vs. toilet water vs. dishwater, etc. Moreover, with a clear idea of waste water mixtures, sensors deployed within sewers, treatment plants, or septic system drainfields can then measure the relative efficacy of treatment technologies across a variety of stoichiometric mixtures and microbial community compositions. In addition, variations in loading rates can be related to socioeconomic data, allowing improved basin scale modeling. As for agriculture, the characterization of fertilizer loadings using technology developed for precision agriculture coupled with an array of edge-of-field sensors can provide unprecedented information on the consequences of a variety of fertilizer application schedules and spatial patterns. Moreover, changes in farming practices could be related to socioeconomic factors such as the increase in absentee land ownership and leased farming. The information gathered in these observatory networks can then be used to inform policy in this complicated environment.

3. Monitoring environmental outcomes, such as swimability and fishability, allowing water quality outcomes to be linked to social and economic values.

Determining the link between water quality and beneficial use support for a water body is a critical step in cost-benefit analysis for water quality projects. Use-support designations also serve as the basis for state and federal regulation of surface water quality in the U.S. Beneficial uses that are valued include navigation, contact recreation, municipal and industrial water supply, and support for aquatic life, including recreational and commercial fisheries. Methods are often used to relate use support to water quality constituents, including dissolved oxygen, biochemical or chemical oxygen demand, dissolved or suspended solids, nitrogen, phosphorus, chlorophyll a, and microorganisms such as *E. Coli* or fecal coliform. In addition to these traditional measures, recent attention has focused on toxic compounds such as mercury and PCBs in fish, sediments, and the water column when determining fishability and other use-support designations for a water body. Intensive and extensive sensing along a waterway to determine pollutant concentrations in the water column, sediment, and biota, coupled with assessments of species abundance and diversity, could significantly advance the scientific basis for use-support designations and subsequent economic valuation. Advances in monitoring and modeling methods and protocols would support state and federal regulatory programs as well as economic assessments of stream, lake, and estuary protection and restorations efforts. The increasing use of citizen volunteer monitoring programs (see: http://www.epa.gov/owow/monitoring/volunteer/) provides another opportunity for extending the available database for resource assessment, as well as a possible test bed for social science research to study the legal and organizational factors that determine the success or failure of these efforts.

While the opportunities for creative integration of social and natural science needs in sensor network design abound, the direct application of emerging sensor technology to social science proper remains underdeveloped. We envision a variety of sensor applications allowing social data collection, particularly focusing on the behavior of individuals or organizations, such as:

- RFID readers and identifiers for cars or people to place human use at sites. Various social science models use travel cost and related studies on expenditures to infer values about water quality improvements.
- Biomarker, scanner, or RFID devices to collect data on human decisions about purchases, or the status of household or firm water treatment technologies (such as the potential use of biomarkers to track septic releases).
- Valuation and attitude data from human subjects. Alternative methods that elicit data directly from people (“sensing” the human environment) include face to face interviews, telephone, mail, and electronic surveys. Such methods may include innovative electronic survey tools available at a field site (such as an electronic kiosk or personal survey device), or web-based survey methods. Applications may be as basic as surveys about purchases or as complex as those about environmental attitudes and willingness to pay for water quality improvement. More advanced studies may be undertaken using new visualization technology for data and model predictions, such as the “decision theater” now under development at Arizona State University. Stakeholders could be given the

opportunity to explore alternative future outcomes of land-use and environmental quality under different management strategies, and to express their preferences regarding these.

A specific way to make survey infrastructure more available is to create a system analogous to the PASSCAL component of the IRIS seismic network. That is, a trailer or other portable building is outfitted as a state-of-the-art call center, complete with auto-dialers, multiple phone lines, and computing facilities to allow instant recording of information. This call center would then be moved around to enable survey campaigns selected in a competitive proposal framework. However, it may be more effective to develop a distributed survey system. That is, the informatics center could develop software tools to take advantage of academic bandwidth resources and emerging technology such as VOIP (voice over internet protocol). Using these tools scientists requiring a call center could occupy a campus computer cluster for an evening or a week to conduct necessary surveys. Either way, social science components of the WATERS Network will require infrastructure allowing the collection of new survey data and other types of human behavioral information.

Supporting and integrating field data connection requires cyberinfrastructure. At the “front end” of field data collections are:

- Improvements in guidance and templates for expert and lay person elicitation,
- Methods “warehouses” of standardized surveys and questions, and
- Legal or organizational infrastructure to allow data collection in human populations through time.

Epidemiology regularly uses cohort studies to examine exposures and human health responses. WATERS Network planning efforts should request money for the informatics infrastructure to solve or manage the logistical and privacy challenges that currently make large cohort studies inaccessible to individual social scientists. While there are clear possibilities for human exposure assessment via blood testing, etc., these cohorts could also be assembled to provide essential and unprecedented social science information relating to the evolution of environmental perception and individual economic responses to environmental forcings.

At the “back end” of field data collections are cyberinfrastructure tools that facilitate the predictive, integrated assessments that combine predictions for environmental quality with predictions for human behavior and impacts. While these tools may primarily be databases or links to other sources, the integrated modeling of environmental and human systems is still evolving rapidly and cyberinfrastructure that connects people as well as data and programs will play a key role. The social science component of the WATERS Network cyberinfrastructure should be developed in close coordination with parallel efforts to develop shared datasets, databases, and tools for analysis for the social and behavioral sciences. The 2005 Final Workshop Report from the NSF SBE/CISE Workshop on Cyberinfrastructure for the Social Sciences highlights the importance of social science research for effective development and use of cyberinfrastructure, as well as the potential contributions of advanced cyberinfrastructure to social and behavioral research. In particular, the report argues that:

> *“Cyberinfrastructure can help the social and behavioral sciences by enabling the development of more realistic models of complex social phenomena, the production and analysis of larger datasets (such as surveys, censuses, textual copora, videotapes, cognitive neuroimaging records, and administrative data) that more completely record human behavior, the integration and coordination of disparate datasets to*

> *enable deeper investigation, and the collection of better data through experiments and simulations on the Internet."* (http://vis.sdsc.edu/sbe/)

Indeed, efforts to begin to build such large-scale, multimedia social and behavioral datasets, and the cyberinfrastructure to provide distributed access and use of these data, are already underway (see for example, http://www.apa.org/science/psa/brief_bennett.html; and http://www.ncess.ac.uk/nodes/moses/).

The ongoing collection of data from the proposed sensor networks cannot be funded with NSF MREFC funding. Nonetheless, pilot studies demonstrating novel data collection, storage, and access mechanisms may be funded. In these cases, substantial work on database design and construction should be covered. There are two important data models we point to for consideration during planning of initial pilot studies for WATERS Network proposals. First, the Inter-university Consortium for Political and Social Research (ICPSR) has organized, stored and distributed essential social science data for over 43 years. Simple interfacing to their data allows powerful end user tools. For example, county-level, historic land-use change contained in ICPSR data is easily accessible using this interface: UVa Historical Census Browser. Second, David Rumsey's work with historical maps has generated interest from a variety of end users. Ultimately, his efforts to scan and serve historical maps have allowed researchers unprecedented access to this rich data source. These two models are the sort of social science data infrastructure that should be integrated into WATERS Network informatics efforts, organizing and providing as yet unorganized data for environmental management.

Additional examples of databases or links that may facilitate integrative work include:

- Links to existing relevant economic databases such as the USEPA Envalue database (http://www.epa.nsw.gov.au/envalue/)
- A water policy database to characterize and archive decisions by local, state, and federal agencies. The study of water fluxes and management in the U.S. requires access to the wide variety of state and local regulatory structures governing water use, allocation, and management. Pilot studies examining the efficiency of water management strategies across an array of water policies might include funding to build a 50-state water policy database, beginning with policies relevant to the question at hand and designed to be easily scalable and updatable to include other policy data as the WATERS Network progresses. Such a database could link to, or build upon, the USEPA Water Quality Standards Database (http://www.epa.gov/wqsdatabase/). Beyond this, careful work establishing a tight ontology and integration of emerging data from the Federal Register and other sources would make such a database a long-lived and important tool.
- land-use information based on integrated local data. Rapid and widespread changes in land-use have been independently identified by all of the major environmental observatory networks as an important driver of environmental change. However, a true process-based inquiry into land-use change must use social science data. The lower profile of social scientists in other planning processes has led to an empirical based observatory schema (e.g., NEON will characterize land-use change largely from space-based remote sensing) rather than a process-based characterization of land-use change processes. One of the most important tools in understanding land-use change is a sophisticated knowledge of antecedent/historical policy, economic, and land-use

conditions. Capital investment in equipment necessary for acquiring and organizing such data are essential to successful prediction and management of land-use change. There are a variety of ways to achieve such a goal. First, this capability may be purchased as part of a pilot study and built into a mobile facility that can move from archive to city hall to engineering office and transform paper-based data into spatially referenced, digital information. Alternatively, and depending on the final organization of the WATERS Network, this equipment could be housed in a central cyber informatics facility allowing on call technological services.

- A waterborne endemic disease occurrence database, perhaps patterned after or building on PulseNet (http://www.cdc.gov/pulsenet/index.htm) and FoodNet (http://www.cdc.gov/foodnet/index.htm), which record foodborne pathogen diseases, currently for 8 regions and 5 pathogens,
- A database of water-related risk assessments perhaps patterned after the University of Maryland Food Safety Risk Analysis Clearinghouse (http://www.foodrisk.org/index.cfm).

Development of these databases will in many cases require partnerships with other organizations or agencies. Alternatively, emerging methods for data mining and knowledge networking might allow this information to be retrieved from existing digital resources.

V. Next Steps

This report has outlined a broad agenda of critical research on human-environmental systems that could be enabled by the WATERS Network initiative. In addition, it has identified the required infrastructure, databases, and data and model integration services needed to support this effort. What are the next steps needed in the WATERS Network planning process to ensure that these critical steps are taken? Social scientists must continue to be involved in the conceptual design process for the WATERS Network field sites to see to it that the required social science infrastructure and services are part of the “standard equipment” of facilities in the observatory program. Solicitations for WATERS Network projects should include exploratory test-bedding activities involving social science hypotheses and social science modeling and decision-support tools that take advantage of both the site-specific and the centralized cyberinfrastructure provided by the Network. Ideally this would occur through initiatives supported by multiple NSF Directorates, encouraging projects that include close and ongoing collaborations between biophysical and social scientists. The recent (January 2007) Workshop on Integrating Social Sciences at NSF Observatories has seeded a number of possible collaborations and identified a coordinated path forward for the different observatory programs. We believe that this can lead to new fundamental knowledge and insights that could not be achieved by any of the single disciplines acting alone.

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Appendix A. WATERS Network Social Science Committee

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