Part I

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Infrastructure for observing local human–environment interactions

BRENT YARNAL, JOHN HARRINGTON, JR., ANDREW COMRIE, COLIN POLSKY, AND OLA AHLQVIST

The vision: sustainable communities on a sustainable planet

Imagine a world where nature and society coexist in a healthy symbiosis, where human impacts on the environment are minimal, and where communities are safe from natural and technological hazards. Imagine a time when scientists can monitor such sustainable human–environment interactions, when they can interactively share and compare data, analyses, and ideas about those interactions from their homes and offices, and when they can collaborate with local, regional, and international colleagues and stakeholders in a global network devoted to the environmental sustainability of their communities and of the planet.

We contend that to build the sustainable world portrayed above, it is necessary to develop an infrastructure[1] that will support such an edifice. Consequently, this chapter introduces our ideas about the infrastructure needed to realize this vision and how the Human–Environment Regional Observatory project (HERO) attempted to take the initial steps to develop that infrastructure. The chapter also demonstrates that HERO addressed several major growth areas of twenty-first-century science – complex systems, interdisciplinary research, usable knowledge/usable science, and transdisciplinarity – as integral parts of its infrastructure development. The chapter ends by laying out the rationale behind and structure of this book.

Achieving the vision: infrastructure development and HERO

Infrastructure for monitoring global change in local places

To paraphrase the American politician Tip O'Neill,[2] "all global change is local." On the one hand, anthropogenic global environmental change is the accumulated result of billions of individual actions occurring at billions of specific locations. On the other hand, people experience the biophysical and socioeconomic impacts of global

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environmental change in identifiable places. Efforts to implement adaptations to those impacts, as well as to implement actions to mitigate the human causes of global environmental change, take place locally. Thus, a critical – but until recently, missing – element of the global change research agenda is the integrated[3] study of global change in local places (Kates and Torrie 1998; Wilbanks and Kates 1999).

This book asserts that to develop sustainable communities and a sustainable Earth, it is essential to monitor global change in local places. Why is it important to conduct such monitoring?[4] The many sustainability indicator projects under way demonstrate that monitoring helps communities gauge their progress toward (or regression from) sustainability (e.g., Farrell and Hart 1998). Monitoring shows which actions are improving the local human–environment dynamic; it points to areas of strength and weakness in local human–environment relations. It identifies emerging vulnerabilities to nature or abuses of nature and how fast they are developing. Moreover, if monitoring detects the source of the vulnerability or abuse, it may suggest ways to diminish or eliminate the problem. Importantly, monitoring enables a community to set goals and to determine how far it is from reaching those goals.

Scientists should monitor global change for similar reasons. At all human levels – international, national, and local – monitoring would help gauge progress on adapting to and mitigating global change. Monitoring would tell scientists what adaptation and mitigation strategies are working and which ones are not working. It would identify when and where global change problems are developing and would suggest how urgently society should address the problems. It would enable international bodies, nations, and communities to set goals and measure advancement towards those goals.

Alas, today's global change monitoring efforts emphasize the global scale. They tend to be disjointed and piecemeal, especially at local scales. We believe that the opportunity exists to promote a coordinated monitoring effort that focuses on global change in local places. It affords the scientific community the chance to implement the infrastructure needed to support effective global change monitoring. What should that infrastructure look like?

The Intergovernmental Panel on Climate Change (IPCC) provides one model of the infrastructure needed to monitor global change – in this case, climate change (e.g., IPCC 2007a, b, c). There are problems with this model, however. First, the IPCC provides five-year snapshots of the state of the climate and related environment, but tracks few clearly defined indicators of climate change and even fewer indicators of climate change impacts. Instead, the process relies on a larger suite of unique case studies; in fact, the main job of IPCC scientists is to synthesize diverse case studies and to judge subjectively what they mean *in toto*. The IPCC process does a better job of tracking the socioeconomic activities that cause climate change because national databases of socioeconomic activity tend to be superior to natural science and human–environment databases. Second, the IPCC focuses on global and continental scales – not on the community scale where people ultimately cause, experience, and respond to climate change. Third, IPCC scientists communicate while compiling the five-year reports, but most agree that communications are cumbersome and influenced by international politics and would benefit from continuous discourse. Finally, although scientists form formal networks to conduct an IPCC assessment, these networks disperse after each assessment, with scientists going back to their organizations to re-engage in research and with governments reforming the networks with new people and ideas for the next assessment. There is no mechanism to maintain an ongoing, worldwide network of researchers joined by common interests, collaborating in real time, and free from political constraints. In order to construct a rich picture of climate change, it is necessary to embrace and accumulate the results and perspectives captured by many local, regional, and global studies. Moreover, to integrate such studies, there needs to be support for formality and logical inference, for diverse opinions and approaches, and for the use of imprecise and contested knowledge.

Thus, science needs a new, alternative model for an infrastructure to monitor global change. That model must enable scientists to monitor the ongoing causes and consequences of environmental change across a continuum of scales, including – and with special emphasis on – the local scale. The model must facilitate convenient real-time sharing of data, analyses, and ideas among scientists working in regions and locales around the planet. It must foster a sense of community, purpose, and intellectual freedom among scientists who study global change and who share the goal of sustainable communities on a sustainable planet.

One important aspect of this envisioned infrastructure is the development of research protocols[5] and data standards for scientists working on global change in local places. Such protocols should be flexible, accommodating a broad spectrum of potential users from diverse geographic areas and with varying resources and training (Tran and Wu 2001). The protocols should be dynamic, incorporating new technologies, methodologies, models, data, and intellectual paradigms over time. They should be standardized so that comparisons are possible, showing how processes influencing global change vary over space and time. In addition, global change research protocols should balance data (e.g., quantitative versus qualitative), models (e.g., deterministic versus stochastic), and scope (e.g., multiple spatial and temporal scales). Clearly, there is a tension among the competing concepts of flexibility, dynamism, standardization, and balance, making the development of research protocols for monitoring global change in local places a non-trivial task.

While protocols have been slow to develop, there has been significant progress on international and national data standards, especially in the realm of geospatial data.

Most of these efforts involve governments at international or national levels, such as the European Committee for Standardization (CEN 2007) or the United States Federal Geographic Data Committee (2007). Taking the lead on geospatial standards for industry, the Open Geospatial Consortium (OGC) aims at increasing the interoperability[6] of hardware and software involving spatial information and location – that is, OGC facilitates communication among geographic information systems, vendor brands, data sources, and computing platforms (OGC 2007). Its members include public and private companies, universities, government agencies, and other organizations interested in building geospatial interoperability. Notably, OGC sponsored the Geospatial Information for Sustainable Development Initial Capability Pilot (GISD-ICP) in summer and fall 2002. This pilot project demonstrated how geospatial information standards can enhance sustainable development efforts and showed why such standards are critical at the local level. This pilot was just the beginning – science must go much farther to scale data standards from the global and national levels to the community level. In sum, the efforts of governments and industry reduce the need to develop data standards for global change monitoring by providing clear guidelines for data storage.

Understanding global change in local places cannot happen in isolation. Scientists who monitor this problem must share their data, methods, and ideas so that they can build a picture that helps them know which characteristics are local, which are regional, and which are truly global. The World Wide Web has made it increasingly possible for scientists around the world to know what other scientists are doing. Most Websites, however, do not promote dynamic intellectual interchange or capture the excitement of dynamic communication. In contrast, a collaboratory[7] uses the interconnectivity of the Web to link scientists in near real time, if not real time (MacEachren 2000, 2001). The concept of the collaboratory goes beyond email and instant messaging to include such dimensions as Web-based video conferencing, electronic Delphi tools, and portals that allow scientists and others to share databases, maps, graphs, notebooks, and workspaces interactively. Pilot collaboratories are being developed around the world, but none have realized their potential because of technical, security, and other issues. Only one, introduced in the next section, has focused on global change in local places.

Finally, an essential part of infrastructure aimed at studying and monitoring global change in local places is a network of scientists who will adopt research protocols and data standards and who will engage each other in a collaboratory. There are already hundreds of local-area research and monitoring sites around the world that focus on environmental change and issues of sustainability; only a few sites concentrate on global change in local places. In all cases, however, these sites function largely independently, collecting unique data in unique ways, thus making cross-site comparison more or less impossible now and in the future. Scientists

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working at these sites sometimes are aware of the work of colleagues at other research and monitoring sites through Web searches, published papers, and conferences, but more often they are unaware of parallel efforts; rarely, if ever, do they coordinate their efforts to leverage natural, but untapped, synergies with their colleagues. It is crucial, therefore, that an international network of researchers develops so that science has an ongoing dialogue about consistent, verifiable, and comparable records of global change in local places over time and over space.

The HERO project

The goal of the Human–Environment Regional Observatory project was to develop a prototype of the infrastructure and concepts needed to understand and monitor global change in local places and to prove that the infrastructure and concepts worked. HERO did not seek to create networks of researchers, but to enable the development of such networks. To reach its goal, the project had three strategies. First, HERO developed research protocols and data standards for collecting human–environment data to facilitate the studying and monitoring of global change at individual sites and to enable cross-site comparisons and generalizations. Second, HERO built a collaboratory to help investigators share data, analyses, and thoughts from remote locations and to collaborate in answering common research questions. Third, HERO tested these ideas by applying the protocols, standards, and networking environment at four proof-of-concept research sites to investigate land-use-induced vulnerability to hydroclimatic variation and change.

The research design came directly from the strategies outlined above and had two essential components. The first component was the Web-based HERO Intelligent Networking Environment (HEROINE, located at The Pennsylvania State University), which had two tasks. One was to develop ways to handle the heterogeneous quantitative and qualitative, biophysical and socioeconomic data generated in local human–environment research. Current approaches to data interoperability, mentioned briefly above, are largely about data communication between different computers in different places. HERO needed to go beyond those approaches to address the issues involved in linking human understanding with formal systems.[8] Consequently, we developed computational methods for modeling knowledge about the conceptual understanding of human–environment interactions and the process of decision-making.

These methods provided a foundation for HEROINE's second task: to build a collaboratory where researchers from around the world could share data; analyze, visualize, and compare those data; and interact with one another while working at their local sites. Approaches developed and tested in the HERO collaboratory included an electronic notebook for posting data of any type (e.g., numbers, words, audio, and video) and of any format at a central repository for instant access by all researchers in the network, no matter where they were located. Codex, a searchable, sharable, dynamic Web portal later replaced the original electronic notebook and allowed researchers to represent different perspectives about information resources. Codex aimed at enabling a global network of scientists to capture, compare, and compute their different approaches to science; it was not limited to data, but included methods, work practices, and the situated nature of any human–environment enquiry (Gahegan and Pike 2006). Another approach was an electronic Delphi tool designed to support remote group decision-making and consensus building through an anonymous, iterative process. A third approach was Web-based video conferencing, which allowed collaborators to interact through their computers regardless of their physical location by seeing and hearing each other, as well as by sharing presentations, documents, and real-time work.

The second component of the HERO research design consisted of proof-of-concept testing. To provide a real-world context for developing the infrastructure, the project focused on the question, "How does changing land use affect the vulnerability of people and places to hydroclimatic variation and change?" Less formally, the question is, "How does land-use change influence vulnerability to droughts and floods?" HERO addressed this question at four HERO proof-of-concept testing sites (HEROs) in diverse biophysical and socioeconomic settings. The four HEROs were located along a decreasing east–west precipitation gradient starting in central and eastern Massachusetts, carrying through central Pennsylvania to southwestern Kansas, and ending in the Arizona–Sonora border region (Figure 1.1). Researchers from these HEROs came from the geography departments at Clark University, The Pennsylvania State University, Kansas State University, and The University of Arizona, respectively. The researchers collected data using the same protocols, stored and shared their data using the same data standards, and interacted through the HERO collaboratory. A vital part of this interaction involved implementing the collaboratory to develop the protocols and standards and to improve tools through group interaction.

To answer the research question posed above, the four HEROs focused on assessing vulnerability and land-use/land-cover change. The vulnerability assessments started by developing a framework for defining vulnerability. Many frameworks exist and some are complementary, but others are not. As a result, HERO team members adopted an iterative approach to frame, operationalize, and report the results of the vulnerability research. The iterations allowed the conceptual framework to adapt to the varying biophysical and socioeconomic contexts of each area as identified by the initial scoping exercise and by later vulnerability analyses.

Vulnerability studies focus on a particular place, at a specific time through its three dimensions – exposure, sensitivity, and adaptive capacity. An understanding

Figure 1.1. Location of HERO study sites.

of place, including the physical characteristics of the landscape and the political and social milieu of the population (Jianchu *et al.* 2005), is essential to analyzing vulnerability. Understanding local vulnerability required examination of local context and knowledge. To develop this understanding, the HEROs engaged in historical research to determine local human–environment interactions and associated land-use/cover changes for each site. After determining vulnerability at the individual sites, cross-site comparison searched for commonalities and differences across the regions.

HERO contended that if society is to study and monitor the local dimensions of global environmental change in the future, then it is essential to develop a cadre of young scientists trained in this research area today. Consequently, an important element of the HERO infrastructure was the training of young scientists. In addition to the many postdoctoral and graduate students who participated in the HERO project, the HERO Research Experiences for Undergraduates (REU) program engaged advanced undergraduate students in field, laboratory, and archival research on human–environment interactions and, especially, global change in local places (Yarnal and Neff 2007). The program followed a cooperative learning model to foster an integrated approach to geographic research and to build collaborative research skills. The program hosted 12–16 students annually, who first engaged in an intensive two-week short course and then formed three- or four-person teams to conduct six weeks of research at the four HEROs. The student teams used the HERO collaboratory to work together across sites and to integrate their research and findings.

Although HERO personnel continually reached out to other national and international networks to share their vision of infrastructure and the collaboratory, the four sites and their faculty, staff, postdoctoral researchers, graduate students, and undergraduate students formed the small network that produced the research covered in this book. Throughout the five years of the project, these researchers turned to a single, overarching question for guidance on infrastructure development:

- How do we understand and monitor local human–environment interactions across space and time?

To answer that all-encompassing question, they addressed three more-focused guiding questions:

- How do we collaborate across space and time?
- How do we build networks of human–environment collaborators?
- How do we benefit from collaboration across academic generations?

The book will return to these questions in Chapter 15.

Addressing complex environmental systems via transdisciplinarity

The vision expressed in the opening paragraph of this chapter asked the reader to imagine a time when scientists could help contribute to community and planetary sustainability by collaborating amongst themselves and with various stakeholders. This vision intersects major growth areas in science over the last several years: complex systems, interdisciplinary research, usable knowledge/usable science, and transdisciplinarity. All of these areas contribute to what the United States National Science Foundation (NSF) calls complex environmental systems (NSF 2003). HERO embraced this approach to science and the concepts behind it.

Complex systems may or may not be complicated, but they are certainly interdependent and integrated. Human–environment systems, which integrate interdependent social and biophysical systems, are therefore complex. HERO, which by its title focused on developing systems to assess, monitor, and study local human–environment interactions, therefore tackled a complex topic.

Interdisciplinary research involves "research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" (National Academy of Sciences 2004). HERO researchers were all from the discipline of geography, but they represented the specialized knowledge of the three of the four research areas of that discipline: human geography (social science), physical geography (physical science), and geographic information science (information science). Reaching the goal of HERO – to explore the possibility of developing the infrastructure needed to build a network of sites devoted to understanding and monitoring human–environment interactions across space and time – was well beyond the scope of any one of these areas of research practice. Instead, investigators worked together in geography's fourth research area – human–environment geography – to build and test the prototype HERO network.

Complex systems, such as integrated human–environment systems, and interdisciplinary research, which integrates the content of multiple bodies of specialized knowledge, work together synergistically. Klein (2004) thinks that the convergence of interdisciplinarity and complexity is part of the larger cultural process of postmodernism in which domains of expertise have become more permeable. She finds that a central feature of postmodernism is the reversal of reductionist tendencies and increasing hybridization, interdependence, and cooperation of science and scientists.

This breakdown of barriers goes beyond the separation among academic disciplines to include greater permeability in the barrier between the academy and larger society, with the related ideas of *usable knowledge* and *usable science* symbolizing the transformation. Usable knowledge is knowledge that generates tools, materials, and ideas that people apply to problem solving and decision making. In human–environment interactions, usable knowledge is "incorporated into the decision making processes of all stakeholders [to enhance] their ability to avoid, mitigate, or adapt to stressors in their environment" (Lemos and Morehouse 2005). Similarly, usable science provides information that specifically addresses societal needs. It is socially distributed, application oriented, and subject to multiple accountabilities (Nowotny *et al*. 2003); rather than being subject only to peer review, science produced for use by society is accountable to the users it aims to serve (Dilling 2007). HERO actively sought not only to build the prototype of an infrastructure to help human–environment scientists break down barriers between areas of scientific specialization, but between those scientists and stakeholders, working together to produce knowledge they could use to develop more sustainable communities.

Transdisciplinarity fuses the concepts of complexity, interdisciplinarity, and usable knowledge/usable science. Klein (2004) cites five keywords that capture the essence of transdisciplinary science: beyond disciplinarity, problem-oriented, practice-oriented, process-oriented, and participatory. She finds that transdisciplinary problem identification does not originate with scientists, but instead with stakeholders, and these real-world problems are not neatly structured, but complex and messy. Moreover, she stresses that transdisciplinarity does not subscribe to reductionist assumptions about how systems work and their components relate, does not operate in the absence of stakeholder and community inputs, and does not suppose that science delivers final, precise estimates with certainty.

The project had the financial and moral support of NSF and the National Oceanic and Atmospheric Administration (NOAA) to take tentative steps into transdisciplinary science. At the time the project received funding in 2000, both agencies were seeking to move their human–environment science into the transdisciplinary realm (see NSF 2003). HERO contributed to NSF initiatives in coupled natural–human systems, coupled biological–physical systems, and people and technology; it also promised to build capacity to address complex environmental challenges through HERO educational programs, scientific outreach, infrastructure development, and technical advances. HERO had the opportunity to move human–environment science into uncharted territory and thereby advance the study of complex environmental systems.

Structure of this book

This book presents an in-depth view of HERO. It is divided into six parts that follow a logical progression and are meant for sequential reading. After this introductory chapter (Part I), Part II discusses the HERO Intelligent Networking Environment and related geospatial technologies and applications. Its three chapters include a look at the theory behind collaboration (Chapter 2), the HERO collaboratory (Chapter 3), and two applications that use local knowledge for representing and reasoning (Chapter 4). Part III sets the scholarly and field contexts for later analyses in its three chapters. The first of these, Chapter 5, offers an overview of the methods HERO used to assess local context and vulnerability, whereas Chapter 6 introduces the historical–environmental context of the four HEROs and Chapter 7 gives a satellite-based overview of the land use and land cover analyses used at these sites. Part IV consists of three chapters on vulnerability. The first of these chapters (Chapter 8) presents the methodological approaches used to assess vulnerability and the second and third chapters (Chapters 9 and 10) apply those methodologies in the four HERO regions. Readers who want to know more about the regions instead of following the intended chapter sequence can jump to Part V, which features four chapters that describe the local human–environment interactions in the HERO regions – central Massachusetts, central Pennsylvania,[9] southwestern Kansas, and the southern Arizona–northern Sonora border lands. The book concludes with Part VI, which reviews the HERO vision; answers the guiding questions and discusses sometimes hard, but necessary lessons learned; and expresses the need for HEROs.