RISING TO THE CHALLENGE: INTEGRATING SOCIAL SCIENCE INTO NSF ENVIRONMENTAL OBSERVATORIES

Shalini Vajjhala, Alan Krupnick, Eleanor McCormick,
Morgan Grove, Patricia McDowell, Charles Redman,
Leonard Shabman, and Mitchell Small

September 2007

RESOURCES
FOR THE FUTURE

Table of Contents

Executive Summary

In early 2006, following meetings of the CLEANER (Collaborative Large-Scale Engineering Analysis Network for Environmental Research) Social Science Committee and Executive Committee, plans were developed for a workshop on improving social science integration into CLEANER and other NSF Environmental Observatories (EOs). This effort was motivated by the realization that first, social, behavioral, and economic science theory and research were centrally important to resolving the major "grand challenge" questions being addressed by the observatories, and second, more coordinated research efforts across social science, natural science, and engineering disciplines were necessary to "rise to these challenges."

This report is the product of these early discussions. Developed for a National Science Foundation-funded workshop, "Integrating Social Science at NSF Observatories," held on January 24-26, 2007, in Arlington, Virginia, the goal of this paper is to address both fundamental research and process questions associated with social science integration at NSF EOs. Given the broad aims of this effort, the workshop and this report target ongoing observatory efforts including National Ecological Observatory Network (NEON), the Water and Environmental Research Systems (WATERS) Network, and parallel developments within the Long Term Ecological Research (LTER) Network, as well as addressing the lessons learned from past observatory initiatives, such as Collaborative Large-Scale Engineering Analysis Network for Environmental Research (CLEANER) and Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI).

These observatories are intended to provide multidecadal, continent-scale platforms for environmental science data collection; however, for a variety of reasons, the process of integrating social science into these efforts needs improvement and encouragement. Because NEON and WATERS are now in the early stages of agenda setting, there is currently a window of opportunity to begin to address basic social science integration issues within ongoing infrastructure planning and decisionmaking. To this end, a workshop was convened to bring together program officers from participating NSF Directorates, members of the different observatories' leadership, and representatives of the broader community of social and natural

scientists. The workshop discussions offered a wide range of ideas for long-term multidisciplinary research and identified many overarching research opportunities and process barriers to linking social and natural science data collection at the observatories.

This report builds on these discussions and expands on the implementation issues facing the EOs as they move toward greater social science integration and large-scale, long-term multidisciplinary research. We identify three research themes—human activities and behaviors, human impacts and responses, and human welfare and development—as opportunity areas for potential advances in core social environmental science research and future collaboration at the EOs. Based on lessons learned from ongoing integration efforts within NSF's Coupled Natural–Human (CNH) program, the Human and Social Dynamics (HSD) priority area, and the LTER Network, we also identify four primary implementation issues—organization, funding, infrastructure, and data—that are central to integration at the observatories. Each of these issues is individually described here, specifically in the context of improving integration, to lay the groundwork for integrated EO planning in the near term.

Finally, to build on the interest and enthusiasm for integration, evidenced by the support of both social and natural scientists for this workshop, and to maintain the momentum from these dynamic discussions, we also make several key recommendations targeted at the research and process issues outlined in this paper. We propose, in collaboration with NSF and the broad community of social and natural scientists to (1) initiate a demonstration or test-bed project for integrated observation; (2) develop a cross-observatory advisory committee to guide integration efforts; (3) coordinate with the Social, Behavioral, and Economic (SBE) Sciences Directorate at NSF to align incentives for social scientists to participate in observatory planning and agenda setting; (4) engage NSF and other funding agencies to design programs and funding vehicles to sustain collaborative observatory research in the long term; and (5) establish a center, modeled on the National Center for Ecological Analysis and Synthesis (NCEAS), to encourage and strengthen observatory collaborations. These recommendations are only a first step toward integration, and we see this paper and workshop as important building blocks in ongoing efforts to address existing and emerging grand challenges in environmental science.

Acknowledgements and Disclaimer

The authors would like to thank all workshop participants and presenters for their contributions to a dynamic and innovative two-day dialogue and gratefully acknowledge their time and efforts. We sincerely appreciate the support of Pat Brezonik, program officer with the NSF Engineering Directorate (ENG), whose financial, logistical, intellectual and moral support over the past 15 months helped to make this work possible. Special thanks to all of the participating National Science Foundation (NSF) Directors and program officers for their active involvement in workshop discussions and for their financial and logistical support. We especially appreciate the contributions of NSF program officers Elizabeth Blood and Henry Gholz, Biological Sciences (BIO), Cheryl Eavey, Social, Behavioral, and Economic Sciences (SBE), Doug James, Geosciences (GEO), and their respective Directorates.

Additional thanks to David Lightfoot, Assistant Director of the National Science Foundation, heading the Directorate of Social, Behavioral and Economic Science (SBE) and members of the "Big Green Working Group" including SBE/SES Division Director Ed Hackett, program officers, Tom Baerwald, Bob O'Connor, and Paul Ciccantell for their early input and comments on this paper and initiative. Several members of the environmental science community also helped this effort enormously by providing detailed descriptions of their own collaborative experiences, and we would especially like to thank Coupled Natural-Human Systems program principal investigators David Campbell, John Loomis, Jiaguo Qi, and Billie Turner for their comments and contributions to this report. Finally, we are grateful for the support of our many colleagues from a wide-variety of disciplines for sharing their experiences with initiating and supporting multidisciplinary research and demonstrating their enthusiasm for new interdisciplinary research looking forward.

Although this white paper was first developed as a background document for the January workshop, this final report and the recommendations herein are solely the views of the authors and do not represent official endorsements by the workshop participants.

Rising to the Challenge: Integrating Social Science into NSF Environmental Observatories

Shalini Vajjhala, Alan Krupnick, Eleanor McCormick, Morgan Grove, Patricia McDowell, Charles Redman, Leonard Shabman, and Mitchell Small*

1. Introduction

As international focus on global environmental problems has intensified, scientific research at the intersection of human and natural systems has drawn a groundswell of interest and attention. In 2001, the National Research Council (NRC) issued a report highlighting eight "grand challenges" in environmental science research. These challenges—ranging from improved understanding of biogeochemical cycles and biodiversity to better characterizations of human resource use—focus specifically on large-scale, policy-relevant problems facing coupled natural–human (CNH) environmental systems.

In its report, the NRC committee stressed the importance of developing new multidisciplinary and interdisciplinary programs, emphasizing that to understand "natural systems—ecosystems; oceans; drainage basins, including agricultural systems; the atmosphere; and so on— […] requires expertise that cuts across several disciplines."[1] The report makes clear that these disciplines include the social sciences; however, it also highlights the complexity of effective integration.

In part as a response to these challenges and the recommendations made by the NRC, the National Science Foundation (NSF) has moved forward with a range of large-scale

[1] NRC uses "multidisciplinary" to mean a collaborative approach involving many disciplines and "interdisciplinary" to mean integration of multidisciplinary knowledge. This usage conforms to the recent literature, and for the purposes of this paper we focus primarily on multidisciplinary collaboration between social and natural scientists, recognizing that this is a first step toward the even greater integration required for interdisciplinary research. NRC, Committee on Grand Challenges in Environmental Sciences, Oversight Commission for the Committee on Grand Challenges in Environmental Sciences. 2001. *Grand Challenges in Environmental Sciences*. Washington, DC: The National Academies Press. http://www.nap.edu/catalog/9975.html (accessed on October 25, 2006).

* Shalini Vajjhala (Resources for the Future), Alan Krupnick (Resources for the Future), Eleanor McCormick (Resources for the Future), Morgan Grove (USDA Forest Service), Patricia McDowell (University of Oregon), Charles Redman (Arizona State University), Leonard Shabman (Resources for the Future), Mitchell Small (Carnegie Mellon University).

multidisciplinary environmental research initiatives, including the following major environmental observatories (EOs):

- NEON (National Ecological Observatory Network), focused on land use and climate variability
- ORION (Ocean Research Interactive Observatory Networks), focused on oceanic research[2]
- WATERS (WATer and Environmental Research Systems) Network, focused on human-stressed aquatic systems and hydrologic sciences, and based on a recent merger of CLEANER (Collaborative Large-Scale Engineering Analysis Network for Environmental Research) and the CUAHSI (Consortium of Universities for the Advancement of Hydrologic Sciences Inc.) Hydrologic Observatories,[3] two earlier observatory efforts in these areas

These initiatives in tandem with long-standing observation programs, such as the Long Term Ecological Research (LTER) Network, are intended to provide platforms for continent-level, multidecadal data gathering to further basic scientific understanding of environmental systems. Although the primary focus of these observatories is on collecting and managing data, the NRC grand challenge research questions form a major part of the observatories' missions and analytic research objectives. Beyond this general acknowledgement of the need for inclusiveness and integration, the social sciences for a variety of reasons have played only a limited role in setting observatory objectives and contributing to research design and planning to date.

The motivation for developing this paper is our belief, shared by the NRC committee and by many natural scientists and engineers involved with the observatories, that to respond to the grand challenges and facilitate better decisionmaking on environmental issues, new social science research, both theoretical and applied, is needed in tandem with emerging biophysical science programs. To create a place for the social sciences as a sustained and fully integrated component of ongoing environmental science research and practice, it is essential that social scientists contribute to the current preliminary stages of observatory research formulation to

---

[2] ORION did not participate in the January 2007 workshop, and therefore, is not discussed in detail within this report.

[3] The CUAHSI Hydrologic Observatories are only one part of CUAHSI, and the consortium continues to operate independently even as its observatory components have been merged into WATERS.

make a successful shift to a more integrated model in the long term. This requires two things: commitment from the community of social and natural scientists to engage in integrated environmental research, such as that evidenced by the enthusiasm for this workshop, and new research and process priorities at the observatories to better engage and sustain collaborations.

The current early stages of observatory planning and research design offer unprecedented opportunities for making such changes to support better integration. Awareness of these opportunities is growing, and LTER's recent Integrative Science for Society and Environment (ISSE) plan highlights several strategic multidisciplinary research questions and also emphasizes the urgent need to improve collaboration and synthesis. This LTER document further draws attention to key environmental science data gaps bridging the social and natural sciences and underscores the importance of conducting environmental research at increasingly larger scale and over longer time frames to address emerging socio-ecological challenges.

The NSF EOs offer the promise of exactly this type of large-scale, long-term environmental research. For example, the WATERS Network plan states that, "The WATERS Network will be an integrated, real-time, distributed observing system that seeks to address deficiencies in our current scientific understanding of the dynamics and spatial variability of water processes by developing a collaborative scientific exploration and engineering analysis network."[4] The NEON Integrated Science and Education Plan (ISEP) expresses similar support for multidisciplinary research in its mission and research agenda.

These EOs have the chance to "leap-frog" LTER scientists' experiences to reach new levels of integrated research. To this end, it is encouraging that NSF has expanded its programmatic support for multidisciplinary research in recent years and that the observatories point to NSF's efforts and suggest additional opportunities for collaborative research. In the case of WATERS, observatory leaders have made important strides toward incorporating social scientists into committees and the early stages of planning document preparation; however, there is still much that needs to be done to avoid having the observatories largely centered on natural science research needs. In particular, a key aspect of designing an EO is performing prototype infrastructure and research development at test-bed locations.

Of the existing NSF-funded EO test-bed projects, there are very limited cases in which social science research has been integrated with natural science research. For example, one

[4] http://watersnet.org/about.html (accessed July 24, 2007).

funded WATERS test-bed project involves observation in Baltimore, alongside an existing LTER site. This LTER site is one of the leading examples of integrated social and natural science research within the LTER Network; however, the proposed WATERS test-bed research is still almost entirely focused on monitoring biogeophysical data.[5] The NEON Integrated Science and Education Plan (ISEP) also acknowledges this gap and states that, "In the past, it has been difficult to assemble the teams and infrastructure to link diverse bodies of [scientific] theory." This is a critical gap that NSF needs to address if social science research is to become a significant component of the EOs.

For these reasons, this paper focuses on the steps required to build collaborations between social and natural scientists and support long-term research partnerships at all of the observatories. This is a two-pronged challenge requiring, first, a clear outline of the research and analytical linkages between social and natural sciences at the EOs and second, a roadmap of the process changes necessary to initiate and sustain research at these disciplinary intersections. Given the broad aims of this effort, this paper targets ongoing developments at NEON, WATERS, and LTER and highlights key lessons learned from past experiences with CLEANER and the CUAHSI Hydrologic Observatories to keep momentum for new integrated multidisciplinary research at all of these observatories moving forward.[6]

Section 2 develops a framework for research integration based on three overarching social science research themes—human activities and behavior, human impacts and responses, and human development and welfare—that connect all eight of the NRC grand challenges. This section expands on the research opportunities identified in the LTER ISSE plan and links the big research questions at the core of integrated observatory research under these larger umbrellas. Section 3 highlights the lessons learned from existing and ongoing efforts to integrate the social and natural sciences through multidirectorate NSF initiatives, such as the CNH program and the Human and Social Dynamics (HSD) priority area, and within the LTER Network. Section 4 presents a worked example of integrated social science planning for a hypothetical CUAHSI hydrologic observatory on the Neuse River to illustrate practical aspects of research integration on large-scale, cross-cutting environmental science problems.

---

[5] See http://www.watersnet.org/wtbs/ for descriptions of all eleven WATERS test-bed sites and projects (accessed September 10, 2007).

[6] As of this writing, the plan for incorporating social sciences into WATERS has not been finalized. There are concrete steps being taken to develop committees and other processes to help this involvement along.

Section 5 transitions from these research fundamentals to the process elements of collaborative research and frames four key implementation issues as both drivers and potential barriers to effective social science integration: organization, funding, infrastructure, and data. Finally, Sections 6 and 7 build on these key research and implementation issues and lay out a set of recommendations and a programmatic agenda for initiating and sustaining social science research that complements the current biophysical science research at each observatory. Because of the breadth of topics covered in this paper, each section focuses directly on the problem of integration and we refer extensively to the LTER ISSE plan, the NEON ISEP, and the WATERS plan for their detailed descriptions of the research advances possible through large-scale observation and their implications for core theoretical developments in different disciplines.

2. The Grand Challenges and Motivation for Multidisciplinary Research

In 1999, the NSF asked the NRC "to determine the most important research challenges [grand challenges] within the environmental sciences, that is, areas of opportunity in which a concerted investment in science could yield new understanding."[7] In response to this question, the NRC committee outlined several criteria for what defined a grand challenge, including a high probability of "scientific novelty and excitement, likelihood of a large practical payoff, feasibility, timeliness, and magnitude."[8] The eight grand challenges that emerged from NRC's assessment include the following:

- Biogeochemical cycles: improve understanding of the Earth's major biogeochemical cycles, evaluate human perturbations, and determine strategies for stabilization
- Biological diversity and ecosystem functioning: further understanding of factors affecting biological diversity and ecosystem structure (including human activity) and develop tools for managing habitats within CNH systems
- Climate variability: increase ability to model and predict climate variations and their impacts on both humans and ecosystems over time

[7] NRC, note 1 above, p. 9.

[8] NRC, note 1 above, p. 60.

- Hydrologic forecasting: develop better characterizations of stresses on aquatic ecosystems (e.g., floods, droughts, sedimentation, contamination) and improve predictions of changes in freshwater resources and their potential impacts
- Infectious disease and the environment: better understand ecological and evolutionary aspects of infectious disease to address threats to plant, animal, and human health
- Institutions and resource use: evaluate drivers of human use of natural resources, such as markets, regulations, and treaties on resource extraction, and waste disposal
- Land-use dynamics: develop systematic understanding of land-use and land-cover changes critical to ecosystem functioning and services and human welfare
- Reinventing the use of materials: quantitatively characterize global budgets and cycles of widely used materials, their life cycles (from raw material through disposal) and environmental impacts, and possible new management strategies

All eight challenges highlight to varying degrees the interactions between human and natural systems and focus on advancing basic understanding of ecosystem dynamics and their human dimensions. As a result, addressing the fundamental research questions underpinning these challenges requires input from anthropology, economics, geography, law, political science, psychology, sociology, and a host of other social science fields.

Although the importance and potential benefits of multidisciplinary research are clearly acknowledged by the NRC and are gaining recognition more broadly, the social sciences are often treated as implicit, rather than explicit, components of such large environmental science research problems. In part this is because environmental science research efforts are frequently highly quantitative, and many aspects of the social sciences are not easily quantified or modeled alongside ecological drivers. Assumptions and constraints implicitly built into long-standing modeling frameworks limit how social science data can be incrementally integrated into analyses. For example, modeling assumptions used by ecologists to understand ecosystem characteristics, such as insect population growth, can constrain how results from integrated models can be interpreted or extrapolated to inform our understanding of related human population dynamics.[9] Fragmented or "end-of-pipe" adjustments to these models can easily result in conclusions that miss underlying social dynamics, such as gender differences in access

[9] Personal communications with CNH PIs, July 5, 2007.

to household fuel and water resources. These barriers are further complicated by the fact that the fundamental social science research questions within the environmental sciences have yet to be as clearly defined as those within the biophysical sciences.

To bridge this gap, we identify three main areas of environmental science and observatory research where the social sciences can potentially make the greatest contributions: 1) human activities and behavior, 2) human impacts and responses, and 3) human welfare and development. These fundamental research themes run through all eight of the NRC grand challenges and provide a basic structure for the big social science research questions, lay the groundwork for anticipating possible theoretical advances in the social sciences as a result of environmental observation, and establish a framework for the types of data and information that social scientists can contribute to the EOs. In turn, natural sciences data from the observatories can also broadly inform social scientists' understanding of these research areas.

It is essential to note here that breakthroughs in social science theories made possible through the observatories are not limited to basic scientific inquiries but can also stem from applied concerns at the intersection of several disciplines. In his book *Pasteur's Quadrant: Basic Science and Technological Innovation*, Donald Stokes traces the historical roots and current roles of "use-inspired basic research."[10] These opportunities are particularly important in multidisciplinary collaborations, where core theories and methods from one discipline can be extended to address applied problems at the interface of other disciplines, and conversely, fundamental research in any discipline can be motivated by applied concerns at the intersection of many disciplines.[11] We see these synergies between basic and applied research and emerging opportunities for new "use-inspired basic research" as important motivations for broad collaborations.

Although this formulation is counter to typical research problem design, where questions associated with advances in theory have traditionally been defined from disciplinary perspectives, it also highlights the great strength of the observatories to support research linking multiple disciplines. It is at these intersections where successful integration can lead to

---

[10] Stokes (1997) further emphasizes that: "The belief that the goals of understanding and use are inherently in conflict, and that the categories of basic and applied research are necessarily separate, is itself in tension with the actual experience of science. Although a great deal of research is wholly guided by one or the other goals of understanding and use, some studies of great importance show that the successive choices of research are influenced by both these goals" (p. 12).

[11] Baddeley A. (1979). "Applied Cognitive and Cognitive Applied Research," in L.G. Nilsson, ed., *Perspectives on Memory Research.* Hillsdale, NJ: Lawrence Erlbaum Associates.

new insights that then trickle back to the cores of different disciplines or alternatively give rise to entirely new fields, such as the development of risk and hazards research, which ultimately led to the Social, Behavioral, and Economic (SBE) Decision, Risk, and Management Sciences program at NSF.[12] As a collection of highly networked sites, the observatories have the potential to support a wide variety of basic social science research topics around these linkages, but in all cases, defining a common social science research agenda will require systematic social science input into how passive and active flows of environmental information are monitored; how the cognitive, perceptual, and behavioral influences on humans within CNH systems are defined; and how resulting ecosystem impacts and dynamics of changing management practices are evaluated.

The observatories have the potential to address these integrative issues by generating better environmental science data at larger scales and over longer time frames than ever before. The LTER Integrative Science for Society and Environment (ISSE) document, the NEON ISEP, and the NSF CNH program all highlight areas where such data could support groundbreaking new research, including studies on vulnerability and resilience of humans and ecosystems to abrupt and long-term environmental changes, group decisionmaking under uncertainty, and ecosystem service provision, among others. The next sections individually discuss the three main social science research themes outlined here to highlight these integrative opportunities and connections.

2.1. Human Activities and Behavior

Human-dominated ecosystems around the world are increasingly recognized as critical areas for environmental science research. These regions, where human activities and behaviors both depend on significant natural resource use/extraction and also drive larger ecosystem changes, provide opportunities to observe the cyclic feedback loops within CNH systems. For example, groundwater availability could drive local irrigation practices and regional agricultural patterns, which in turn could change the rate of groundwater recharge. To this end, social, economic, and perceptual data are essential to understanding environmental influences on key human activities and behaviors and their resulting ecosystem impacts.

Such data, when obtained in concert with natural science data, have the potential to fill major gaps in environmental science knowledge and eventually lead to broader impacts on resource management and environmental policy. One specific example of these relationships is

[12] Personal communication with Billie Turner. June 27, 2007.

an ongoing CNH project that uses new Geographic Information Systems (GIS) science and methods to examine the dynamics of land-use and land-cover change. This project has focused on generating a better understanding of the social and physical drivers of deforestation, and in this process has contributed to the emerging study of ecosystem services as it relates to core theories in geography, economics, and related disciplines.[13]

In a similar manner, the breadth and depth of data collected through the EOs are anticipated to allow for major breakthroughs in both basic and applied sciences. By incorporating data on human cognition, attitudes, perceptions, values, and beliefs, the observatories can support a broad range of research with the potential for discovery of new concepts and phenomena in multiple fields of social and biophysical science. An example of this type of research opportunity is the study of human and ecosystem vulnerability to extreme weather events and climate variability that can then inform responses to flood, drought, storms, and other disasters. Specific research questions under this theme, adapted from the LTER ISSE plan and NEON ISEP, include:[14]

- How do changes in vital ecosystem services feed back to alter human behavior?
- Which human actions influence the frequency, magnitude, or form of disturbances across ecosystems, and what determines these human actions?
- How will ecosystems and their components respond to changes in natural- and human-induced drivers such as climate, land use, and invasive species across a range of spatial and temporal scales? What is the pace and pattern of responses?

Other integrated analyses on vulnerability could also provide longer-term policy contributions to, for example, invasive species management by characterizing transportation corridor, human movement, climate change, and land-use drivers of species invasions, all of which are research priorities at NEON. Possible social science activities in support of this research could include household surveys and focus group interviews on individuals' and groups' perceptions of various local invasive species, evaluations of their awareness of related existing or emerging infectious disease threats, such as Lyme disease, and studies of activities or behaviors that could contribute to the spread of invasives or influence exposure to diseases.

---

[13] Personal communication with Tom Baerwald and Billie Turner regarding CNH award #0410016. July 27, 2007.

[14] Collins, Scott L., et al. 2007. Integrative Science for Society and Environment (ISSE): A Strategic Research Plan. Developed Research Initiatives Subcommittee of the LTER Planning Process Conference Committee and the Cyberinfrastructure Core Team. LTER. p. 12. NEON. October 23, 2006. Integrated Science and Education Plan (ISEP) for the National Ecological Observatory Network (NEON). http://neoninc.org/milestones/2006/isep.html (accessed September 10, 2007). p. 14.

Similarly, at WATERS sites social scientists can elicit individual, household, and community water use practices and preferences to evaluate human impacts on hydrologic systems.

The potential for theoretical advances as a result of improved data collection over larger areas and longer time frames is enormous. In the long term the integrated EO projects that carefully incorporate human behaviors and activities into their analyses could impact a wide variety of broader efforts, such as informing policy makers about resource allocation; structures of markets and transactions; and public health, environmental management, and conservation issues across the United States.

2.2. Human Impacts and Responses

Just as human activities and behaviors are affected by and influence resource availability and quality at any given time, changes in ecosystems can similarly drive impacts on human and dynamic responses. As a result, social scientists must play a central role in evaluating and predicting social, political, and economic impacts of and responses to environmental change. To this end, this second social science research theme highlights feedbacks between ecosystem change and the human dimensions of environmental systems. Possible research topics under this umbrella include the following:[15]

- How do people come to understand ecological systems? How does this influence their attitudes toward their environment and the ecosystem benefits they derive?
- How can cost–benefit analysis of key ecosystem services (water supply, flood control, aesthetics, recreation, etc.) and their trade-offs determine the politics of environmental decisionmaking?
- How do the internal responses and feedbacks of biogeochemistry, biodiversity, hydroecology, and biotic structure and function interact with changes in climate, land use, and invasive species? And, how do these feedbacks vary with ecological context and spatial and temporal scales?

Basic social science environmental observation under this theme could include surveys to understand how changes in the timing, quality, and amount of water available in different areas could drive different responses and impacts on recreation, consumption, and conservation, among other behaviors. These data, in turn, could support analyses on the

[15] NEON, 2006. pp. 14 and 78. LTER ISSE. 2007. p. 26.

resilience of natural and man-made systems to major water resource changes and inform impact assessments and interventions, such as identification and protection of critical species in a watershed.

In this vein, an example of an ongoing research effort funded by the CNH program is a project that focuses on jointly characterizing road and river systems and their underlying drivers. By evaluating both transport and water pathways as critical networked systems, this project draws attention to the similarities and differences between natural and man-made networks and characterizes the potential impacts of their intersections.[16] Just as this project links the analysis of human and natural systems in multiple ways, the observatories provide opportunities to improve natural science inputs into social science analyses of human impacts and responses and vice versa, informing core theories in both types of disciplines.

For example, data collection at NEON sites on changes in land use and land cover could inform studies on the adaptive capacity of communities and ecosystems to stresses, such as hurricanes, which in turn could support risk and hazards research related to short-term evacuation plans, allocation of relief efforts, and development and ecosystem restoration alternatives in at-risk areas in the long term. Similarly, observatory-supported social scientists within the WATERS Network could develop predictive models of behaviors to avoid drinking contaminated water and evaluate responses to various measures to improve drinking water quality. Social science contributions to this type of data collection would require observatory support for integrated modeling, including siting of monitors and sensors to collect relevant types, frequencies, and locations of social science data to allow for improved analysis of possible impacts on "services that are not evident in common economic measures—such as protection of open space and wildlife habitat."[17]

2.3. Human Welfare and Development

The final social science research theme put forward here as a link across EOs stems from the central role of natural resources in human welfare and development over the long term. Researchers, particularly environmental scientists, face significant pressures to be more outcome-oriented and to demonstrate practical results in the near term. To this end, both social and natural science research efforts with explicit attention to improving human welfare and

[16] Personal communication with Tom Baerwald regarding John Loomis, PI, award # 0308414. July 27, 2007.

[17] WATERS Network Project Office Physical Science and Engineering Committee. 2006. WATERS: A Summary of the Grand Challenges It Seeks to Address. Arlington, VA: CLEANER Project Office, p. 13.

development have gained increasing attention and priority. One such area of both social and natural science research is the study of ecosystem services. This topic is currently not covered by any single observatory, but it is an implicit social science theme within both the NEON and WATERS research plans, bringing together aspects of the health and productivity of land, aquatic, and marine systems; population livelihoods; and measures to judge individual and institutional resource use and related management activities.

As one workshop participant described it, "There is an opportunity right now to build a model for social science data as it relates to ecological data. The alternative [waiting until after agendas are set] is to see every social scientist inventing their own wheel; creating data sets which are often incompatible." As a result, it is important for social scientists to participate in agenda setting and decisionmaking to assess if and to what extent planned monitoring and sensing activities correspond to existing socioeconomic database, indices, and measures of human development and welfare. Relevant research questions defined in the ISSE plan and ISEP range across the following:[18]

- How does intensive management (e.g., introduced species, subsidized resources, pest and fire protection) interact with [and] affect biotic structure and ecosystem function?
- What are the indirect effects of intentional management (e.g., introduced species and accelerated decomposition and biomass removal) on plant, microbial, insect, and vertebrate populations and the ecosystem functions that they mediate?
- How do social, structural, institutional, and economic factors affect human decisions about ecosystem management?

As a specific social science example, effective human adaptation to climate change in the near- and long-term depends heavily on existing governance structures and institutions to manage resource scarcity, mitigate extreme impacts, and make social, political, and economic transitions in vulnerable communities. Social science data collection to this end could support evaluations of incremental changes in local livelihoods up to large-scale studies of changes in social networks resulting from major population resettlements. In all cases, clear assessments of local governance systems for environmental planning and decisionmaking are critical.

[18] Collins et al., 2007. p. 26.

One project that relates to this particular theme is a CNH study focused on characterizing the magnitude and nature of the interaction between land use and climate change at regional and local scales. While the goal of the project is to develop a series of climate–land system feedback experiments identifying the magnitude and nature of interactions between land and climate dynamics, the experiment design is simultaneously intended to strengthen and explicitly address the integration of biocomplexity theory and complex system modeling by characterizing feedbacks, thresholds, uncertainty, and nonlinearity in fundamental climatic, ecological, and socioeconomic processes.[19]

2.4. Summary

Taken together, all three of the social science themes discussed in this section are embedded in ongoing observatory planning discussions; however, the research topics and questions outlined explicitly here and in the LTER ISSE plan, the NEON ISEP, and the WATERS plan have yet to translate into the diffusion of multidisciplinary research within and across observatories. Currently, multidisciplinary research and integration are being nurtured at a much broader level within the EOs. For example, WATERS committees are working toward integrating their findings with previous CUAHSI reports into three major documents—the conceptual design, the ISEP, and the networking and informatics document—that will go forward to the conceptual design review.

It is at these stages of early research formulation and agenda setting that incorporating social science research questions is critical. Moving forward, during the fall and winter of 2007, WATERS aspires to bring in other social science researchers to review documents and provide comments to ensure that a broad perspective of social science views are represented in them.[20] These efforts being made at WATERS suggest that exciting new research questions alone are insufficient to motivate significant and sustained collaborations at the scale required for integrated research at the observatories, and significant planning is also necessary.

Because many environmental science research efforts focus first on advances in areas of incomplete natural scientific knowledge, it is less widely recognized that these natural systems exist within social, economic, and political contexts that are also poorly understood.[21] The social science themes here are intended to complement the research opportunities and needs

---

[19] Personal communications with CNH PIs. June 2007.

[20] Personal communications with Barbara Minsker and Jami Montgomery. WATERS. July 27, 2007.

[21] WATERS Network Project Office Physical Science and Engineering Committee. 2006.

identified by LTER, NEON, and WATERS and address the shortcomings of the current state of integration in defining basic social science research questions in parallel to natural science drivers of observatory data collection. The next sections build on the experiences of other cross-cutting environmental science programs to outline the process issues that must be addressed to effectively support integrated social and natural science observation in the long term.

3. Cross-Cutting Environmental Research Programs

NSF has in recent years expressed a serious commitment to supporting new multidirectorate research. This commitment has led to the integration of the social and natural sciences to answer broad environmental science research questions in both long-standing initiatives and new, cross-cutting programs. This section presents three important programmatic examples of multidisciplinary research and integration: the CNH program, the NSF HSD priority area, and LTER Network integrative activities. These three efforts demonstrate very different approaches to integration that provide valuable context for both the opportunities and challenges facing NSF EOs. We highlight best practices and experiences, lessons learned, and future prospects for multidisciplinary research at all of the environmental observatories.

3.1. Coupled Natural–Human (CNH) Systems

The CNH program at NSF is an important model for integrated research at the EOs. Formerly funded as a Biocomplexity special solicitation, CNH was established as a standing multidirectorate (Biological Sciences [BIO], Geosciences [GEO], and SBE) program in January 2007. With committed funding from the three directorates, this program is a significant investment by NSF in new interdisciplinary research equally focused on the social and natural sciences. This program's guidelines clearly state that the focus of awards is on balanced analysis of "the complex interactions among human and natural systems at diverse scales."[22]

Exemplary CNH proposals, like those referenced in the previous section, are those that successfully couple social and natural science methods and tools and go beyond a simple linear approach to capture and evaluate a full set of dynamic feedback loops. For example, an ongoing CNH project focused on modeling land use in the Puget Sound region examines the dynamic

[22] CNH program synopsis: http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13681&fom=fund

linkages between songbird populations and housing preferences.[23] Analyses and results have made contributions to basic theory and knowledge of song bird populations and diversity, in addition to improving land-use modeling to capture the relationships between social and natural science variables ranging from songbird nest predation to local preferences for new residential development. Improved basic understanding within disciplines has led to even broader impacts and resulted in the adoption of the project team's land-use model by local authorities for planning and evaluation purposes.

As part of its approach to soliciting high-quality proposals from balanced research teams, CNH has relied on having clear program guidelines without setting quotas or mandates for the numbers of social or natural scientists from specific disciplines required on a team. To ensure that disciplinary expertise, research advances, and multidisciplinary integration are given weight in proposal review processes, the program has also maintained these same standards for its proposal review panels, which draw evenly from the social and biophysical sciences. In this way, the CNH program acknowledges and works to overcome traditional forces, like promotion and tenure reviews or publication requirements, which often pull researchers back to their own disciplines. On the whole, CNH PIs expressed strong support for the program, and noted that having a program that supports integration as its primary goal has created an important niche for researchers working on a wide range of human–environment issues and provided a stable home for collaborative research more generally.[24]

3.2. Human and Social Dynamics (HSD)

Like CNH, the HSD program is a multidirectorate NSF priority area started in 2003. This program focuses specifically on understanding human and social behavior in the face of dynamic risks, uncertainty, and profound or rapid change. As an NSF-wide effort, HSD has three main characteristics that distinguish it from both CNH and traditional NSF-funded environmental research. First, unlike CNH, HSD program solicitations require that principal investigators represent a minimum of two distinctly different disciplines, and the program more generally encourages even broader collaborations.

Second, scientists on HSD proposal teams come primarily from the social sciences. To date, the SBE Directorate has funded 80 percent of the total grants awarded through this program, allowing social scientists to take leadership roles on teams that include natural

[23] Tom Baerwald, personal communication regarding Marina Alberti, PI, CNH Award #0120024. July 27, 2007.

[24] Personal communications with CNH PIs. June 2007.

scientists in traditional natural science research domains.[25] The balance between team members remains project specific, and there is no "right answer" according to the program guidelines. In many cases social scientists bring together and lead HSD teams that include, but are not dominated by, natural scientists. This is atypical in the environmental sciences. In most cases, it is incumbent on natural science researchers to select and lead multidisciplinary teams. HSD PIs noted this latter approach often resulted in the ad hoc "patching on" of researchers, especially social scientists, without true integration.

Finally, the research supported by the HSD program is in many cases significantly more applied than other NSF-funded research. For example, HSD's Small Grants for Exploratory Research program supports short-term, high-risk research primarily focused on immediate data collection in the aftermath of catastrophic events, such as the 2004 Indian Ocean tsunami and the 2005 Gulf Coast hurricanes. Because HSD projects are typically smaller scale (with less funding and shorter time frames) than CNH projects, these efforts highlight some of the challenges associated with initiating and sustaining project-specific collaborations.

In a 2006 HSD PI meeting, researchers outlined a variety of benefits and barriers to interdisciplinary collaboration. PIs emphasized that although one of the greatest benefits of collaboration is the ability to gain new insights from other disciplines and make the space for both theoretical and applied serendipitous discoveries, these seemingly opportune moments are often the result of extended dialogues and interactions. Informal, ad hoc, and short-term collaborations are unlikely to yield these same benefits.[26] Therefore activities that often stretch project budgets to their limits, such as maintaining close ties with collaborators or colleagues over long distances, impose even greater demands on researchers' time in collaborative projects. In these cases, trust among team members, respect for different methods in other disciplines, and strong communications were emphasized as being even more critical than in cases where close proximity among collaborators allowed for consistent meetings or time was sufficient for the types of long-term relationship-building activities emphasized by PIs of larger CNH projects.[27]

---

[25] This value is based on a search of NSF's downloadable database of HSD awards through fiscal year 2007. The 247 awards included here have start dates ranging from September 1, 2004 to January 1, 2007. Additional funding for the program was provided by the Biological Sciences (BIO), Geosciences (GEO), and Engineering (ENG) Directorates.

[26] NSF HSD PI Annual Meeting. September 14–15, 2006, Washington, DC. Personal communications with CNH PIs. June 2007.

[27] NSF HSD PI Annual Meeting. September 14–15, 2006, Washington, DC.

3.3. Long Term Ecological Research (LTER) Network

In contrast to both the newer CNH and HSD programs, the LTER Network is a much older and more established effort to help integrate social scientists into ecological research. Established by NSF in 1980, the LTER Network consists of 26 independent research sites, representing diverse locations and ecosystem types, designed to study ecological processes over broad temporal and spatial scales. The LTER Network as a whole includes more than 1,800 researchers and focuses on bringing together scientists through meetings, workshops, and virtual links to take advantage of shared research opportunities while still allowing for site-specific environmental observation.

Unlike CNH and HSD, which bring together multidisciplinary teams at the outset of every project, the teams at LTER sites have historically consisted primarily of natural scientists. As part of its 10- and 20-year reviews, the LTER Network has increasingly acknowledged that its research cannot be fully understood or properly managed through the lens of one discipline—or along the lines of traditional domains.[28] In response to these reviews, LTER took steps to integrate social sciences within its programs as early as 1988. In spite of the long history of these efforts, the majority of social science research to date has occurred at only 4 of the 26 LTER sites, and social scientists have yet to be systematically included more widely in site research and network activities.[29] Moreover, in contrast to CNH's success with assembling balanced proposal review teams, LTER reviews have noted problems with proposal evaluations where "although NSF's review process for LTER proposals was considered fair, proposals with long-term, interdisciplinary or network-level goals were not valued as highly as they should have been."[30]

To overcome these barriers, social science representatives from all but three LTER sites met in an August 2005 workshop in Athens, Georgia, funded by NSF's SBE Directorate, to discuss the current status and role of social science and make recommendations for the future of social science within LTER. Workshop participants examined how social scientists could make

---

[28] LTER. 2003. LTER 2000–2010: A Decade of Synthesis. Albuquerque, New Mexico: LTER Network Office. http://intranet.lternet.edu/archives/documents/reports/lter_2010/lter_2010_GRS.html (accessed October 16, 2006).
[29] Gragson et al. (2004) identified that 8 out of 19 LTER sites had at least one social scientist directly involved in site-level research (8 have none), but the maximum representation of the social sciences at a single site was still only 20 scientists. This contrasts to the large numbers of natural scientists at most sites, where social scientists are outnumbered 6:1 at the most-integrated site to a high of 20:1 at the least-integrated site. Gragson, Ted L., J. Morgan Grove, and Dan Childers. 2004. *Engaging the Social Sciences to LTER Network-Level Science & Synthesis.* Albuquerque, New Mexico: LTER Network Office. http://caplter.asu.edu/docs/crosssite/Athens_Workshop_Final_Report-Sept_05.pdf (accessed December 21, 2006).
[30] LTER, note 28 above, p. 9.

the shift from their current isolated roles on committees to an established and integrated community within the LTER Network.

The workshop exposed some of the barriers, actual and perceived, to social science research within the LTER Network, including organizational barriers, funding limitations, lack of cross-disciplinary communication and understanding, inadequate time to build collaborations and engage in dialogue, and the absence of knowledge among social scientists outside the Network about the research at different sites. Most significantly, this conference illuminated the fact that there was no "official means by which social scientists at any LTER site can determine who is active at other sites or what the object of their research is."[31] The recommendations from this conference and related NSF workshops to encourage cross-site projects have since led to the development of six new integrative projects to study transitional agrarian landscapes using a multidisciplinary cross-scale approach and to improve collaboration between different sites.[32]

Now in its third decade, the LTER Network is embarking on "a decade of synthesis" and the enthusiastic reception of the ISSE plan by the LTER National Advisory Board reflects the Network's success in supporting more collaborative research.[33] At a larger scale, it is encouraging that LTER's strategic plan also clearly states the Network's intention to participate fully in the community of observatories, alongside NEON and WATERS, to "ensure integration across sites, time and disciplines." However, the fact that this level of integration has evolved over nearly 30 years suggests that without a systematic process to establish and maintain a critical mass of social scientists, significant integration is unlikely to occur quickly or organically. The next section highlights these and other lessons learned for multidisciplinary research at the observatory level.

---

[31] Gragson et al., note 29 above, p. 9.

[32] Redman, C., J.M. Grove, and L.H. Kuby. 2004. Integrating Social Science into the Long-Term Ecological Research (LTER) Network: Social Dimensions of Ecological Change and Ecological Dimensions of Social Change. *Ecosystems* 7: 161-171.Gragson et al., note 29 above.

[33] LTER National Advisory Board. Report of the National Advisory Board, National Advisory Board Meeting. March 8–9 2007, Arlington, Virginia. http://intranet.lternet.edu/modules.php?name=UpDownload&req=viewsdownload&sid=13 (accessed September 13, 2007).

3.4. Lessons Learned from CNH, HSD, and LTER

Although CNH, HSD, and LTER are all widely regarded as important models for social and natural science integration, both social and natural scientists within these programs have identified several barriers to collaborations and opportunities for improvement. From various meetings and reports on all of these programs, there are four major institutional obstacles to integration: 1) organizational barriers, 2) funding constraints, 3) infrastructure limitations, and 4) data coordination and management issues. This section describes and highlights the potential pitfalls for observatory integration associated with each of these larger issues, recognizing the progress that has been made while focusing on opportunities for improved integration. Outlined below are several key lessons for initiating and sustaining multidisciplinary, collaborative research. Together these lessons are intended to provide a constructive base from which to address problems with integration early in observatory planning and decisionmaking.

1. Enthusiasm for collaboration is necessary but insufficient on its own. According to the LTER ISSE, "Scientists have repeatedly called for more opportunities for collaborative research between the ecological, geological, and social sciences (Grimm et al. 2000; Palmer et al. 2004; Robertson et al. 2004; Newell et al. 2005; Pickett et al. 2005; Kremen and Ostfeld 2005; Balmford and Bond 2005; Farber et al. 2006; Haberl et al. 2006)."[34] In spite of the broad interest in integrated research expressed by numerous social and natural scientists within the larger environmental science community, multidisciplinary collaborations remain difficult to initiate and sustain. This suggests that substantive interactions among the social scientists and the biological, physical, and information scientists who are currently leading the NSF observatories will take significant institutional support and coordinated investment to grow and move beyond existing barriers to integration, especially as participation in the observatories broadens.

2. Achieving a critical mass of different disciplines requires clear incentives. The relatively low numbers of social scientists currently involved in the early planning phases of the observatories indicate that all EOs could face the same problems with inclusion and representativeness that the LTER Network did prior to its commitment to significantly expand support for social science and collaborative research. Reasons for the lack of long-term effective integration are numerous and can range from funding and time limitations to communication problems.[35] It is important to note that achieving critical mass or representation from different disciplines within

---

[34] Collins et al., 2007. p. 11.

[35] See, for example: Schutz, A. 1954. Concept and Theory Formation in the Social Sciences. *Journal of Philosophy* 51(9): 257–273.

individual projects may not be sufficient when aggregated to the program or observatory level. Therefore, it is necessary to pay careful attention to incentives for having diverse expertise on large research teams to motivate participation at multiple levels (see Appendix A).

3. Short-term collaborations are unlikely to yield long-term partnerships. In the case of CNH, many of the projects supported by large awards through the program involve teams with long histories of collaboration and experience with leveraging funds from a wide variety of sources. This suggests that a start-from-scratch approach to integrated observatory research or even project-by-project collaborations could meet with limited success. On the other hand, building on existing teams could present new opportunities for broad collaboration at the outset of observatory research and simultaneously support the education and integration of the next generation of collaborators and colleagues.

4. Multidisciplinary research is time consuming, requiring implicit training in new fields. As one CNH PI pointed out, a fundamental prerequisite for effective collaboration is "developing a set of science questions or objectives that are interesting to [multiple] disciplines." Developing questions (like those in Section 2) requires both flexibility and learning on the parts of all collaborators to sustain effective communication among members of large and diverse research teams. On the other hand, it is also important to acknowledge that even though well-defined integrated research questions can motivate multidisciplinary collaborations, there are also hosts of countervailing forces pulling team members back to their own disciplines that must consistently be addressed for any collaboration to remain effective in the long term.

5. Collaborations need to be assigned value in proposal review processes. As the experiences from CNH, HSD, and LTER highlight, proposal reviews are a critical part of integrated research efforts. Ensuring that awards are sufficient to cover the novel and discipline-reshaping subjects and approaches at the overlap of multiple disciplines requires explicit acknowledgement of the risks and rewards associated with interdisciplinary research. Along these lines, building on the CNH experience with joint and integrated review of proposals could help to avoid having collaborative projects funded in fragments, where a natural science component is funded while the complementary social science component goes unfunded, or vice versa.

6. Collaborators need to be involved early and often in large-scale decisions. Engaging diverse groups of researchers in large-scale program decisionmaking requires early involvement and continued dialogues. Timing, proximity, and continuity are especially important when considering the scale and scope of observatory decisionmaking. Accommodating the needs of multiple disciplines, projects, and teams requires trade-offs, and these trade-offs are critical, for example, when making long-term infrastructure siting or data-collection decisions. Data needs (and therefore infrastructure needs) can vary greatly even among collaborators from similar disciplines, and these differences are only likely to be magnified as teams become more diverse. At the observatory level this suggests that getting sufficiently broad and representative input into large-scale planning and research agenda-setting decisions will require disciplinary diversity in the observatory leadership. Furthermore, as trade-offs and compromises are made in observatory budget negotiations, leaders will need to prioritize funds for collaboration and key infrastructure and data programs to avoid fragmentation of interdisciplinary projects and patchworks of small-scale collaborations that are unlikely to survive beyond specific projects.

7. Institutional changes can lead to major breakthroughs in integration. Despite all the barriers to integration outlined here, there are causes for optimism. In a 2004 evaluation of the social sciences within the LTER program, Gragson and colleagues note that changing existing organizational structures, such as improving access to funding opportunities, can significantly improve communication and coordination between social and natural scientists.[36] Drawing attention to a successful natural science funding pool within NSF's Research Coordination Network program, they point to funds directed specifically at biologists to support outreach among different teams of biologists and bridge geographical and institutional boundaries as a model for groups of social scientists or multidisciplinary teams with similar needs.

8. Integrated research requires continued support and engagement to thrive. The overarching lessons learned from CNH, HSD, and the LTER experiences to date are that multidisciplinary collaboration takes work and cannot be expected to thrive without the continued support and engagement of participating researchers, their host institutions, and funding agencies. As Granger Morgan, head of the interdisciplinary Engineering and Public Policy department at Carnegie Mellon University, stated in his presentation to workshop participants, "the lessons from the history of U.S. interdisciplinary academic programs is that these programs involve an unstable equilibrium and sustaining them requires continual input of attention and energy." The same can be said for the observatories, and early recognition of this is essential to ensuring sufficient support for future integrated research.

Taken as a whole, the experiences of the CNH, HSD, and LTER programs all illustrate that achieving integration can occur in a variety of ways and there is no silver bullet for starting and sustaining collaborative research. The fact that the LTER Network is still working to

[36] Gragson et al., note 29 above.

prioritize and implement integrated research after nearly three decades of research hints at the complexity of achieving integration at the larger-scale observatories. The next section extrapolates these lessons to the much larger scale of planned observatory research, and discusses several key implementation issues raised by an early CUAHSI effort to develop a prototype observatory on the Neuse River in North Carolina.

4. Neuse River: Observatory Example

Although CNH, HSD, and LTER provide valuable examples of how collaborative research can be initiated and encouraged at the project and program levels, there are even larger challenges associated with integrated decisionmaking at the observatory scale. This section presents the example of the CUAHSI Neuse River Paper prototype observatory, designed prior to the integration of CLEANER and the CUAHSI Hydrologic Observatories into WATERS, to give further context to some of the institutional opportunities and barriers to integrated research and to illustrate the implications of these challenges in practice.[37] Here we seek to place social science issues in perspective within both large-scale environmental observation and the grand challenge research questions to underscore the potential contributions of social scientists to problem framing, research design, data collection, and analysis at all stages of observatory planning and research.

In the early phases of observatory development, CUAHSI, with support from NSF, brought together a team of researchers to develop a hypothetical or paper prototype for a Neuse River hydrologic observatory. The Neuse River, an approximately 200-mile long permanent stream contained entirely within the state of North Carolina, is part of a major watershed where municipal and agricultural wastewater discharge and other human activities have significantly changed water quantity and quality in recent years.[38] The focus of this early CUAHSI Hydrologic Observatory effort was to examine the Neuse estuary as a possible observation site

---

[37] It is important to note that the Neuse Observatory was designed solely as a "paper exercise." The final report was never intended to become a future funding proposal or serve as the basis for an implementation plan. Instead the sole purpose of this exercise was to anticipate and examine issues that might arise in a real-world observatory planning process.

[38] CUAHSI. December 2004. Designing Hydrologic Observatories: A Paper Prototype of the Neuse Watershed. A Report to the Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. by Neuse Prototype Hydrologic Observatory Design. CUAHSI Technical Report No. 6. Washington, DC: CUAHSI. http://www.cuahsi.org/publications/Neuse_Report_final.pdf (accessed October 6, 2006).

and develop this paper prototype to inform the NSF GEO Directorate of what a large-scale observatory would require, look like, and cost over time.

A Neuse River Committee, selected from the membership of various CUAHSI committees, was tasked with developing a report on 1) the critical science questions and hypotheses to be tested, 2) the detailed strategies for making relevant measurements and testing hypotheses, and 3) the budget and implementation requirements of monitoring and data collection in the given study area. The final report from this effort was divided into several sections, with the social science elements represented largely as a separate section. Generally, the goals stated in the natural science pieces of the report were to describe the ecosystem characteristics in the study region, and the goal of the social science segment was to "enhance the ability to characterize the water and land use at each of these different sites."[39] Taken as a whole, the report highlights the detailed substantive and implementation requirements for such large-scale environmental science observation. As a worked example, this effort illustrates where the research goals and needs of natural scientists and social scientists complement one another and where they diverge in practice.

It is important to emphasize here that the scale and breadth of this undertaking were markedly different from current NEON or WATERS proposals.[40] The Neuse sites were designed and developed as large research projects, built incrementally, like LTER sites, and funded primarily by appropriations like the NSF Research and Related Activities (R&RA) Account. In contrast, the capital-intensive NEON and WATERS infrastructure proposals are directed at the NSF Major Research Equipment and Facilities Construction (MREFC) Account.[41] Moreover, the inclusion of social sciences was solely an initiative of CUAHSI, not NSF's GEO Directorate, and there was significant ambiguity around the extent to which the focus was on what social sciences could do *for* hydrologic observation versus what social sciences research (applied or fundamental) could be done *at* hydrologic observatories.[42] Given these differences between the Neuse example and current efforts at NEON and WATERS, the Neuse experience is intended to serve not as a critique of social science involvement in an observatory effort, but as a general illustration of the practical issues associated with integration.

---

39 CUAHSI, note 38 above, p. 59.

40 Personal Communication with Richard Hooper. CUAHSI. July 30, 2007.

41 Further discussion of the NSF MREFC Account is included in Section 5.2 to follow.

42 Personal communication with Richard Hooper. CUAHSI. July 30, 2007.

For the purposes of this discussion on integration, this section focuses on the drivers, linkages, overlaps, and conflicts between natural and social science data needs, specifically:

- What are the natural and social scientists trying to measure? (core data)
- Where? (scope and placement of sensors/arrays)
- How frequently? (timing of measurements from real time to annual)
- To what extent? (compatibility with existing data sources)

The Neuse design team identified six substantive areas of research: 1) river/stream discharge and overland flow; 2) precipitation; 3) energy budgets, evapotranspiration, and land surface–atmosphere exchange; 4) groundwater; 5) groundwater exchange; and 6) water quality. All six of these research areas require some common in situ measurements, remote-sensing data collection, and modeling of "three fundamental hydrologic characteristics of the basin: the flux, flowpath and residence time of water, sediment, nutrients, and contaminants among the atmospheric, surface and subsurface stores of the basin."[43] Beyond these shared measurements, however, the scope, timing, and compatibility of the planned data collection vary significantly.

Based on the six selected research topics, the team's report identified several natural science core data needs, including seasonal and "long-term data on river/stream discharge, precipitation, [evapotranspiration], and other hydrologic fluxes and stores, … model-based water budget calculations, … predictions of flood frequency and extent under future climate and land use scenarios" among others. To gather these data, the team recommended the observatory develop a total of 54 new river/stream gauging sites.

The primary drivers of site selection were *coverage*, *proximity*, *size*, and *specificity*. Using these criteria, the team chose 5 sites that represented upstream and downstream variations across the full watershed; 5 sites at the mouths of the largest tidal streams immediately adjacent to the Neuse estuary; 17 intermediate-sized watershed sites at the outlets or confluence points of each of these smaller zones with the Neuse River; and subsections of intermediate watersheds representing different ecological zones with varying degrees of urbanization at hillslope, plot, field, catchment, and subdivision scales for further disaggregated measurement. The locations of these sites were proposed as complements to existing U.S. Geological Survey monitoring locations to allow for broad spatial and temporal distribution of sensors and arrays.

[43] CUAHSI, note 38 above, p. 70.

Although the site selection criteria above do not explicitly exclude data collection on social science variables (e.g., human activities, behaviors, impacts, and development), it is not apparent from the selected sites whether the criteria were interpreted sufficiently broadly to support key social science research priorities.[44] For example, it is uncertain whether the selected sites could allow for effective comparative analyses of socioeconomic issues, such as variability in water use in rural, suburban, and urban areas; vulnerability or resilience to changes in water quality or availability; or evaluation of the drivers of seasonal changes in agricultural applications of fertilizers. Moreover, the frequency of measurements at each of the 54 proposed sites varied from continuous to highly intermittent depending on the data being gathered, and without more detailed information, it is unclear how the optimal measurement frequencies for natural science data collection might correspond with related social science data-collection needs and relevant historic demographic and socioeconomic databases, such as the U.S. Census.

Because the Neuse River observatory design team included only a single social scientist, when the team divided into subgroups to assemble different sections of the final report, by necessity, the social sciences were represented by a group of one. Although collaboration was supported by the entire team and the dialogue and research decisions involved contributions by all members, in the end, the vision of the way the social sciences might logically fit into the observatories was entirely that of the single participating social scientist. This outcome illustrates the lack of integration that can occur even in a group open to collaboration and inclusive of the social sciences.

Considering this example in context of the observatories, there are several general factors that could lead to limited or ineffective integration. One possibility is that inclusion of social scientists is made a program or project requirement, but there is little interest on the part of social or natural scientists in meaningful engagement with one another. A second is that there is so much ambiguity and debate over what should be done in the natural sciences that there are few incentives or little time to incorporate any significant social science pieces. A third is that any proposed social science components are relatively noncontroversial, fitting well enough with the logic of natural science decisions that they are trusted as complete and representative by the rest of a team, even if they are based on very limited social science input.

---

[44] For the Neuse observatory as a whole, the estimated budget included capital costs of approximately $9.0 million and annual operating costs of approximately $3.8 million for all proposed facilities in the study area. Of this total, the social sciences budget was a single line item in the operating costs section for $104,500 per year. The overall budget was not detailed enough to determine if the social science research topics included in natural science programs could be adequately supported with this amount of funding.

A fourth possible explanation for failed integration is that in a team with limited social science representation no individual feels sufficiently well informed about the social science research elements to challenge or expand on any of the ideas put forward.

These barriers and implementation issues are particularly relevant for the observatories, given that all are currently in the same early stages of research design and planning as the CUAHSI Neuse team was when it assembled its report. Both WATERS and NEON have already made steps to ensure that social scientists are actively engaged and participating in observatory committees. Their early efforts have already begun to overcome many of the problems encountered by the Neuse prototype team, where there was initiative but few incentives for integration, and social science needs and possible contributions were defined by a relatively small group or by a single social scientist, without continuing attention to the issue of social science representation at multiple levels of observatory design and decisionmaking. Despite these early signs of progress, additional measures will be required to maintain and expand the current levels of integration at both WATERS and NEON. The issues reported by the social scientist on the Neuse team simply encapsulate the difficulties that are likely to emerge if social scientists are "patched on" to future observatory research projects and agenda-setting processes.

This example highlights the importance of acknowledging and addressing potential barriers to collaboration and related organizational, financial, and infrastructural issues up front. As Gragson and colleagues emphasize in their review of social sciences within the LTER Network, "Short-term funding does not yield long-term results."[45] Initiating collaboration, like the example of the Neuse prototype, is only one step toward sustaining the type of integrated research required to effectively address the grand challenges. Section 5 builds on these experiences and opportunities to suggest both near- and long-term activities and process changes necessary to support multidisciplinary research at all of the observatories.

5. Framing Integration

The three previous sections focused primarily on the research topics and questions motivating large-scale multidisciplinary integration at the observatories. This section builds on these research opportunities and experiences to outline four key process and implementation considerations—organization, funding, infrastructure, and data—that support effective

---

[45] Gragson et al., note 29 above, p. 1.

environmental science integration at the observatories. Together these four issues (drawn from the lessons learned in Section 3.4) are at the core of how integrated research can be institutionally initiated and sustained. While each observatory ultimately has it own agenda for implementation, because of their common mission to "foster experimentation and observation on spatial and temporal scales that were previously constrained by technological and/or organizational limitations," NEON and WATERS share several early planning activities.

The scope of these activities and the common use of cyberinfrastructure to link sites and researchers, in theory, allow for significant inclusion of social scientists in all phases of implementation from facilities siting to data collection and data management.[46] The next sections individually address these four issues and highlight both the promises and pitfalls of different observatory structures as they relate to the integration of the social sciences. These discussions are not intended to be exhaustive. Instead they are put forward here to lay the groundwork for integrated research. Each section touches on key issues raised by the CNH, HSD, LTER, and Neuse experiences and highlights the pros and cons of various organizational models, funding vehicles, infrastructure requirements, and data systems for sustained observatory collaboration.

5.1. Organization

The EOs provide new opportunities to centralize long-term, large-scale environmental data for general use. Although data of this magnitude and scale is likely to be compiled centrally for final dissemination, the early collection and management of EO data within and between EOs can occur under a wide variety of organizational arrangements from highly decentralized to highly centralized. Therefore, a key organizational question for all of the observatories is: which organizational model—centralized, decentralized, or hybrid—allows for the best integration of social and natural scientists into planned observatory research?

Currently, both WATERS and NEON have largely centralized structures, supported by a main project office and organized around committees selected to manage different aspects of research and implementation. In contrast, the LTER Network has long been an example of decentralized observation, historically based on site-specific research loosely linked at the network level. As its research priorities have shifted toward greater collaboration and synthesis,

---

[46] See Piasecki, M. et al. (2004) for more information on different types of cyberinfrastructure and their potential applications, such as the use of cybercollaboratories or virtual communication environments, to enable network-level observation and test-bed research.

LTER has correspondingly moved toward a hybrid structure with more centralized authority and network-wide coordination to balance traditional site-level–research priority setting. Currently, individual LTER sites (projects) now have less autonomy than they did in the past with the focus shifting toward network mandates, clustering of sites (projects) with common activities, and more formal encouragement of cross-site synthesis activities.

LTER's transformation suggests that organizational systems at other observatories are also unlikely to remain static or based on any one model. Although both NEON and WATERS currently have highly centralized decisionmaking structures, as site-level activity gets underway, organizational decisions at both observatories will necessarily evolve. As a result, how the organization of research and decisionmaking are anticipated to evolve under different models has especially critical implications for integration. There is no single system—centralized, decentralized, or hybrid—that is always best for the integration of social scientists and natural scientists into observatory-level research.

Because the observatories are likely to support larger numbers of natural scientists even if social scientists are effectively integrated into the observatories, it is important in all of these models that observatory leaders clearly define what qualifies as a critical mass of scientists from different disciplines to decide how collaborative teams can best be developed, supported, and distributed across committees, sites, and programs to sustain integrated research projects at different phases. To date efforts on the part of social scientists to participate in EO activities and outreach on the part of natural scientists to include selected social scientists have been largely ad hoc. Organizationally, it is important to establish systems to make opportunities for collaboration more visible, frequent, and accessible to interested collaborators from different disciplines. Supporting natural scientists who reach out and engage in collaborations could simultaneously allow social scientists who have taken the initiative to make greater inroads within observatory committees, programs, projects, and teams.

There are several drivers of observatory organization, including size, number of sites, number of researchers, committee structure, and leadership, among others. In the case of the Neuse prototype, as discussed in Section 4, the observatory study area was estimated to be approximately two to four times as large as a typical LTER research site. As a result, measurements were divided up across "nested" watershed facilities specifically designed to allow for independent research and analysis at each monitoring site, and later dissemination of data and communication of results to other sites.

The highly site-specific Neuse approach appears to have been driven by the scale of the study area, not a deliberate decision to move to a decentralized organizational model. However, without corresponding attention to how social science data could be gathered and analyzed across sites under this structure, this shift could create new barriers to integration. Therefore, an overarching organizational issue for effective collaboration is the diffusion and representation of social science expertise within and across sites and the aggregation of relevant data from each site to allow for independent or centralized social science research and analysis.

From a social science perspective, the advantage of a centralized social science project office is that social scientists could work collectively at a common location and choose to participate in various aspects of site-level research on an intermittent basis. A disadvantage of this approach is that social scientists are less likely to be involved in site-level decisionmaking on infrastructure siting or data collection. In contrast, under a decentralized system, social scientists could be embedded at each site and actively participate in project teams and in field data collection and research, but interaction between social scientists across sites would only be as effective as the diffuse network linking sites allowed. The third option, the hybrid approach, has the advantage of combining the benefits of both integrated, network-level decisionmaking and extensive, site-specific interaction under the other two models; however, this approach could also require greater coordination and possibly even greater numbers of social scientists to ensure adequate representation at all sites and within a centralized social science office.

The message here is that any of these models can be implemented effectively or ineffectively depending on the amount of time and effort invested in integrative activities. For any of these models to succeed, a fundamental organizational prerequisite is greater encouragement of outreach activities targeted at integration and multidisciplinary collaboration at the observatories generally. One such activity could involve the development of a joint observatory directory of collaborators. HSD researchers noted that identifying effective collaborators was still one of the more difficult tasks in starting new multidisciplinary projects.[47]

Developing a searchable database of social scientists interested in different aspects of environmental science research could allow observatory natural scientists to identify collaborators for multidisciplinary research proposals and projects early in observatory research agenda setting. Moreover, this type of immediate activity could help social scientists within observatory committees and even LTER sites become better informed about the parallel and

[47] NSF HSD PI annual meeting. September 14–15, 2006, Washington, DC.

related social science research ongoing at other locations. This type of advanced online tool could further allow observatory researchers to search for people, datasets, and papers while interactively listing new sources and interested research collaborators.[48] In this way, organizational integrative activities could build on existing cybercollaboratory plans and benefit all observatory researchers by raising the profile and visibility of observatory data and networks. Additional outreach efforts within the observatories and across sites (once established) could include presentations by collaborators at various academic meetings publicizing best practices for collaboration, targeted networking of sites to address regional problems, and data sharing across sites through multidisciplinary PI seminars and workshops.

Overall, these are only a few organizational activities that could occur under all of the models described here. None of these organizational models is perfect, and each approach has its own strengths and weaknesses. The heterogeneity of the LTER sites and the diversity of CNH and HSD project teams provide valuable context for all these systems and highlight the need to prioritize organizational issues early in observatory development to anticipate how different organizational models might evolve and still remain integrated across diverse sites.

5.2. Funding

The second implementation issue for integration at the EOs is funding. Under any organizational model, both social and biophysical scientists within and across NSF observatories will require sustained support and funding to undertake large, complex multidisciplinary projects and take advantage of project economies of scale and scope in parallel to their disciplinary counterparts. CNH, HSD, and LTER PIs all describe problems associated with finding sufficient funding for all components of a multidisciplinary project and coordinating and balancing funds across partner institutions. To quote one workshop participant, "If it is not required, it must be incentivized, otherwise it does not happen."

Incentivizing collaborative research is complex. In many cases, the line between capital costs of social science facilities and project costs is less clear than for natural science facilities. For example, social science data collection on human behaviors and perceptions, in parallel to ecological monitor- and sensor-based measurements, would typically involve the development

---

[48] Workshop participants in the core data session (see Appendixes A and B for summary and slides) suggested that an online research directory could be modeled on the Amazon.com website, which interactively makes suggestions for new books and related materials based on the selections of other website visitors. Having a similar "other people who read this also read…" section of links could help observatories reach broader audiences and bring in new collaborators.

of detailed surveys or interviews at the individual, group, or household levels. Unlike installed monitors and sensors, which are funded under capital investment programs until they are "turned on," at which point any operations and maintenance costs associated with data collection must be covered by research project funds, there is no bright line between when a survey is being developed or "installed" and when it is actually "turned on."

The discussion in the next two subsections illustrates how existing funding vehicles and their programmatic requirements can significantly influence how these differences come into play to affect how and how many social scientists participate in observatory research. These sections focus respectively on two key aspects of observatory funding, capital investments in new facilities and operations and maintenance (O&M) support for data collection and research.

5.2.1. Capital Investments

Capital investments at the observatories are anticipated to be supported by the MREFC Account, a long-standing NSF funding vehicle. MREFC investments enable research by providing infrastructure and/or data-collection equipment, but these funds do not support the actual processes of data collection, analysis, or research.[49] Instead, as one workshop participant stated, "MRE[FC] investment enables science by providing infrastructure (or data), but [it] does not perform the science. That is the role of scientists proposing to use the infrastructure." This account is the primary source of construction funds for large capital projects such as telescope arrays, particle colliders, marine research vessels, and only more recently distributed infrastructures, including the EOs. In the case of the social sciences, examples of potential social science infrastructure at this scale could include remote sensing facilities, human sensing equipment, or spaces such as decision theaters, as discussed in Section 5.3 to follow.

Preparing MREFC proposals is an involved process, spanning several years, and requiring significant support from NSF program officers and Directorates to shepherd proposals through the development and evaluation process and to ensure that future project O&M funds are guaranteed and sufficient to justify the proposed scale of infrastructure development. Given the types of projects funded through the MREFC Account in the past, there has been little involvement of social scientists in MREFC proposals, and there is no precedent for SBE Directorate–supported programs to receive MREFC support.[50] Because the current

---

[49] Personal communication with Richard Hooper. CUAHSI. July 30, 2007.

[50] The same is true of the BIO Directorate, although the BIO Directorate is currently the primary Directorate pursuing MREFC support for the NEON Observatory.

MREFC evaluation criteria are sufficiently broad to support social science facilities and capital-intensive data-collection activities, it is important for social scientists and representatives of SBE to participate in current MREFC proposal development efforts at both the WATERS Network and NEON. This would ensure that social science infrastructure and data needs are included alongside their biophysical science counterparts and that future collaborative research is made possible through early investments.

According to LTER social scientists who are also involved in observatory committees, in the process of defining and prioritizing infrastructure needs for MREFC funding, social science requests have been seen as last in line, especially when natural scientists are unable to meet their core goals with the available funding. Although LTER sites have historically been funded in a more bottom-up manner through the Research and Related Activities Account at NSF (among other sources of funding), social scientists at these sites have identified common funding barriers to the newer, more formal, and more top-down observatory MREFC applications. To overcome some of these barriers within LTER, the Network has developed a funding model that supports facilities and equipment requests within renewable program grants. This model has its benefits, as the security of funding has allowed individual sites to leverage significant amounts of external funding, with nearly $3.50 of outside funds for every $1 of NSF funds, on average, across sites.[51]

Under either the separate MREFC capital-investment model or the joint capital and research LTER–funding model, early social science input is critical. Workshop participants in both the funding and infrastructure breakout sessions stressed the importance of having the SBE Directorate (representing the broader community of environmental social scientists) involved in proposal development and evaluation to ensure balanced participation of social scientists in observatory grant-review panels and proposed multidisciplinary programs (see Appendix A for additional information). The early involvement of a critical mass of social scientists in defining infrastructure requirements and related capital investments at the observatories could also help to overcome barriers to facilities funding and help to set a precedent for social science facilities funded by the MREFC Account.

5.2.2. Operations, Maintenance, and Research Costs

In addition to the capital investments required for observatory-scale data collection and management, there is also the need for ongoing program and project funding commitments. As

[51] Personal communications with LTER researchers. April 20, 2006.

stated above, MREFC funds can support the construction and installation of facilities only up to the point where equipment would be "turned on"; after this point, operating and maintaining these facilities require other sources of support, such as standard NSF research program grants that would also support analysis of any collected data. For the social sciences, the line between installation and operation of data-collection instruments is not always clear. This distinction as it relates to specific types of facilities and equipment is discussed further in the infrastructure subsection to follow; this section focuses on general issues with program and project funding.

There are several possible observatory funding models, including the examples from CNH, HSD, and LTER described in Section 3, that could support both independent social science research and related collaborative or integrative research projects. Alternatives include CNH- or HSD-type awards, separate matching funds to support inclusion of social scientists within larger natural science–funded project proposals, or renewable program grants like those awarded to LTER projects and sites for capital, O&M, and research costs. All of these types of programs could coexist at observatories, and each has its strengths and weaknesses. For example, LTER program grants have the benefit of minimizing internal competition and cross-site competition for funds by structuring research programs around renewable, 6-year funding commitments instead of competitive proposal processes, while CNH awards have a solid track record of funding broad collaborations.

LTER also provides a model for possible new matching fund programs at the observatories. Currently, social scientists at LTER sites also have access to at least one NSF special supplemental fund just to support site-specific social science research. One particularly successful example of how this type of set-aside or matching fund can motivate new research is the LTER Baltimore site. The U.S. Forest Service provides this site with approximately $1 million a year, $300,000 of which goes to social scientists. This dedicated funding has in part contributed to stronger links between social science and multidisciplinary collaborators, strengthened ties between basic and applied work, and allowed social scientists to compete for research support where they would otherwise have had a hard time obtaining sufficient funds.

Building on these integrated research efforts, the NEON ISEP references the project as a possible model for future evaluation and collaboration, stating that "the Baltimore Ecosystem Study LTER is currently working with the City of Baltimore to assess and evaluate the City's efforts to improve the water quality of its storm water runoff [and] address the City's goal to double the area of its tree canopy from 19% to 38% over the next 30 years. NEON's observational network and mobile capacity are a powerful toolkit to test the hypothesis that ecological responses at the local level are correlated to changes in policy or management."[52] Overall, the continuity and stability of LTER project funds in addition to the special set-aside funds for social scientists have helped to move social science integration forward. However, the limited funding available for integrative activities means that core support for the social sciences is still necessary for larger collaborations within and across sites and observatories.

Another model for funding to help address the lack of O&M and project funding for integrative activities is the National Aeronautics and Space Administration's Earth Science program. This program, through its Education and Public Outreach Initiative, requires that all proposals for new satellite infrastructure and data collection identify a partner, such as a museum or exploratorium that would (eventually) use the data collected, and set aside 1 to 2 percent of the total requested project funding to work collaboratively with this partner to reach broader audiences.[53] In the case of the observatories, this type of programmatic requirement and funding could motivate sustained collaborations between teams of social scientists and natural scientists and support integrative activities like workshops, meetings, or other outreach efforts.

5.3. Infrastructure

As the discussion on funding suggests, social scientists share some but not all of the infrastructure needs of natural scientists. A few of the most common infrastructure needs of both social and natural scientists include cyberinfrastructure to support computing and communications, remote sensing equipment, and related mapping tools and supporting facilities. Other types of facilities specific to social environmental science observation and/or the social science components of multidisciplinary research projects include experimental labs, decision theaters, and spaces to support survey and interview development, among others. Additionally, a possible new area of dedicated social science infrastructure could come from the emerging field of "human-sensing."[54] To illustrate some of the problems with defining social science infrastructure needs based on natural science criteria, this section focuses on the similarities and differences between remote-sensing and human-sensing infrastructures.

Human sensing is the science of dynamically monitoring and recording human movements, surrounding environmental characteristics (e.g., temperature, pressure, and

[52] NEON, note 14 above, p. 19.

[53] Personal conversation with Molly Macauley. Resources for the Future. March 8, 2007.

[54] Presentation by Joseph Paradiso, NSF Workshop, Arlington, VA. January 24-25, 2007.

moisture), activities, and interactions (e.g., proximity). The equipment required for this type of observation is typically very small, involving wearable or portable sensors embedded in shoes, pieces of clothing, or handheld objects. A familiar example (and one that appears as part of other more complex human sensors) is a simple GPS device. It is not the size of the equipment itself that makes human sensing equipment a possible social science observation infrastructure comparable to large-scale ecological monitoring networks, but the number of sensors and monitors deployed over large areas for broad-based sensing at the scale of the observatories.

In contrast, remote sensing typically involves large-scale spatial data infrastructure and equipment. This type of infrastructure, shared with natural scientists, has the potential to connect social and natural science information under a common framework, linking human activities, behaviors, impacts, and developments to ecosystem dynamics in a wide variety of environments. The value of remote sensing is that it can provide explicit, extensive, and synoptic spatial views that can be replicated for different areas or time periods.

The potential of this technology to produce robust longitudinal data sets has been demonstrated by the popular and widely used Landsat databases on land cover spanning 1972 to the present. This type of data has broad application in both the social and biophysical sciences, offering a wide range of possibilities for measuring and monitoring key social science–related variables including traffic, outdoor recreation, energy use, and development and urbanization, among a host of other variables. More importantly, the use of common infrastructures, such as GPS and GIS technologies, for geospatial data collection could provide a bridge between social science data and related biophysical science data and help to integrate other less compatible types of data.

The strength of these infrastructures for integrated observation is their broad relevance and adaptability to both social and natural science applications; however, this link is weakened by the fact that these technologies have typically been used far less by social scientists than by natural scientists and engineers. If spatial data are collected with an eye to integration, social scientists need program support to employ shared GIS visualization and analysis tools, such as spatial statistics, mapping, and animation, in tandem with natural scientists to ensure that social science data-collection priorities are not overwhelmed by larger natural science goals. To this end, training and infrastructure development for social scientists in geospatial technology could help foster shared use of this common equipment. The simultaneous convergence and divergence of social and natural science remote–sensing infrastructure needs illustrate the importance of integrated decisionmaking on site selection, monitoring, and data collection.

In contrast to the joint decisionmaking required for shared use of remote-sensing equipment, human-sensing infrastructure use is almost entirely driven by social science needs and expertise. These "facilities" provide the capabilities to permeate our cities, dwellings, objects, and even clothing to facilitate social science data collection at a wide variety of temporal and geographic scales. As Joe Paradiso of MIT's MediaLab noted in his workshop presentation, the reduced cost and complexity of human-sensing technologies means that "Sensor networks are the foot soldiers at the front lines of ubiquitous computing." As a result, human and ecosystem "sensing, computation, and communication [will necessarily] become tightly integrated and commonly embedded." The problem that arises in infrastructure planning in this case is not one of sharing infrastructure, but instead ensuring that budgets and allocations for parallel social science investments are sufficient.

Taken together, remote-sensing and human-sensing infrastructures illustrate both the promise of integrated environmental and human observation and the pitfalls associated with current narrow definitions of infrastructure. Both of these cases highlight the social science contributions to the observatories that are possible with dedicated infrastructure investments. In these specific examples and others where social science variables can be monitored by using existing or planned natural science sensors, the primary infrastructure issues for integration have to do with site selection, scope, timing, and frequency of measurements and related data-collection decisions. In almost all cases, there are likely to be some compatible and some conflicting social and biophysical science measurement needs.

Therefore, in order to open the door to additional funding and support for observatory-level social science infrastructure, the community of social scientists needs to think creatively and expansively about new types of facilities and equipment. One possibility for consideration is the inclusion of baseline surveys (as opposed to their administration, when they would be "turned on") as key infrastructures. The creation of survey instruments that can be replicated, revised, and used for multiple audiences over many places and times could in principle constitute a valuable social science capital investment. The important point is that social scientists need to be involved in infrastructure dialogues to make these suggestions and clarify the real trade-offs between additional natural science data and potentially new and innovative social science data. The next subsection expands on these data issues.

5.4. Information/Core Data

Social science integration into all of the observatories centers on the types of information and core data that need to be collected in parallel to natural science observations. Defining these data needs from both the social and the natural science perspectives has been a fundamental part of observatory development and planning debates to date. However, as described in the discussion of research themes and opportunities in Section 2, many fundamental social science research questions are still in the process of being clearly defined. This poses a chicken-and-egg problem for social scientists. It is difficult to define the core data needs of the wider community of social–environmental scientists without having a well-defined set of projects based on common research goals. Similarly, without a clear picture of the types of data that can be collected through the observatories it is difficult to develop a detailed research agenda.

This divide also exists in the natural sciences; however, the significant efforts invested in the LTER ISSE, NEON ISEP, and the WATERS plans to date have helped to bridge this gap and define natural science research opportunities and data needs in tandem with one another. As the ISSE states, "our ability to tackle complex problems and generate synthesis research over space, time, and disciplines has been limited by impediments to data integration, the need for increased spatial coverage and additional long-term measurements, and coordinated, cross-disciplinary research which fully integrates social, geophysical, and ecological sciences."[55] This section (in combination with the research themes in Section 2) is intended to complement the steps taken by LTER, NEON, and WATERS to address integrated data-collection issues by drawing attention to connected needs and opportunities in the social sciences.

As funds are not unlimited, attempts must be made to understand the value of using the observatory resources to add new social science data–collection programs versus adding another data point to an existing natural science data stream. This is a design and value-of-information question that can only be answered by professional judgment and the inclusion of one or more social scientists on the research design team for the observatories. In this case, one job of a leading social scientist will be to understand the natural science questions and develop a data-collection and analysis protocol that will provide the required understanding of human activities, impacts, and developments at different scales and across multiple sites in a study area, so these can be taken into account in the modeling of natural phenomena.

[55] Collins et al., 2007, p. 13.

The marginal cost of collecting more data as a part of the observatory system and then organizing data to allow for research on choices and behavior may be quite low. However, analyses of social science data, as opposed to its collection and archiving, can be expensive in terms of time, labor, and skills required for analysis. Much of that skill is likely to come from outside the observatory itself, and these costs may need to be supported by other programs and funds leveraged from a variety of different funding agencies. Here the challenge is to find ways to mesh the agendas of diverse groups to ensure that the collection, coordination, and archiving of observatory data fulfill the needs of the broader research community. In part this requires a thorough knowledge of existing and complementary sources of already widely available data and careful evaluation of planned baseline (longitudinal and special-project) data collection.

To move forward with these efforts the natural and social scientists leading the observatories will need to create ongoing opportunities to discuss and evaluate trade-offs in cases where specific types of core data collection could allow social science to influence natural science data collection and vice versa. To engage in these discussions, social scientists will also need to define the different data management and archival systems required for social versus natural science data, and address discipline-specific issues, such as quantitative and qualitative data integration, database aggregation, dissemination, and privacy concerns, where necessary. This process, though complicated, has the potential to inform and improve both social and natural science decisions on what kinds of data should be collected, where, and how frequently.

A first step to this end is for participating observatory social scientists to examine key existing social science data sources and limitations, prioritize new data-gathering efforts, and evaluate win-win opportunities for joint social and natural science data collection. As these social science needs are outlined in greater detail, integrated research could require adjustments to the planned scale, location, and frequency of new natural science data monitors to allow for comparative analyses. Additionally, social scientists within each observatory will need to assess how the outputs from different data-collection processes (based on site-specific collection practices or disciplinary differences in methods and tools) can best be collectively evaluated. In all cases, closely aligning traditional social science data-collection methods, including surveys and interviews, with new sensor-based data-collection tools will require iterative dialogues with input from both the social and natural scientists that will eventually use the collected data.

6. Recommendations for Integration

Based on both the research and process elements of social science integration discussed throughout this paper, this section outlines five preliminary recommendations for facilitating and improving the integration of social and natural sciences within NSF observatories. We recognize the truth, in the words of one SBE official, that we should "focus on solving problems; the process of integration will work itself out." Nevertheless, we also feel strongly that having additional institutional support and resources for multidisciplinary collaborations are important to overcome the countervailing forces driving stove-piped, disciplinary environmental science research. At the scale and magnitude of planned observatory research, without sustained input of funds and energy researchers are likely to return to their separate fields rather than coordinating research and working together. To this end, the recommendations below are an effort to collect the ideas that came out of the workshop discussions and make progress toward sustained collaboration in the long term.

1. **Develop a demonstration or test-bed project to inform detailed design elements of an integrated observatory program.** We recommend that NSF, with support from SBE, encourage the development of a multisite test-bed project to address selected social science research topics relevant to the observatories. Integrated research, for example, on local perceptions of environmental change and their dynamic impacts on different natural resources and ecosystem services across regions could lay the groundwork for larger follow-on studies on vulnerability, resilience, and adaptation as outlined in Section 2. In the spirit of the Neuse River exercise, this effort could bring together members of existing multidisciplinary collaborations at LTER, CNH, WATERS, and NEON to clarify social science data and infrastructure needs and inform social science contributions to the planning, siting, and implementation of the first observatory measurements.

   Underlying this recommendation is the idea that there are few models of true interdisciplinary research and that much can be learned about how such research can be successful through demonstration projects. We believe that the development of good models should not be an ad hoc process. As one workshop participant said "true integration with the social sciences requires inclusion in the core data set the necessary variables to 'transform' social sciences research."[56] To this end, this effort could build on the 11 WATERS Network test-bed projects already funded by CUAHSI and NSF's ENG and GEO Directorates. It is our

[56] Personal communication with Richard Hooper. CUAHSI. July 30, 2007.

hope that SBE, representing the broad community of social scientists, could contribute to this effort by establishing opportunities for interested members of the social science community to participate in complementary research at the selected test-bed sites and identify personnel and practices across sites to best support future joint research.

Unlike the start-from-scratch effort of the Neuse River Observatory team, these test beds would build on evolving observatory research plans and would provide important contributions to the ongoing development of both WATERS and NEON MREFC applications. Additionally, we strongly support the suggestion of the LTER National Advisory Board (NAB) in response to the ISSE plan that NSF "create a flagship activity in research, education, and applications at the socio-ecological interface… [and] open a dialog with a broader range of researchers in the SBE community by holding a workshop in which select members of that community would articulate their research ideas around the conceptual framework of the ISSE."[57] With encouragement, a collaborative test-bed project team could seek support through an NSF development grant, similar to the 2-year CNH planning grant that supported the development of the LTER ISSE report, to initiate this research dialogue.[58]

2. **Establish cross-observatory social science advisory and infrastructure committees for guidance to both the WATERS Network and NEON.** In order to build on the demonstration project outlined above, we recommend that the WATERS and NEON Executive Committees support the formation of a single advisory committee of social and natural scientists to guide integration efforts across all observatories. This committee could consist of a rotating membership, selected by current observatory teams and NSF program officers in multiple Directorates, including SBE, BIO, GEO, and ENG, to prioritize multidisciplinary research objectives and identify the low-hanging fruit in joint social and natural science data collection. In recognition of the similarities between the types of multidisciplinary research questions that could be addressed by LTER, NEON, and WATERS and the infrastructure needed to do so for all three networks, it could also be efficient to have a single social science infrastructure committee advising all observatories.

---

[57] LTER National Advisory Board. Report of the National Advisory Board, National Advisory Board Meeting. March 8–9, 2007, Arlington, Virginia. http://intranet.lternet.edu/modules.php?name=UpDownload&req=viewsdownload&sid=13 (accessed September 13, 2007).

[58] Development of the ISSE was supported by NSF grant # DEB-0435546.

The infrastructure needs of social scientists are going to be very similar, if not identical, across observatories; therefore, we believe that time and resources could be saved if issues about the appropriate and fundable infrastructure needed to conduct social science research were investigated in one place. This committee could exist as a subcommittee of the larger social science advisory committee described above, but we can also see the merits of having these two committees operate in parallel to one another (see breakout session summaries in Appendix A).

3. **Coordinate with SBE to develop and align incentives for social scientists to participate as full, long-term partners in the process of funding and operationalizing all observatories.** To date, the financial burden for all of the observatories has been carried by the BIO Directorate in the case of NEON and the ENG and GEO Directorates in the case of WATERS. We see significant opportunities to coordinate with the SBE Directorate to expand social science involvement and have SBE itself play a larger role in the development of both of these observatories. The substantial participation of SBE directors and program officers in the planning and activities of the January workshop is an important and welcome step in this direction.

   The process of securing MREFC funding is long and arduous, requiring significant resources and time to develop a detailed plan before an application is submitted. For social scientists to be full partners with natural scientists and engineers in this planning process, there needs to be broader recognition of the huge paybacks possible in future core social science research opportunities. We see SBE as having a critically important role in this process, both as a representative and champion of the broader social science community.

4. **Develop new programs along the lines of the HSD and CNH programs to encourage future collaborative proposals using the observatories and observatory data.** Once the observatories are funded and instrumentation and other infrastructures are in place, social scientists will need the support of research programs that fund specific social science research efforts using the observatories' equipment and data. For core social science studies as well as integrated research, SBE support is essential. As outlined in Section 5.2, there are a variety of models for possible programs ranging from general competitive grants and awards to multidisciplinary funding opportunities like HSD and CNH. These initiatives

could be further supplemented by specific social science programs that provide matching funds or set-asides for social scientists to participate in and make contributions to larger collaborative projects.

In addition to signaling SBE's commitment to the observatories and the wider social science community, the intent to develop such a program could appear in the observatories' MREFC submissions to enhance their saliency by providing a vehicle for sustained social and natural science partnership up front and to help assure funding. In order to better engage observatory social scientists in large-scale projects, the CNH program model could be modified to support longer collaborations. For instance, current project funding under CNH typically ranges from 3 to 5 years; however, a 6-year commitment, along the lines of the LTER renewable program grants, could help with the long-term development of newer collaborations. Other steps in this direction could include active social science and SBE participation in observatory proposal reviews to balance review panels and explicitly promote multidisciplinary collaborations and effectively evaluate interdisciplinary research.

5. **Establish a center, like the National Center for Ecological Analysis and Synthesis (NCEAS), to allow for intense, short-term interactions among natural and social scientists and create both incentives and opportunities for collaboration.** In the workshop discussions and extended conversations with HSD, CNH, and LTER PIs, proximity and face-to-face contact were identified as essential to building collaborations and developing a shared understanding between disciplines required for successful interdisciplinary research. To this end, we recommend that observatory leadership and the SBE, BIO, GEO, and ENG Directorates at NSF coordinate to develop, as part of the observatory infrastructure, a central meeting place for social and natural scientists to come together for short periods to take advantage of the research advances possible with very close collaboration. This facility could be modeled based on the NCEAS, which provides meeting spaces, high-level information, and computer capability and research support through one or more resident post-docs who then engage in and build upon the collaborative work initiated by visiting groups.

In the NCEAS model, researchers can submit short proposals for use of the NCEAS facility and housing and travel costs for up to 20 people (including post-docs) for periods of about 1–3 weeks. The integrative center proposed here could also support non–site-specific observatory social science infrastructure, such as decision theaters, and simultaneously provide opportunities to bring in individuals with specialized skills, such as expertise in GIS, from outside the observatories to work with preexisting teams. In the case of the observatories, we believe that having such a center could also help bring together dedicated groups of natural and social scientists from across observatories to share insights and engage in interobservatory analysis. This effort would not exclude the desire and recommendation to promote ongoing communication and collaboration between the EOs and the existing NCEAS center to "maximize the return on investments in cyberinfrastructure, promote the desired interoperability, and help disseminate the products of synthetic research to user groups."[59]

7. Conclusions and a Way Forward

In conclusion, we strongly believe that the NSF observatories have the potential to make major advances in environmental science research and decisionmaking. We also think that each observatory discussed in this paper (WATERS, NEON, and related research at LTER sites) has made significant strides in initiating opportunities for social and natural science research integration. We are strongly supportive of these efforts, and see this paper as another voice in ongoing dialogues on how integration can best be improved and sustained. The EOs will play a central role in the efforts to address the NRC's grand challenges, and effectively generating and disseminating the data to support research on these challenges will involve bringing together multiple disciplines and fostering greater social science participation in future collaborative research.

The recommendations presented here are targeted at these developments with the intention of eliminating the barriers remaining to initiating and implementing sustained collaborative environmental research in practice. As expressed throughout this paper, we believe that many synergies and opportunities exist for new, path-breaking environmental science research at the interface of the social and natural sciences. To take full advantage of these opportunities and make major research advances, organization, funding, infrastructure, and data-related issues and barriers need to be addressed. Efforts to this end do not have to wait for observatory infrastructures and agendas to be in place, and in fact, it is at the current stage of observatory planning that these important decisions on integration need to be made.

---

[59] Collins et al., 2007, pp. 16–17.

Overall, if we are to rise to the level of the grand challenges, then the multidisciplinary community of scientists participating in and represented by the EOs must work with NSF and the observatory leadership to make the immediate and incremental changes necessary to establish a concrete agenda for future integrated observatory research. This workshop and paper demonstrate the broad support and commitment to this effort.

References and Supporting Documents

AAAS (American Association for the Advancement of Science). 2005. An AAAS R&D Funding Update on R&D in the FY 2005 NSF Budget. http://www.aaas.org/spp/rd/nsf05p.htm (accessed November 29, 2006).

———. Intersociety Working Group, AAAS. 2005. *AAAS XXX: Research and Development FY 2006.* Washington, DC: AAAS. http://www.aaas.org/spp/rd/rd06main.htm (accessed November 29, 2006).

———. Intersociety Working Group, AAAS. 2004. *AAAS Report XXIX: Research and Development FY 2005*. Washington, DC: AAAS. http://www.aaas.org/spp/rd/rd05main.htm (accessed October 16, 2006).

Brewer, G. 1999. The Challenges of Interdisciplinarity. *Policy Sciences* 32(4): 335–36.

Casman, E., B. Fischhoff, M. Small, H. Dowlatabadi, J. Rose, and M.G. Morgan. 2001. Climate Change and Cryptosporidiosis: A Qualitative Analysis. *Climatic Change* 50: 219–49.

Clark, William C., Jill Jaeger, Losee van Eijndhoven, and Nancy M. Dickson. 2000. *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion, and Acid Rain*. Cambridge: MIT Press.

CLEANER (Collaborative Large-Scale Engineering Analysis Network for Environmental Research). CLEANER Project Office. http://www.cleaner.ncsa.uiuc.edu/home/ (accessed October 16, 2006).

Collins, Scott L., et al. 2007. Integrative Science for Society and Environment (ISSE): A Strategic Research Plan. Developed by the Research Initiatives Subcommittee of the LTER Planning Process Conference Committee and the Cyberinfrastructure Core Team. LTER (Long Term Ecological Research Network).

CUAHSI (Consortium of Universities for the Advancement of Hydrologic Sciences Inc.). Homepage. http://www.cuahsi.org/index.html (accessed October 16, 2006).

———. December 2004. Designing Hydrologic Observatories: A Paper Prototype of the Neuse Watershed. A Report to the Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. Neuse Prototype Hydrologic Observatory Design. CUAHSI Technical Report No. 6. Washington, DC: CUAHSI.

http://www.cuahsi.org/publications/Neuse_Report_final.pdf (accessed October 6, 2006).

Frederick, S., and B. Fischhoff. 1998. Scope Insensitivity in Elicited Values. *Risk Decision and Policy* 3: 109–24.

Jasny, Barbara, Donald Kennedy, and Eliot Marshall. 2006. Science Looks at Life. *Science* 312 (5782): 1893.

Kandlikar, Milind. 1996. Indices for Comparing Greenhouse Gas Emissions: Integrating Science and Economics. *Energy Economics* 18(4): 265–81.

LTER (Long Term Ecological Research) Network. 2006. Engaging Social Scientists in LTER Research. *The LTER Network News* 19(1): 4. http://www.lternet.edu/news/images/spring06/Spring06_NNews.pdf or http://www.lternet.edu/news/Article78.html (accessed October 16, 2006).

———. Baltimore Ecosystem Study. http://beslter.org (accessed October 16, 2006).

———. Central Arizona–Phoenix Long-Term Ecological Research. http://caplter.asu.edu (accessed October 16, 2006).

———. Coweeta Long Term Ecological Research. http://coweeta.ecology.uga.edu (accessed October 6, 2006).

———. North Temperate Lakes Long Term Ecological Research. http://lter.limnology.wisc.edu (accessed on October 16, 2006).

LTER National Advisory Board. Report of the National Advisory Board, National Advisory Board Meeting. March 8–9, 2007, Arlington, Virginia. http://intranet.lternet.edu/modules.php?name=UpDownload&req=viewsdownload&sid=13 (accessed September 13, 2007).

McDaniels, T., L. Axelrod, N. Cavanagh, and P. Slovic. 1997. Characterizing Perception of Ecological Risk to Water Environments. *Risk Analysis* 17(3): 341–52.

McDaniels, T., L. Axelrod, N. Cavanagh. 1998. Public Perceptions of Water Quality and Attributes towards Water Conservation in the Lower Fraser Basin. *Water Resources Research* 34(5): 1299–1306.

NEON (National Ecological Observatory Network). Homepage. http://www.neoninc.org/ (accessed October 16, 2006).

———. October 23, 2006. Integrated Science and Education Plan (ISEP) for the National Ecological Observatory Network (NEON). http://neoninc.org/milestones/2006/isep.html (accessed September 10, 2007).

———. 2002. *Report to the National Science Foundation from the Sixth Workshop on the Development of a National Ecological Observatory Network (NEON): Information Management.* Held at the National Center for Ecological Analysis and Synthesis. Santa Barbara, CA: National Center for Ecological Analysis and Synthesis, and Arlington, VA: National Science Foundation. http://www.neoninc.org/documents/NEON6_Sept2002.pdf (accessed October 25, 2006).

National Science Board. December 28, 2005. *2020 Vision for the National Science Foundation*. NSB-05-142. Arlington, VA: National Science Foundation. http://www.nsf.gov/pubs/2006/nsb05142/nsb05142.pdf (accessed October 16, 2006).

NSF (National Science Foundation). September 2006. *Investing in America's Future: Draft National Science Foundation Strategic Plan FY2006–2011*. Arlington, VA: National Science Foundation. http://www.nsf.gov/about/performance/nsfplandraft.pdf (accessed October 14, 2006).

———. April 2002. *Long-Term Ecological Research Program Twenty-Year Review*. Arlington, VA: National Science Foundation. http://intranet.lternet.edu/archives/documents/reports/20_yr_review/ (accessed October 16, 2006).

———. Directorate for Social, Behavioral, and Economic Sciences. http://www.nsf.gov/dir/index.jsp?dir=SBE (accessed October 16, 2006).

———. Priority Area—Human & Social Dynamics. http://www.nsf.gov/news/priority_areas/humansocial/index.jsp (accessed October 16, 2006).

———. Division of Behavioral & Cognitive Sciences. http://www.nsf.gov/div/index.jsp?org=BCS (accessed October 16, 2006).

———. Division of Social & Economic Sciences. http://www.nsf.gov/div/index.jsp?org=SES (accessed October 16, 2006).

ORION (Ocean Research Interactive Observatory Networks). Homepage. http://www.orionprogram.org/ (accessed October 14, 2006).

———. Executive Steering Committee. 2005. *Ocean Observatories Initiative Science Plan: Revealing the Secrets of Our Ocean Planet*. Washington, DC: ORION. http://www.orionprogram.org/PDFs/OOI_Science_Plan.pdf (accessed October 16, 2006).

Orlikowski, W.J., and S.R. Barley. 2001. Technology and Institutions: What Can Research on Information Technology and Research on Organizations Learn from Each Other? *MIS Quarterly* 25(2): 145-165.

Stokes, D.E. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington, DC: The Brookings Institution.

WATERS (WATer and Environmental Research Systems) Network Project Office Physical Science and Engineering Committee. 2006. WATERS: A Summary of the Grand Challenges It Seeks to Address. Arlington, VA: CLEANER Project Office.

Water Science and Technology Board, Division of Life Studies, National Research Council. 2006. *CLEANER and NSF's Environmental Observatories*. Washington, DC: National Academies Press. http://fermat.nap.edu/books/0309102294/html/R2.html (accessed December 22, 2006).

West, J.J., M.J. Small, and H. Dowlatabadi. 2001. Storms, Investor Decisions, and the Economic Impacts of Sea Level Rise. *Climatic Change* 48: 317–42.

Yates, David N., and Kenneth M. Strzepek. 1998. An Assessment of Integrated Climate Change Impacts on the Agricultural Economy of Egypt. *Climatic Change* 38: 261–67.

Appendix A: Summary of Workshop Breakout Sessions

This appendix briefly summarizes the discussions from four breakout sessions held during the January 24–25, 2007, workshop. These sessions focused separately on the key integration topics described in Section 5: organization, funding, infrastructure, and information/core data. As part of each breakout session, participants either selected into or were assigned to small groups of 5–10 workshop participants to discuss questions associated with each main topic and make recommendations for improving integration. Each topic was addressed by two groups, and group discussions were moderated by members of the workshop steering committee. The next four subsections individually summarize the main issues identified in each session.

A.1. Organization Breakout Groups

Members of the organization breakout sessions were tasked with outlining the organizational needs of social scientists and evaluating strengths and weaknesses of different organizational structures for integration of social scientists and natural scientists. The following questions were introduced to help structure the conversations:

1. How can social scientists best organize themselves to engage in and support observatory research?
2. What is the necessary committee representation (critical mass) of social scientists at observatories to achieve integration in both research and planning?
3. What specific organizational efforts would help start/sustain communications among social scientists and between social and natural scientists?

In addressing these questions, both breakout groups on this topic championed a multidimensional approach to integration starting with building solid project collaborations, having broad meetings, and engaging in large-scale cross-cutting activities. Participants suggested that initial face-to-face meetings between observatory social scientists (economists, geographers, sociologists, etc.) were a prerequisite of successful project- and site-level collaboration. Broader meetings with diverse natural and social science representation could simultaneously help to solidify these collaborations and support new integration initiatives, such as a multiobservatory social science advisory council, as proposed by members of one breakout group.

This Social Science Advisory Council was put forward as an entity that could be charged with setting priorities for social science and collaborative research, supporting a process for data-protocol development, developing data-collection goals, and overseeing meetings of diverse stakeholders. Given the unavoidable reality of varied research needs across disciplines, both breakout groups preferred some combination of centralized and decentralized social science oversight at all of the observatories. In balancing these elements, a centralized office was seen as best supporting data collection and model development and addressing interoperability and communication issues, while decentralized or site-specific activities could better address research and collaboration issues of greatest local interest. Participants emphasized that such a hybrid approach should also be flexible to avoid setting either observatory-level or site-specific priorities that might impose artificial limits on integrated research in the future.

A.2. Funding Breakout Groups

The funding breakout session discussions focused on possible social science funding opportunities, such as the NSF MREFC Account, and strategies for overcoming barriers to the development and support of interdisciplinary proposals. Discussions in this session were motivated by the following questions:

1. What are some of the possible funding models that could support social science integration and what are their strengths and weakness? (Social science set-asides within grants and awards, requirements for multidisciplinary PIs, etc.)
2. How and to whom should social science proposals be targeted to support both start-up investments and long-term project operations and maintenance?
3. How can observatory social scientists overcome internal competition for funds between social and natural scientists and cross-site competition?
4. What degree of flexibility is there in MREFC rules and practices to make more social science needs eligible for funding through this Account?

The responses to these questions all touched upon one theme: commitment. Participants in this group saw dedicated funding, projects, and resources as critical requirements for both immediate and long-term social science integration. On the whole, participants saw SBE as a crucial actor in supporting social scientists. Both breakout groups agreed that it was essential for SBE to make long-term, sustained commitments to contribute to the joint funding of the observatories. These commitments to integration and collaboration by SBE and the community were viewed as especially important in the process of defining and implementing key social science priorities within early observatory agenda setting. As one participant said "RFPs must explicitly require integrated, multidisciplinary research involving social as well as biophysical researchers."

Like the organization breakout groups, the funding groups also suggested the development of a centralized funding committee to help social scientists prioritize, organize, and react to new RFPs as funding sources change over time. According to the group members, this type of committee could also bring social scientists together to discuss future funding opportunities that would support innovation and new characterizations of data, priorities for distribution of core funds, guidelines for proposal review, and any system-level problems that might arise. Additionally, a centralized funding committee or similar entity could serve as an important mediator in internal competitions for social science funding.

A.3. Infrastructure Breakout Groups

Like the organization and funding sessions, the infrastructure breakout groups were tasked with identifying key infrastructure issues associated with integration. This session focused on defining and prioritizing the types of primary facilities and equipment needed for social science observation, both shared with and independent of natural scientists. The following questions were introduced to structure this session:

1. What are the primary facilities needs of social scientists in parallel to natural science equipment needs? (Survey facilities, decision theaters, sensing equipment, etc.)
2. How can planned natural science infrastructure (cybercollaboratories; virtual networks; and data sharing, outreach, and archival systems) be leveraged to also support social science integration?

To address social science infrastructure needs, participants in both of these breakout discussions highlighted the need to engage in a formal evaluation or needs assessment. This assessment could build on key social science research questions (including those identified in this report, the LTER ISSE, and the NEON ISEP, among others) to clearly identify the specific infrastructure and facilities required to answer these questions and dividing these needs into categories that could be assessed relative to proposed natural science investments.

Generally, participants suggested a wide variety of possible social science facilities and infrastructures including remote-sensing equipment, cameras, motion sensors, and mobile versions of fixed infrastructure allowing for rapid data collection on patterns, such as recreation and migration. Decision theaters were discussed as tools for both research and communication. On the one hand these facilities were seen as serving an experimental function, supporting studies on individual or group decisionmaking under uncertainty or different scenarios. On the other hand, these theaters were also viewed as communication infrastructures, like the NCEAS facility, that could help bring together groups of social scientists or other collaborators across sites and observatories. Human-sensing equipment also received substantial attention for its ability to give more realistic input on human behavior, including a better understanding of human response(s) to environmental changes and stresses such as traffic or disease.

In all cases, participants stressed the need for new incentives. They asserted that "equal-opportunity funding" is essential for both initial infrastructure design specific to social science as well as the leveraging of natural science infrastructure. Participants in this session also built on the concept of an advisory council and suggested having a dedicated infrastructure committee that could focus explicitly on infrastructure synergies and commonalities among disciplines. Additionally, participants suggested pursuing opportunities to test novel social science infrastructure at LTER or other established sites before the EOs are fully operational. Discussants were optimistic about the opportunities for test-bed projects to engage interested members of the social and natural science communities to participate in and build on evolving observatory infrastructure proposals and long-term research plans.

A.4. Information/Core Data Breakout Groups

The final breakout session on information and core data covered perhaps the most complex topic. This session focused on identifying the primary data needs of social scientists and the potential for gathering these data through the observatories. As stated in the main text, the big social science research questions in the environmental sciences have yet to be clearly defined; therefore, groups in this session built on the three main research topics discussed in Section 2 to answer the following questions on data collection and integration:

1. What are the specific types of core data (human activities and behaviors, human impacts and responses, and human welfare and development) that allow social science to serve as an input into natural science data collection and vice versa?
2. Are there different data management and archival systems required for social versus natural science data? (quantitative and qualitative data integration)
3. What are the existing sources (readily available, historically important, widely used, etc.) of social science data that could be used in parallel to observatory data?

Participants in this session discussed the need for clearer social science research questions and goals and the difficulties associated with identifying social science data needs and contributions to the observatories in the absence of these shared goals. Nonetheless, several broad categories of core social science data were identified during these discussions, including population, demographic, health/disease vector, housing and land use, quality-of-life indicators, ecosystem service values, and related consumption, regulation, and impact data. In all of these cases, scale was a key issue with the emphasis on the household level data collection as a priority for social science analysis.

Participants also highlighted key issues associated with data management, compilation, archiving, and dissemination, such as data accessibility, confidentiality/privacy, spatial and temporal fit with existing social science data sources, and data usability. Both groups proposed social science use of observatory data repositories and cyberinfrastructure to help integrate and aggregate data that cut across multiple bounds and categories and index sources of information to other databases. It was generally agreed that this type of system, designed to support robust, integrated datasets at the observatories, would in and of itself attract social scientists.

Appendix B: Presentation Slides from Workshop Breakout Sessions

At the conclusion of each breakout discussion, one member from each group made a brief summary presentation back to the plenary session. This appendix includes slides from all eight presentations, organized by session.

Day I, Social Science Organization: Group I

Len Shabman (Moderator)

Social science vs. other science disciplines

- Feeling of separation
- Study of nature vs. building upon nature
- Social science needs multiple representatives and internal collaboration
- Problem solving vs. building theory and funding
- Value of data collection and limited opportunity
- Natural science vs. social science funding opportunities
- LTBR funding goes to predetermined ideas, and integration is required of some disciplines and not others

Organization

- Is the "tweener" community large enough?
- First evaluative criteria vs. second, practical impact vs. larger scientific impact
- What worked in term of organization? What created opportunity for cross-disciplinary work? What made collaboration work? What was a barrier?
- Face-to-face meetings, at least initially. Intense intro, retreats, few times per year.
- Centralized vs. decentralized
  - Hybrid model of frequent interaction, need not be permanent

Thoughts on organization

- Incentives to participate
- Bring social scientists together over data
- Moved away from top-heavy organization.
  - Too much separation from data and daily decisions.
- Local systems have different problems at individual facilities, central office would not be able to cover it all
  - Centralized function taken over by board
- Something like the field stations with both central and local systems

Data and Organization

- How to get scientists out to use the data?
- How to make the data useable to different scientists?
  - Comprehensive models of systems only recently include human aspects
- LTERs would now allow anybody to scale up, just a bunch of little data sets
- Are the observatories about collecting data or about turning data into knowledge?
  - If both, how do they differ from universities?
- No one has the capacity to produce long term data sets

Social scientists and engineers need each other to achieve change

- Engineering is going to be top-down
- Where do social scientists fit into observatories and the observatory network?
- Some top-down organization
- PI driven research as well
- Social scientists need to be affiliated with observatories, possibly universities

Interdisciplinary Organization

- Who decides what data gets collected, when, for social scientists?
- Data collected with aim to answer questions
- "Tweener" projects get slaughtered in both the social and physical sciences at NSF
- Disincentives for social scientists make it difficult to get interdisciplinary funding
- If it is not required, it must be incentivized, otherwise it does not happen

Other thoughts and questions

- Long-term data collection can be helped by social scientists in what ways? What to collect? When?
- Incentives to include social scientists
- Budget organization often means that there is competition for money between social and physical sciences
- New questions often arise after research has begun, which is too late for funding
- Data needs an infrastructure such that it can be shared in different places at the same time
- Satellite data is difficult to organize and deal with because it is so huge

Other thoughts and questions

- What data is needed to explain behaviors, rather than just observe?
- Longitudinal survey data collection is needed in the social sciences

Day I, Social Science Organization: Group II

Mitch Small (Moderator)

Early Input for Problem Framing and Formulation

- NEON
  - Emphasis on LULC
  - Support from a Center for Modeling & Data Synthesis (~NCEAS)
  - RFI: Role for social scientists not prescribed -- emergent?
- CLEANER
  - Full range of economic, behavioral, perception, and decision-making studies
  - Centralized Program Office & Cybercollaboratory
  - Social Science participation in network design
- LTER
  - Social science has been added from the bottom up

Top down vs. Bottom up?

- Need strong centralized organization to support data collection, model development, interoperability and communication to others
  - Must be adaptive to emerging needs and evolving foci of local sites
- Need strong, local (site) groups of social and physical scientists working together on problems of local interest
  - Social scientists must be able to bring their own dependent variables to the table -- lasting collaborations

Ability to Utilize Existing Social Science Initiatives and Datasets

- Local site datasets should be comparable with national survey data (and as a result, datasets from other observatory sites)
- Interoperability across Observatories?

Social Science Data Compatibility

- Protocols are not already set up to integrate data from different social science projects
- There is an opportunity right now to build a model for social data as it relates to ecological data.
- The alternative is every Social Scientist inventing their own wheel; creating data sets which are often incompatible.

--> Need to support process for protocol development

How do we decide what Social Science to include?

- Different disciplines have different scopes
- Should we leave it up to individuals?
  - Creates a smattering of data that is difficult to integrate
- A Social Science advisory council?
  - A collaborative group that would make data models and priorities available before projects are designed
  - Could potentially ensure wide scale compatibility

Current Social Science Knowledge Base

- Millennium Project revealed that we have minimal knowledge currently of indirect social drivers towards environmental change

Idea: Social Science Advisory Council

- A committee of Social Scientists and Ecologists that meets regularly to determine and assess priorities in research
- Any system adopted must ensure flexibility.
  - Should we allow Social Scientists to bring their own variables to their projects?
    - In NEON's example, the variables had to relate to NEON's priorities
- Deciding which questions take priority is extremely difficult, controversial

Difficulty of Determining Priority

- It can take years to get Social Scientists to agree on questions, data collection goals, language
- Such a body would have to be institutionalized in order to be effective
- Even harder to make sure guidelines are being followed
- High cost of actually bringing people

How can we utilize technology and the Internet?

- Brining people together easier?
- We could actually use data collection from people's homes via electronic energy use censors, water use censors.

Ethics of Social Science Priorities

- Would a codified set of priorities set artificial limits on Social Science research?
  - NEON example
    - Social Science looks at Human use of water on a local scale

Human Impact

- Human impact can be measured, for instance in water quality.

Day I, Information and Core Data: Group I

Patricia McDowell (Moderator)

What are the types of core data sets needed to address ecological problems? (1)

- Population: disaggregated census data
  - Make Census NSF-RDC data more accessible
  - Population movement/migration
- Health: expand HANES data to more diseases, better spatial scales
  - Make more useable: cyber infrastructure
- Disease vectors: collect on more vectors

What are the types of core data sets needed to address ecological problems? (2)

- County assessor parcel data: make other SS data sets available at this scale
  - Preserve confidentiality
- House sales/prices (Board of Realtors)
- Quality of life indicators
- Ecosystem service values

What are the types of core data sets needed to address ecological problems? (3)

- Economic impacts of the ecosystem
  - Jobs created/jobs lost (LEHD)
  - Economic impacts of regulation/management
  - PUMS data
- Recreation: focus on environment-related recreation vs. tourism
- Cars: auto registration
  - Traffic?
- Consumption: use commercial marketing data, postal deliveries

What are the types of core data sets needed to address ecological problems? (4)

- Regulation and management: data on zoning laws, planning requirements, etc.
- LU/LC
  - Remote sensing at night: energy use
- Human perceptions and values of the environment
  - Regional surveys: PASS (Phoenix)

Data management and archival systems

- Cyber-infrastructure to make different data sets more accessible
  - Data mining of existing data
  - Use existing data, bring to same spatial resolution (fine-scale)
  - Develop new technologies and methods that prevent individual identification
- Value of spatially-gridded data
  - But preserve it in original format too

Other issues

- How data is used in decision-making and science?
- Who uses the data, are new networks of people being created? (scientists and policymakers, ss and ns, etc.)
  - Will people use the data properly?
- Create a robust data set around the sites; that will attract social scientists (where the data is the scientist will go)
- Converting archival data into usable data

Day I, Information and Core Data: Group II

Morgan Grove (Moderator)

What are the specific types of core data?

- Working at the household data for everything
- Surveys
- Commercial data sets
- Administrative Data
  - Medical records etc.
  - Often ignored by biophysical sciences
  - "Tyranny of the Survey"

Breakdown of core data types

- Data on consumption
  - From decision-making units (multiple levels)
- Data on consequences
- Data on mitigation
  - Leads to resolutions
- Not just measuring data at a certain border/point crossed
  - Knowing where it actually comes from

Limits to core data gathering and reporting

- Data quality/access and confidentiality
  - Privacy act
  - NAS upcoming report
- Constraints on Infrastructure Data
  - Socially slow variables
  - Infrastructure networks
    - Where is the power line structure, the dam, the bridge?

Are there different data management and archival systems required for social versus natural science data?

- Past Efforts: A number of case studies, synthesized with review articles
- New ideas:
  - Xml, model descriptions
  - Model library
- Data is difficult to correlate
  - Past social data hard to link to a coordinate system
  - Today, with forethought, pre. thought on the survey design
  - Privacy act

A System of Archiving

- Before the System
  - have agencies agree to give information to one central repository
- The system
  - Will pass all of the agencies security measures
- Data all in one place and already integrated
  - Technologies for indexing others sites (linking)
- Create aggregates that cut across multiple bounds

What are the existing sources of social science data that could be used in parallel to observatory data?

- Digital
- Archive
  - analog

Outstanding questions

- Linkages
  - Another jump between archival architects and the user (user interface)
  - Indexing and multiple types of search

Day II,
Government Initiatives and Social Science Support: Group I

Mitch Small (Moderator)

What are some of the possible funding models that could support social science integration?

- RFPs must explicitly require integrated, multidisciplinary research involving social as well as biophysical researchers
- Social scientists will be integral to projects
- Integrated research by social scientists will be part of observatory core, and funded as core

Set asides?

- Not set-asides, but general commitment to long-term support by SBE
- <u>Expectation</u> by other directorates of supporting research that includes social scientists

SBE

- **It will be essential for SBE to make a long-term, sustained commitment to being part of joint funding for observatory support
- SBE might use this, and other Green initiatives to increase its budget

How and to whom should social science proposals be targeted?

- NSF: Core proposals will be part of larger, multidisciplinary proposals sent to core directorates
- Non-core proposals will go to appropriate directorates (competitive, as usual)

Funding sources, other

- LTER model, core funding to leverage additional support (inside and outside of NSF)
- The Hope: Build it and they will come and ask to support it (especially for applications)
- Non-NSF funding possibilities:
  - Municipalities
  - States
  - Foundations
  - Other fed -- USDA, Homeland Security
  - Industry

How can observatory social scientists overcome internal competition for funds?

- NSF needs to commit to continue to fund competitions for transdisciplinary research
- Multidisciplinary proposals will need to be reviewed by multi-disciplinary panels

What degree of flexibility is there in MREFC rules and practices to make more social science needs eligible?

- Not much apparent flexibility
- Some capital investment, e.g., sensors, decision-theaters and other data integration and visualization tools
- Cyber infrastructure

Day II, Government Initiatives and Social Science Support: Group II

Leonard Shabman (Moderator)

What are some of the possible funding models that could support social science integration?

- A dedicated portion of money for bringing social scientists to observatories
- Information on the funding infrastructure and networking needs to be more available, especially LTERs
- Maintain a list of kinds of data, and work from it and add to it
- Require a certain number of projects funded to be social science
- Prioritize research questions from data streams with a science steering group, and include social scientists at the beginning of the process
- A committee of social scientists should be formed to address this
- Interdisciplinary funding must be dedicated in some way

What are their strengths and weaknesses?

- Funding must be cost-based & trade-off driven at start
- NSF SBE could, perhaps, review the wish-lists that have already been compiled and price it, allowing progress in funding requests

How and to whom should social science proposals be targeted?

- Funding still goes through the NSF
- Observatories do not fund research
- The usual sources of funding would remain the same
- We should get a plan together and not worry right now about who is going to fund it years in the future
- Funding opportunities and sources will change, so the central committee will be there to prioritize and organize

How can observatory social scientists overcome internal competition for funds?

- Refinement at each observatory & inclusion at the start
- Social scientists need to be at the table to discuss innovation and characterization of data
- Social scientists need to sort out their own needs as individual disciplines and then come together
- Committees at individual observatories review priorities and proposals

Competition between social and natural scientists…

- These groups need to work together for data collection and advice on future data needs
- Interdisciplinary knowledge is very important, and social scientists know more about physical scientists than vice versa.
- Membership should be equal between social science and bio-physical sciences

Cross site competition…

- The committees will determine, at the beginning of the research process, how the core funds will be distributed
- Some data will be specialized, and other data will be useful cross-disciplinarily

What degree of flexibility is there in MREFC rules and practices to make more social science needs eligible?

- Highly trained technicians are not professors, training could be MREFC charged

Additional thoughts and questions

- Infrastructure is not the same as in other sciences in terms of surveys etc.
- Research money cannot go through observatories, so what do social scientists work for at observatories?
- We must invest in the future research opportunities now
- This central funding should not come out of existing funding for proposals

Day II, Social Science Infrastructure: Group I

Patricia McDowell (Moderator)

Questions

- What are the primary facilities needs of social scientists independent of natural science equipment?
- How can planned natural science infrastructure be leveraged to also support social science integration?

High-resolution remote sensing

- Urban areas
- Multiple variables: building height, impervious surface, green space, vegetation cover, traffic (foot and vehicle), etc.
- Questions:
  - Cities as ecosystems
  - LU/LC change response to political and economic drivers
  - LU/LC change regulating flows of water, nutrients, etc.

Other remote sensing

- Detailed sensor networks at "observatories"
- Use RS for scaling up from detailed data to region, nation, etc.

Human sensing

- General interest and support
- Uses/questions:
  - More realistic input on human behavior for agent-based models
  - Human response to disasters
  - Exposure to air pollution; current sensors don’t measure the environments that people actually live in
  - Traffic: how people respond to traffic conditions
  - Epidemiological: where/how people catch diseases
  - Sustainability: allocating resources in building where people are

Decision theaters

- General interest and support
- Portability – take it to the people
  - Staff needs
- Uses/questions:
  - How stakeholder groups make decisions; improving their decision-making
  - Interdisciplinary science collaboration
  - Multiple-agent models; i.e., understanding individual, economic, institutions, etc. factors in land-use change
  - How visualization influences uncertainty in decision-making

Virtual observatories

- Explore remote site, data available on it
  - Do you want to use it as a research site?
  - Comparison with your existing sites
- Uses/questions:
  - How people perceive their environment/ changes in their environment
  - Environmental valuation, eco. services valuation
  - Allow social scientists to use experimental approach (more)

Virtual observatories

- Need to include social science data
- Use more standard data visualization; does not need to be immersive
- Think about costs relative to benefits, to the research
- Worry about uncertainties
- Ecologists should go in the field; so should social scientists

Other thoughts and questions

- Cyber-information infrastructure (CUAHSI HIS): seamless data to analysis
  - General support
- Importance of geospatial data
- It is still hard to “plug and play” with data
- Geospatial data servers as an example of cyber infrastructure
  - Have not yet fully met their promise
- Challenges of increasingly large data bases

Day II, Social Science Infrastructure: Group II

Morgan Grove (Moderator)

What are the primary facilities needs of social scientists independent of natural science equipment?

- Cameras: produce more than one type of data
  - Quick and dirty
  - Pictures
- Motion censors
- Mobile versions of fixed infrastructure
  - To see rapid change
  - To understand recreational use patterns
    - Hikers
    - Hunters
    - Water sports

Ideal…

- Infrastructure may need infrastructure
  - Network of collection: takes information from the sensors and brings it to the central repository
  - Putting in cell tower coverage in domains of interest
- Context model
  - Fairly constrained: how well do you understand the situation
  - Badges in the social situation
  - People have to buy into this: benefit and utility necessary
- What we have learned from NCEAS
  - Build a network that uses this model
  - One is not enough
  - This could be a "theatre" for viewing the entire network

Approaches to identifying infrastructure needs

- Look at systems to ask infrastructure questions
  - i.e. based on the ecosystem
- Focus on the questions: an organizing principle
- Divide infrastructure needs into categories

How to link up to biophysical infrastructure…

- Geographically explicit data needed
- Data funnels
  - Towers etc.
  - NEON already designed with power capabilities
    - Guarantee for data collection capacity over time
- Digitize
  - "hard-copy" data, improve utility
  - An infrastructure to digitize the existing 200 so years of social science data
    - Iceland: genetic data

How can planned natural science infrastructure be leveraged to also support social science integration?

- Joint human and animal sensing
  - Audubon citizen science work as model
- Sensors infrastructure tied into already existing natural science infrastructure
  - Deborah Estrin's work
    - Inform discussion: current and future capacity groundtruthing
  - Sound sensing

Problems to address…

- Encouraging adoption of sensing devices
  - Incentives essential
    - Competition
    - Family history
    - Safety
- Volume
    - The band-width must be cut down

Testing on real places

- Complimentary exercise
  - 1. Asking LTER social scientists: what are your big research questions, what are you collecting, what would you like to collect
  - 2. To test novel social science infrastructure at LTER sites
  - Associate with NEON RFI
    - Already testing sensors

Concluding thoughts

- Co-designing opportunities to make infrastructure decisions
  - Frontiers workshops
  - Three years, rolling membership
  - Explicit focus on infrastructure synergies/commonalities between disciplines
    - Outcomes all the way back to the drivers
    - Do the end to end solution on what is needed
    - A great way to gel engaging questions

Independent. Balanced. Objective.

RESOURCES
FOR THE FUTURE

1616 P Street, NW · Washington, DC 20036-1400
Telephone: (202) 328-5000 · Fax: (202) 939-3460
www.rff.org