INFRASTRUCTURE TO DEVELOP A HUMAN-ENVIRONMENT REGIONAL OBSERVATORY (HERO) NETWORK

2003-2004 Annual Report

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1. PROJECT ACTIVITIES

Goal and Strategies

Scientists and policy makers now realize that localities will play a central role in addressing the causes and consequences of global environmental change. For example, to mitigate global greenhouse gas emissions, national governments will take actions at specific places (such as cutting point-source emissions from manufacturing processes) or across small regions (such as managing forests to maximize carbon sequestration). At the same time, people will experience the positive and negative impacts of climate change locally and will implement adaptation strategies locally.

Despite this awareness, science has no systematic effort to monitor global environmental change and related human-environment interactions at local scales. One reason is that infrastructure does not exist that allows and promotes such monitoring.

Consequently, the goal of the Human-Environment Regional Observatory project (HERO) is to develop the infrastructure needed to monitor and understand the local dimensions of global environmental change, with emphasis on human-environment interactions. To reach that goal, the project has four strategies. First, HERO is developing research protocols and data standards for collecting data. These protocols and standards will facilitate the studying and monitoring of human-environment interactions at individual sites and, at the same time, will enable cross-site comparisons and generalizations. Second, HERO is building a Web-based networking environment that will help investigators share data, analyses, and ideas from remote locations. Third, HERO is field-testing these concepts by applying the protocols, standards, and networking environment in diverse biophysical and socioeconomic settings. Finally, HERO is organizing a network of researchers who are investigating the local dimensions of global environmental change and who will use the HERO infrastructure.

Research Design

The research design comes directly from the strategies outlined above and has three components. The first component is the Web-based HERO Intelligent Networking Environment (***HEROINE***), which has four ongoing tasks. The first is to develop methods for handling the heterogeneous quantitative and qualitative, biophysical and socioeconomic data generated in local human-environment research. The second is to develop innovative geocomputational techniques to analyze these diverse data. The third is to develop ways to visualize these heterogeneous data and analyses. The fourth is to build a geocollaboratory where researchers from around the world can share, analyze, visualize, and compare those data, interacting with one another while working at their personal computers or in small conference rooms.

The second component of the HERO research design consists of proof-of-concept testing. To provide a real-world context for developing the infrastructure, testing focuses on the question,

"How does changing land use affect the vulnerability of people and places to hydroclimatic variation and change?" HERO is addressing this question at four HERO proof-of-concept testing sites (***HEROs***) in diverse biophysical and socioeconomic settings. Researchers from these HEROs are collecting data using the same protocols, storing and sharing the data using the same data standards, analyzing and visualizing the data using the same geocomputation and visualization tools, and interacting through the HERO collaboratory. An important part of this interaction is to use the collaboratory to develop the protocols, standards, and tools through computer-assisted group decision-support techniques (e.g., the e-Delphi method).

For the third component of the research design, HERO is striving to build a network of researchers working on the local dimensions of environmental change. As a starting point, HERO has developed relationships with four consortia of human-environment researchers. One consortium is the international Land Use/Land Cover Change (LUCC) Programme, a Programme Element of the International Human Dimensions Programme (IHDP) and the International Geosphere-Biosphere Programme (IGBP). The second consortium involves the US Long-Term Ecological Research (LTER) Network funded by NSF, which is adding a social science component to its ongoing biophysical monitoring and research. The third consortium is the incipient Sustainability Geoscope, an initiative of the Potsdam Institute for Climate Impact Research (PIK) that is funded by the German government. Much like HERO, Geoscope aims to develop an international network of sites monitoring local sustainability. The fourth consortium is the incipient National Ecological Observatory Network (NEON) funded by NSF. NEON has an explicit human-environment component, and HERO is in on the ground floor, infusing the developing network with HERO ideas. HERO is treating LUCC, LTER, Geoscope, NEON, and other research and monitoring sites as a stakeholder network, simultaneously linking them through the HERO infrastructure and working with them to develop infrastructure that meets their needs.

All-HERO Activities

HERO is a collaborative project linking the four HEROs, HEROINE, and USGS partners. Four clusters of activities engaged the entire HERO team in Year 4: all-hands meetings, intensified cross-site collaboration aided by collaboratory tools, poster and paper presentations at the Annual Meeting of the Association of American Geographers (AAG), and undergraduate research.

Two all-hands meetings connected team members. The first involved a brief assembly at the Annual Meeting of the AAG in Philadelphia, March 17, 2004. The purpose of the meeting was to update project members on progress, to make plans for the remainder of Year 4, and to touch base with one another. Activities included a presentation on the state of the HERO project at the two-thirds mark, breakouts of working groups, reports summarizing the working group breakouts, and an open discussion. The second all-hands meeting took place May 16-19, 2004 in the SOuthwest-Mexico Border Region HERO (SOMBRHERO) region on the University of Arizona campus. Representatives from all HEROs attended the meeting, thus enabling significant progress. Formal presentations were minimal, but those that did occur focused on specific research topics to enhance cross-site collaboration in five crucial subjects: vulnerability, land use/cover change (LUCC), knowledge management, development and implementation of

the HERO Research Experiences for Undergraduates (REU) site, and cross-site comparison of the most historically significant human-environment interactions in each study area. Woven throughout the meeting were research and writing breakouts, where teams representing the five research areas worked on extant papers and on developing collaborative research and products for Year 5.

Intensification of cross-site collaboration marked advancement in the way HERO protocols are developed. For instance, the HERO vulnerability assessment protocol tested during REU activities in summer 2002 was developed at Penn State and distributed to the other three sites, then applied and tested at all four HEROs by the REU students and their faculty mentors—a top-down approach to protocol development. The results of that research include vulnerability assessments for all four HEROs, datasets detailing the spatial distribution of natural and technological hazards and vulnerable demographic groups, and two journal articles: one performing a cross-site comparison of vulnerability to natural and technological hazards (in preparation), and a second on the pedagogy of involving undergraduates in collaborative human-environment research (under review). While these products are significant achievements, one of the most important findings of the summer 2002 research was that the protocol was not entirely robust across all four study sites due to differences in scale and the physiographic and demographic diversity among the sites. Consequently, a cross-site working group was formed shortly after the completion of the REU research period to address shortcomings in the protocol. This vulnerability group instituted a new collaborative model of protocol development that involves an iterative consensus-building process—a bottom-up approach. This approach, discussed in more detail below, focuses on commonalities among the sites to ensure comparability across sites, while allowing each site the flexibility it needs to retain the unique characteristics of each place in its analyses. The other working groups have adopted similar approaches.

The HERO Collaboratory greatly enhanced cross-site collaboration. As will be noted in the section on HEROINE activities, the collaboratory foci were e-Delphi, e-Conferencing, and Codex. The HERO team participated in two e-Delphi exercises. The first exercise aimed at deepening the team's understanding of vulnerability. In a Year 3 e-Delphi exercise, the HERO team decided to use the IPCC definition of vulnerability, which states that vulnerability is a function of exposure, sensitivity, and adaptive capacity. In this Year 4 exercise, the team moved beyond the earlier concentration on exposure to probe the concepts of sensitivity and, especially, adaptive capacity. The second Year 4 exercise focused on developing the research for the summer 2004 REU program. The e-Conferencing tool played a central role in connecting researchers at all four HEROs. The Vulnerability Working Group and the REU Planning Group held e-conferences regularly; although not without significant modifications to the original conception of the tool, e-Conferencing moved from the experimental stage into the realm of everyday experience. The third focus of the HERO Collaboratory was development and use of Codex, that name given to our knowledge management system. We used Codex to enhance and improve data management and dissemination and to understand the concepts behind HERO protocols and research.

A third all-HERO activity was a series of papers and posters presented at the Annual Meeting of the AAG in Philadelphia in March 2004. Although HERO special sessions at the 2002 and 2003 Annual Meetings of the AAG were highly successful, the team decided not to concentrate the researchers in one or two sessions but instead to spread papers throughout the 2004 meeting, thereby giving the project even greater visibility. Consequently, HERO investigators presented

papers at several well-attended sessions. In addition, undergraduate student participants of the summer 2003 REU program presented four posters—one for each HERO site.

The fourth all-HERO activity concerned the ongoing commitment to undergraduate research through NSF's REU program. In the last quarter of Year 1 and first three quarters of Year 2, the team hosted five REU students supported by five REU Supplements to HERO. These students became integral members of the project, producing important research and contributing both to the all-hands meetings and to an illustrated poster session in Los Angeles. Encouraged by the success of this activity, the HERO team applied for and received funding to conduct a formal HERO REU Site during summer 2002 (i.e., Year 2). This innovative REU Site supported 12 undergraduates—three each from Massachusetts, Pennsylvania, Kansas, and Arizona. The program started with a two-week short course at Penn State, taught by the PI and a team of post docs and graduate students, where the REU students learned basic theory and methods used in human-environment research. Laboratory and field methods received equal emphasis. At the end of the short course, mentors from all four HEROs flew to Penn State to meet the students, participated in an all-hands meeting that overlapped the last two days of the short course (thus integrating the REU students into the project and allowing them to meet many of the HERO investigators virtually, if not really), and escorted the students back to their HEROs. During the remaining six weeks of the HERO REU Site, students worked in three-person teams to conduct a vulnerability assessment of their study areas using the quantitative vulnerability assessment protocol discussed in the 2002 Annual Report. Unique features of this REU Site are not only the distributed nature of the REU experience, but also the cross-site collaboration using the HERO collaboratory. For example, weekly e-Conferences allow the REU students to compare research experiences and to maintain ties with the rest of their cohort. An important benefit of the REU process is that it has drawn the HERO team members closer through planning, interaction, and shared experience. It has accelerated the collaboratory development and provided additional motivation for protocol development. The summer 2002 experience was so positive that the HERO project applied for and received funding from NSF to continue the HERO REU Site through summer 2005. With considerable input and guidance from the faculty mentors, the summer 2003 REU cohort interviewed community water system managers and transcribed, coded, and interpreted the interview audio tapes to develop an understanding of community water system vulnerability to climate-induced water quality and quantity problems. Students used the HEROINE collaboratory tools intensively, communicating and sharing complex ideas and data across sites. In the end, the fact that smart, hard-working undergraduate students can grasp the core HERO ideas and can use the HEROINE tools effectively proves that the HERO concept works.

HEROINE

HEROINE's aims are to develop computational infrastructure to support collaborative human-environment research and to assess the benefits of advanced collaboration tools for the research process. While the three original research areas within the HEROINE effort – collaboratory, data management, and geocomputation –all received attention during Year 4, the focus of the HEROINE team's recent work was on the convergence of these areas around a fourth component, the problem of knowledge management for the complex environmental

sciences. This convergence further integrated HEROINE's computational infrastructure with the proof-of-concept studies under way at the HERO sites. The following sections outline HEROINE's recent work in its four research areas.

COLLABORATORY

The HERO Collaboratory is a suite of integrated tools that take advantage of ubiquitous desktop networking technology to enable collaborative scientific exploration and decision-making by teams of distributed users. The four HERO sites are presently the primary users of the collaboratory tools, although the tool design accounts for a broad user base. Several of the HERO Collaboratory tools have attracted interest from groups unaffiliated with the HERO project; the project actively encourages their use by such groups.

e-Delphi. The Delphi method is an approach to group problem solving appropriate for questions that require the estimates by a panel of experts or interested parties. Through an iterative series of questions and feedback, a moderator guides participants toward a synthesis of group belief. For issues in human-environment relations, the Delphi method is a useful technique for gathering predictions on the drivers or effects of global change and choosing phenomena to monitor.

HERO e-Delphi (http://hero.geog.psu.edu/eDelphi), an asynchronous system that allows users to contribute at any time throughout the course of a Delphi activity, is a Web-based implementation of traditional mail Delphi surveys. The e-Delphi tool has undergone further refinement during Year 4. Participants use a secure login to access a personalized e-Delphi start page from which they can enter current activities; participants can also start new Delphi activities and select a panel of new or existing users to invite. While HERO's e-Delphi tool is not the first computer-based Delphi system, it is the only one that is available to the public over the Internet. The e-Delphi system was designed to support human moderators by taking care of most managerial tasks (such as emailing reminders to participants, controlling the length or style of responses), allowing moderators to spend more time working with the participants. E-Delphi is also anonymous, removing many of the barriers to frank discussion (e.g., social status, personality) that accompany face-to-face meetings.

HERO's e-Delphi also allows outside users who visit through links from other sites or search engines (the HERO tool is one of the top listings on Google for online Delphi systems) to request access for their own groups. To date, over a dozens of requests to use the tool have come from around the world, and many groups (in health and medicine, construction, and economics) are planning to include e-Delphi as part of their collaboration. While its use by external organizations helps spread HERO's message, the e-Delphi tools help collect usability information from users, allowing HEROINE researchers to improve understanding of the process of group decision and negotiation as well as the nature of communication supported by asynchronous technologies.

An example of an external organization that has successfully used the e-Delphi component of the HERO collaboratory is the Consortium of Atlantic Regional Assessments (CARA), an EPA-sponsored research project aimed at disseminating useful information on the local and regional impacts of climate change to stakeholders. Participants in CARA's e-Delphi exercise included nearly ninety stakeholders from government, industry, and environmental groups, as well as private citizens. The purpose of the activity was to determine ways for CARA to refine its

message about climate impacts so that it would have meaning for the diverse audiences consuming CARA's research products. The primary benefit CARA derived from e-Delphi was the ability to engage many participants from a range of interests, geographic areas, and demographic backgrounds. While in-person meetings, focus groups, or workshops are necessarily limited in who can attend and contribute, the e-Delphi process can accommodate as many people as a moderator wishes. For CARA, it allows communities often left out of research decisions to participate. The anonymous nature of the activity helped CARA's participants, particularly those who might otherwise have been uncomfortable collaborating with researchers, share their ideas forthrightly. CARA used a voting feature in e-Delphi to help participants select and refine key climate impacts messages over time. Because they could not be identified, participants were more likely to vote for ideas they felt strongly about rather than those proposed by "important" people.

e-Conferencing. The HERO Collaboratory aims to provide tools that support the range of collaborative activities required for truly global, integrative research. The e-Delphi component of the collaboratory is asynchronous, enabling researchers to connect with each other at any time and in any place, without requiring simultaneous interaction. There are times when direct communication is necessary, however, because the efficient solution of problems hinges on synchronous dialogue. The aim of HEROINE's e-Conferencing solution is to provide desktop videoconferencing services to HERO sites, allowing spontaneous meetings between individuals or groups of HERO researchers. The e-Conferencing implementation also extends basic video communication with data sharing; researchers can use the conferencing system to explore data sets or give presentations collaboratively, viewing and even controlling the desktop of remote machines.

During Years 2 and 3, HEROINE deployed videoconferencing equipment to each of the four HERO sites. This equipment consists of an integrated camera and microphone unit, conferencing software, and (at Penn State) a Multipoint Conferencing Unit (time on which is offered by Penn State Information Technology Services) that brokers communication between the sites. Two all-hands meetings were held using this equipment, demonstrating the feasibility of inexpensive substitutes for group travel. When it worked, the sense of presence and fluidity of dialogue supported by integrated video and audio communication surpassed that afforded through audio-only (e.g., telephone) conferences. The REU students made extensive—almost daily—use of videoconferences, consulting about research methods and cross-site protocol development in real-time while located at their distributed research sites.

One of the most promising aspects of HEROINE's e-Conferencing system is the ability to send an auxiliary data signal in association with the voice and video streams. This facility offers two primary uses. First, users can broadcast any computer program on their machine, such as a Microsoft PowerPoint presentation, to other participants in a conference. Second, a group of users can share control of a single machine, taking turns controlling the display of data in a Geographic Information System, for example, to support a point being made verbally. The integration of data sharing and conferencing streams mimics the same sort of informal discussions around a computer screen that might take place among researchers at the same location, but allows scientists anywhere in the world to participate. REU students used the data sharing capability to communicate problem-solving approaches they had developed. For instance, a student familiar with mapping software used desktop sharing to allow another student to follow along as he explained a series of operations required to map Census data. The students

then swapped control, so the "expert" student could watch as the other person attempted the same operations on her machine (and offered control of her desktop so the expert could help out as needed). Throughout, each participant could see and hear each other in a corner of their screens.

In Year 4, however, e-Conferencing took an unexpected turn. Despite continuing work to improve the implementation of the system, videoconferences actually became worse, rather than better, with degraded video and, especially, audio. Meetings became dysfunctional. HEROINE team members worked directly with software developers and hardware experts to solve the problems. In the end, short of installing an expensive dedicated videoconferencing system, which would defeat the HERO goal of providing inexpensive e-Conferencing via the Internet, HERO made the difficult decision to abandon video temporarily and to concentrate on other avenues for successful synchronous interaction. Much to HEROINE's surprise, interaction and meeting productivity actually *increased* when the researchers shifted to weekly teleconferences with supplemental desktop sharing. It appears that having clear audio and a visual object on which to focus—such as a graph or set of bullet points—is much more important for successful same-time discussions than having a colleague's video image. The drawback to this substitute for Web-based videoconferencing is that teleconferences cost money. The HEROINE team will work on inexpensive Internet-based audio solutions in Year 5.

Knowledge management. Recognizing the importance of preserving a record of the process of scientific investigation, the HEROINE team used the Electronic Laboratory Notebook software developed at Pacific Northwest National Laboratories to design a Web portal for all of HERO's data resources, including working documents, plans, sketches, measurements, and more. The e-Notebook tool allowed researchers not only to improve the efficiency of their own work (by having ready access to all of their past products), but also to increase the effectiveness of collaboration. E-Notebook permitted other team members to have access to the records of analyses performed in other places or at other times, thus allowing them to reuse data, replicate methods, or compare problem-solving strategies. This tool served as the primary data distribution resource for the HERO project and allowed researchers easy access to each other's data and documents. The system also proved invaluable as a means of preserving project resources after the researchers who created them moved on.

There were a number of shortcomings in the implementation, however, that limited its usefulness and prompted development of next-generation tools. First, e-Notebook was organized around a hierarchical file structure that limits the flexibility users have in viewing and storing information. Second, search functionality was limited. Third, there was no effective way to create links between notebook elements that would help organize files around common themes (nor was there a way to record the themes to which a file applied). Lastly, there was no way to preserve changes to the notebook to help users summarize the development of individual or group reasoning. Because of these and other usability problems with the original e-Notebook, the adoption of the tool among HERO collaborators was not as great as it could have been. Based on the experience gained with e-Notebook, HEROINE researchers developed a new system from the ground up that better supports the work practices of those engaged in human-environment research.

The need to capture and share the rich record of the scientific investigation process led HEROINE researchers to work toward the convergence of several of its research streams under the theme of Knowledge Management. The data and other concrete research products that tools

such as the e-Notebook can store do not necessarily reflect how researchers conceive of a problem, what methods they used to explore the problem, and what outcomes resulted from their exploration. In an age of electronic science, rapid growth in the quantity and resolution of observations has not been matched by the development of computational representations of knowledge structures helping human analysts to classify and explain high-dimension data.

HEROINE's knowledge management activity concerns the development of tools that capture concept definitions as they evolve. These software components help meet the recognized need for interactive tools that can operate at the same levels of abstraction as their human users. Moreover, knowledge management tools that foster the integration of analyses across different researchers, different places, and different times are vital to fulfilling many of the goals of integrative complex environmental science. Assessing long-term climate trends, ecosystem change, carbon-cycle dynamics, and land-use change, for instance, require the integration of space-, surface- and laboratory-based measurements made in different places and of different quantities. Reconciling these measurements necessitates a semantics of environmental information, which this effort helps scientists create. HERO is also concerned with making current thinking available to future generations; is it possible to share not just data, but how these data guided our decisions (or how our decisions guided the collection of data)?

HEROINE's new knowledge management tool, Codex, supports this spatial, temporal, and conceptual integration by creating a computational infrastructure that encodes concepts, thus allowing them to be defined, refined, and reused collectively by teams of collaborators. The applications for such a knowledge management system include:

- Revealing what data and methods are applied to problems (and at what stage they are applied), thereby guiding future data collection and tool development efforts.
- Comparing methodologies, concepts, and solutions with those of collaborators.
- Reusing or modifying existing methodologies or concepts to suit new problems, increasing problem-solving efficiency.
- Discovering core concepts that indicate levels of agreement within and between research domains.
- Describing the different perspectives—or worldviews—that inform how individual researchers approach problems.
- Maintaining an organizational knowledge base that archives the evolving state of institutional belief.

HEROINE has implemented a Web portal with a series of tools that allow researchers to encode conceptual information in an easy-to-use graphical interface. The core of this new system is a *concept representation* framework that stores concept definitions and relationships; this framework is built around the DAML (DARPA Agent Markup Language) notation that is commonly used to describe knowledge structures for the Semantic Web. *Concept capture* tools allow for both diagrammatic and form-based input; users can draw concept maps that are stored as concept definitions and can view the results of a concept or database query as a graphical network of relations. *Concept comparison* tools enable users to discover how similar concepts are constructed in different places, at different times, or by different people; it is also possible to compute levels of agreement among different versions of a concept to define the core elements that are shared among researchers.

HEROINE deployed most components of the knowledge management system in time for the summer 2003 HERO REU Site program, in which it played an important role for both the students and the HEROINE investigators. Students had a suite of tools that helped them explore their problem-solving approaches and link data and methods in digital experiments. The HEROINE team gained a record of the knowledge structures that were built during the course of investigation.

The HEROs—Site Descriptions and Year 4 Activities

HERO for Central Massachusetts (HERO-CM)

During 2003-2004, HERO-CM has made progress concerning on-going projects and generated tangible final products.

We have made progress on:

- digitzing a historic map of 1951 for more than 100 categories of land cover for the central Massachusetts study area.
- building the digital data archive concerning water quality in central Massachusetts.
- coordinating with the Mayor of the City of Worcester to revitalize brownfields and reduce energy consumption.
- writing a multi-authored paper on the vulnerability to climate change.

Our tangible final products are associated directly with the accomplishments of Clark University students who are or recently have been HERO fellows. Specifically:

- Nick Malizia won $500 and was selected to present his research as a finalist in a competition at the meeting of the Association of American Geographers. Malizia also presented his work as an invited speaker at the Open Meeting of the Human Dimensions of Global Environmental Change in Montreal, Canada. Malizia's related undergraduate thesis won Highest Honors.
- Chris Lippitt won the award for the best undergraduate paper in a competition at meeting of the Association of American Geographers. His paper has been accepted to be published in the Conference Proceedings of the joint meeting of The Fifteenth Annual Conference of The International Environmetrics Society and The Sixth Annual Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences in Portland ME.
- Matt Holden presented his research on digitizing maps in an illustrated poster competition at the meeting of the Association of American Geographers.
- Maatsi Angwafo and Yasmin Bowers co-presented both a poster and an oral presentation at the meeting of the Association of American Geographers.
- Holden, Lippitt and Williams published a paper in the Biological Bulletin concerning their work on digitizing historical maps and methods to compare maps between two points in time.

- Jeff Malanson won five years of funding to pursue his PhD at Boston College. His HERO research has been accepted for publication in the International Journal of Geographical Information Science.
- Emily Shusas published her HERO research in the journal Agriculture, Ecosystems & Environment.

Susquehanna River Basin (SRB-) HERO

Although it is a rural landscape, the Susquehanna River Basin (SRB) has suffered intensive human use for more than two centuries. Three stages of lumbering—driven by demand for agricultural land, then fuel, and finally paper and other wood products—resulted in total deforestation of the basin by the early 20th century. Forest management has promoted significant regrowth in recent decades. Coal mining changed the cover of large portions of the basin and led to severe acid mine drainage in many of the basin's sub-watersheds. Transportation, first in the form of canals and later in the form of railroads and highways, transformed the land and opened the basin for settlement. Towns and small cities dot the basin today, but the surprisingly large rural population dominates the landscape. Agriculture flourishes in the valley bottoms and piedmont, from which nutrient runoff aggregates on its way to the Chesapeake Bay. Economic restructuring took place over the last few decades, replacing mining and the limited manufacturing base with high-tech and service-based enterprises. Urbanization and suburbanization is gobbling up prime farmland in dynamic growth poles, such as Centre County, although serious socioeconomic problems exist in many declining areas, such as contiguous Huntingdon and Clearfield Counties.

The long-range goal of the SRB-HERO is to engage this landscape of rich human-environment interactions by operating at multiple spatial and temporal scales. It will reconstruct LUCC history and its drivers and will model future LUCC to determine the present and future vulnerabilities of the basin's inhabitants to climate variation and change. It also will study carbon fluxes in the basin in an attempt to understand the contributions of the basin to climate forcing and the potential for managing the land to mitigate climate change. Spatially, it will be concerned with the effects on data and analysis of using both natural units (e.g., watersheds and ecoregions) and political units (e.g., townships and counties). It will compare data and analyses across small sub-basins (e.g., Spring Creek), large sub-basins (e.g., the West Branch of the Susquehanna), and the entire SRB. Temporally, it will address the effects caused by aggregating disparate data and processes by the units imposed by the daily, weekly, monthly, and annual calendars.

During the five proof-of-concept years, the SRB-HERO team is focusing its activities on Centre County, a microcosm of the SRB. The county has experienced, is experiencing, and will experience: deforestation, forest regrowth, and intense forest management; coal mining and acid mine drainage; conventional American and traditional Amish agriculture; development of the transportation network; significant economic restructuring; rapid urbanization in the midst of a rural landscape; and significant socioeconomic disparities.

During Year 1, the SRB-HERO team worked on developing: (1) a historical baseline, (2) a conceptual model linking LUCC and climate variation and change, and (3) a vulnerability protocol based on the intersection of land-use and natural and technological hazards. Year 2 research focused on vulnerability assessment of the Spring Creek Watershed, land-use change,

and carbon. Using the evolving vulnerability assessment protocol, SRB-HERO investigators assessed the vulnerability of people and places in the Penns Creek Watershed to climate-related natural hazards and to technological hazards during Year 3. Research on LUCC took place at two spatial scales: Upper Penns Creek Watershed and Centre County. The Upper Penns Creek work focused on the vulnerability assessment, relating land use to the distribution of environmental hazards and socioeconomic groups. The Centre County research concentrated on LUCC over the period of satellite observations and resulted in complete LUCC maps that have been ground-truthed pixel by pixel. Carbon and greenhouse gas (GHG) inventories are also a focus of the SRB-HERO. Investigators have conducted GHG emissions inventories for Pennsylvania, five counties in central Pennsylvania (including Centre County), and the Penn State main campus.[1] HERO investigators also inventoried Centre County carbon stocks as part of the LUCC research.

In Year 4, SRB-HERO researchers continued to refine previous work on the Spring Creek Watershed and the Upper Penns Creek Watershed. In addition, members of the team undertook research on the following topics:

- Assessment of community water system vulnerability to droughts and floods
- Assessment of Moshannon Creek Watershed vulnerability to environmental hazards
- Assessment of Bald Eagle Creek Watershed vulnerability to environmental hazards
- Assessment of Centre County songbirds as indicators of environmental change
- Agent-based modeling of community water system vulnerability
- Updated and improved hydroclimatic database for Centre County
- Carbon flux modeling associated with regional LUCC
- Climate impact scenario development
- Updated greenhouse gas emissions inventory and projection for Penn State

See Section 2, “Project Findings” for details of the findings from these activities.

High Plains-Ogallala HERO (HPO-HERO)

HPO-HERO focuses on a nineteen-county area in southwestern Kansas. Land cover has been significantly transformed in the study area by irrigation agriculture, extensive dryland cultivation, the development of mega-beef packing plants, and extraction of natural gas from the Hugoton gas field. Islands of population growth exist within a sea of long-term population decline. Local LUCC is a response to at least five major factors:

- Climate change (both interannual and longer-term variations)

[1] GHG inventories are useful for many reasons (US Environmental Protection Agency, 2002. In Brief: The US Greenhouse Gas Inventory. A brochure accessed at http://www.epa.gov/globalwarming/publications/emissions/ghgbrochure.pdf). Scientists use inventories to understand those physical and human processes that first cause emissions and then respond to increased GHG concentrations in the atmosphere. Decision-makers use inventories to develop strategies and policies for emissions reductions and to track the progress of those policies. Regulatory agencies and corporations rely on inventories to establish compliance records. Businesses, the public, and other interest groups use inventories to understand the sources and trends in emissions.

- Agricultural and other policy changes
- Socioeconomic and demographic factors
- Resource availability (especially water resources)
- Local thinking, external influences, and decision-making

HPO-HERO is developing research protocols and data standards for mapping, monitoring, and explaining human-environment interactions in agricultural landscapes. Specific to southwestern Kansas, the research team places emphasis on natural resource issues such as groundwater depletion, technological innovation, farm policy, crop and animal prices, and agricultural restructuring. Methods are being designed to observe and record human response to climate change, stressing the themes of vulnerability, adaptation, and mitigation. HPO-HERO is developing methods for monitoring the impacts of human-induced climate change on the long-term economic, social, and demographic aspects associated with maintaining regional sustainability. It is clear that the local acceptance of global climate change is beginning to have tremendous implications for federal and state-level farm policy within the region. Investigations therefore will include how shifts in attitudes and beliefs about global warming influence the pattern of LUCC. Year 1 and Year 2 activities pursued these agenda items and included work on the HPO-HERO region's historical database, the concept of vulnerability, and the impacts of endogenous agents of change in the study area.

Year 3 and Year 4 activities included work on LUCC and associated socioeconomic change, as well as on climate change, vulnerability, sustainability, and protocol development. The fourth year of HPO-HERO activities included continued data compilation and analysis. Both the 2003 REU students and regular HERO faculty and graduate students gathered data related to public water supplies and vulnerability of the 19-county study area. Investigators also collected data related to agricultural production and LUCC. Agricultural change and change in water-table depth are being related to drought conditions by using the Standardized Precipitation Index (SPI). The proportion of water used specifically for irrigation is uniquely high in this HERO, with past changes and future vulnerabilities particularly related to agriculture. Some of the agricultural data have been extended to encompass approximately the western third of Kansas in order to capture broader patterns of agricultural, water resource, and population change than can be captured by the HPO-HERO region of southwestern Kansas.

In addition to building crop agricultural datasets and analyzing crop changes, researchers with the HPO-HERO also are addressing livestock change in the study area. Modern "mega" dairies, in a feedyard setting, have expanded significantly in this HERO over the last decade. Such new activities/land uses have implications for resource use, and their development in this area may not be sustainable; i.e., dairy cattle require high-moisture feed such as alfalfa, which in turn requires more water than other crops. In a region of declining water tables, such new activities may be vulnerable to changes in climate and land-use conditions.

Work is continuing to identify major human-environment interactions that have shaped the four HERO proof-of-concept sites, with an HPO-HERO researcher taking the lead.

In March 2004, the 2003 HPO-HERO REU students presented the findings of their research at the Annual Meeting of AAG in Philadelphia. Members of the HPO-HERO team have presented and have plans to present work at various professional meetings, including the 2003 UK-US-Canadian [quadrennial] Rural Geography Conference, 2004 national AAG meeting, the 2004 International Geographical Union meeting in Scotland, the 2004 Applied Geography

Conference in St. Louis, and the 2004 American Society for Photogrammetry and Remote Sensing meeting in Denver, among others.

Southwest and Mexico Border Region HERO (SOMBRHERO)

The geographical extent of the SOMBRHERO study region is the United States/Mexico border region that divides southeastern Arizona (AZ), United States and northeast Sonora (SO), Mexico. The border runs through a diverse mix of environments ranging from fragile upland deserts to open grasslands and oak woodlands, to spruce-fir forests at elevations reaching 10,000 feet above sea level. Two transboundary river basins are situated in the region, the Santa Cruz River Basin and the San Pedro River Basin. Both rivers are distinctive because they flow south to north and, thus, Mexican land-use decisions influence United States water access and quality. The sister river basins fall within two counties on the Arizona side—Santa Cruz and Cochise—and four municipios on the Sonoran side—Cananea, Nogales, Naco, and Santa Cruz. In addition, there are several major population centers, including Tucson, AZ, Nogales, AZ/SO, Cananea, SO and Hermosillo, SO.

The SOMBRHERO region is changing rapidly as NAFTA continues to rearrange economic relations towards open markets that encourage a dynamic border region. This dynamic makes the border region a particularly appropriate place to monitor and study local human-environment relationships because it exhibits different cultures, political institutions, resource management strategies, livelihood strategies, and socioeconomic processes—all of which operate at local scales but are influenced by globalizing forces. The study region also reflects the challenges embedded within transboundary environmental regimes that are increasingly positioned within globalized environmental issues.

More specifically, the region exhibits many problems associated with border industrialization including rapid urbanization, increased water and air pollution, poor or nonexistent sanitation infrastructure, and other problems associated with mounting traffic and migration flows. It also has a historical rural frontier presence that is particularly affected by and vulnerable to drought and land-cover change. On the American side, ranching exists on public and private rangeland, alongside irrigated agriculture and orchard farming of both large and small scales. On the Mexican side, most ranching is on ejido (common property) land, but with privatization, these lands are being parceled off and irrigated for intensive cropping (Figure 1). While these economic strategies may seem to be predominately rural, the linkages between urban and rural areas are increasingly important in evaluating human vulnerability, as well as environmental impacts. Moreover, the study region has a historically integrated resource economy based in mining that draws heavily on water sources, and exhibits some of the economic inequities and problems that recent border industrialization exemplifies.

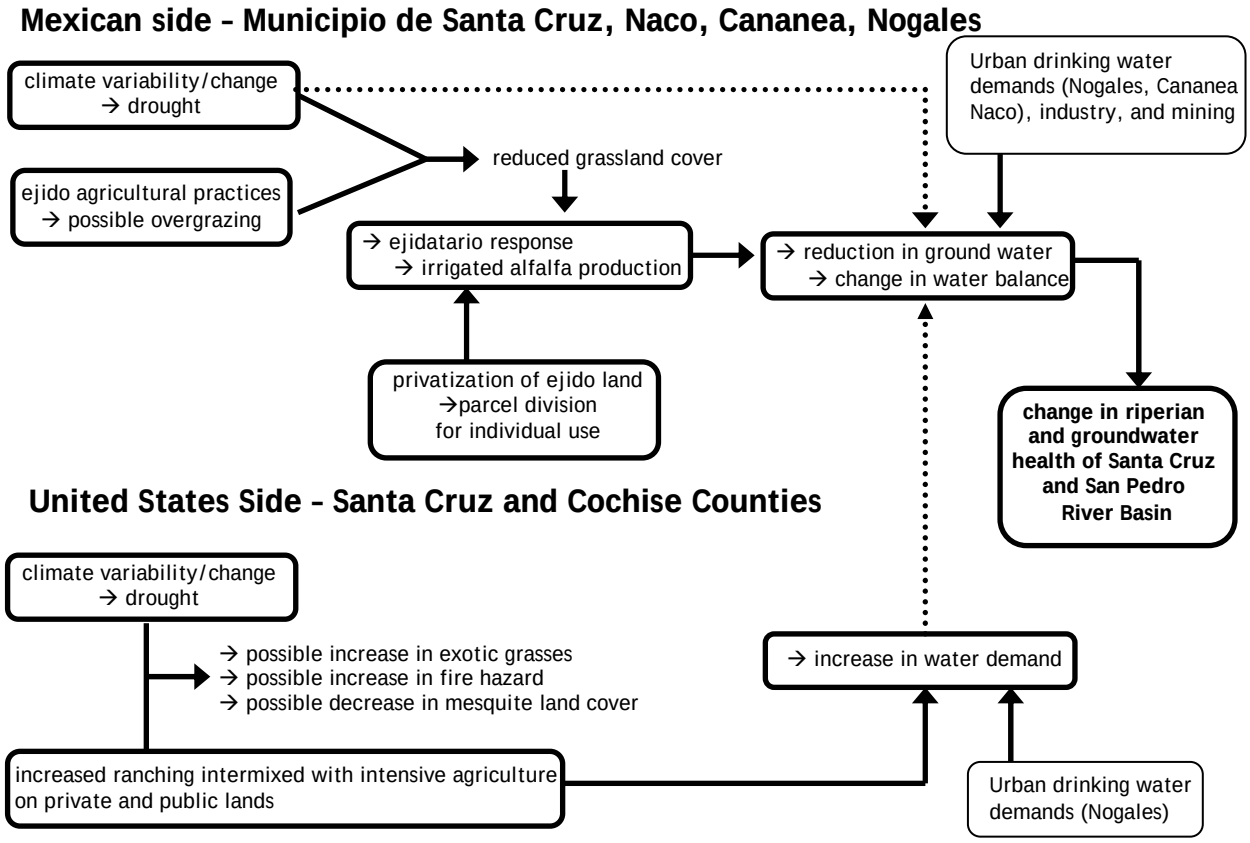


Figure 1: Problem definition for initial research on Upper Santa Cruz River Basin

Given this context, SOMBRHERO research draws from the following set of research questions:

- What are the major dynamics of LUCC and how do they reflect specific geographic patterns of land tenure, agricultural systems, mineral development, ecosystems, and urban change?
- How are larger forces of globalization and privatization (e.g., land and water reform in Mexico) influencing trends and patterns in land use and land cover?
- In what ways do climate variability and change, as influencing factors on ecosystems, shape both land cover and livelihoods that are dependent on this land cover?
- What are the social determinants and indicators of vulnerability to drought and other climate changes? How might new policies and technologies (e.g., seasonal forecasting and altered water institutions) foster adaptation?
- What linkages exist between rural and urban populations, and how do such linkages shift and/or influence vulnerability of people and landscapes to climate and environmental change?
- How are agricultural activities in response to climate change and variability, impacting riparian vegetation and water table balance in border watersheds?

- How has urbanization, in response to larger globalizing forces, affected water quantity, quality, and balance in border watersheds?

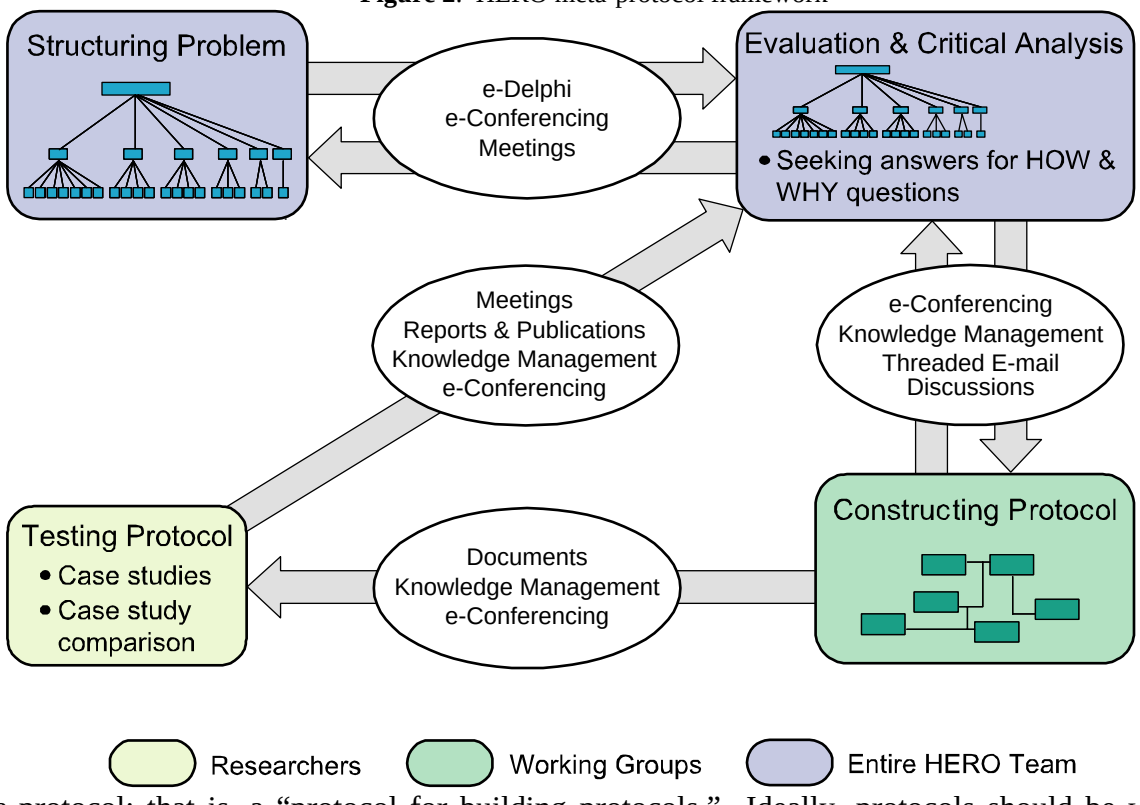
2. PROJECT FINDINGS

HERO is an infrastructure development project, so most of its "findings" are not typical of NSF-sponsored research. Given this caveat, the four strategies used to develop the HERO infrastructure—protocol development, intelligent networking, proof of concept, and network building—continued laying down a strong foundation for the infrastructure in Year 4. Note that network building is an outreach activity (reported in section 4, below) and as such cannot produce findings.

Protocol Development

Two cornerstones of protocol development were continued: a meta-protocol and a vulnerability assessment protocol. In addition, based on the HERO meta-protocol, protocol development began on LUCC; future protocol development for linking LUCC and vulnerability and for linking climate change to both phenomena is planned for Year 5. HERO has developed a

Figure 2. HERO meta-protocol framework



meta-protocol; that is, a "protocol for building protocols." Ideally, protocols should be well-structured, dynamic, and flexible. They should accommodate multiple criteria and should be

multidisciplinary in scope. The HERO meta-protocol meets these standards by presenting four interactive phases of activity (Figure 2).

The meta-protocol framework is an iterative, flexible process that allows researchers to jump forward or backward from one phase to another at any time to address changing needs, knowledge, and technology. It is highly structured so that scientists can compare the framework at any two points in time, thereby seeing how their knowledge changed and improved. The framework facilitates collective efforts and consensus building; it allows different research groups and stakeholders to work together in an integrated process.

Two protocol-development activities involve the entire HERO team: Problem Structuring and Evaluation and Critical Analysis. Problem Structuring involves activities such as broadly defining terms, research questions, etc. Evaluation and Critical Analysis necessarily occurs at all stages of protocol development to ensure that the diverse expertise of the entire HERO team is utilized. However, to make the process of consensus building tractable, smaller groups are involved in actual protocol construction and testing. Protocol construction is done in cross-site working groups to ensure protocol elements are robust across all HERO sites and that the protocol is flexible enough to capture the uniqueness of each place. While the protocol is circulated among the entire HERO team for evaluation and critique, the final determination of the elements (topical foci, methods, and data) of any protocol is made by the appropriate working group. Finally, the protocol is tested by researchers at all four sites and—through meetings, reports, and HEROINE collaboratory activities—is critically evaluated by the entire HERO team in preparation for the next iteration of the ongoing process.

HERO investigators started this process by applying a vulnerability assessment protocol—developed for contemporary coastal zones by NOAA's Coastal Services Center on a theoretical foundation laid by Susan Cutter and colleagues at the University of South Carolina—to Cape May County, New Jersey. The investigators extended this protocol to a climate change context that included socioeconomic and LUCC change (Wu et al., 2002). The vulnerability assessment was able to demonstrate that even with uncertainty concerning the number and strength of future coastal storms, sea-level rise will make wealthy residents much more physically vulnerable to storms while socioeconomically disadvantaged residents will be much more economically vulnerable to storms. The HERO investigators then moved the protocol inland to the Spring Creek watershed, Centre County, Pennsylvania (Brendle, 2002). The researchers found that weather and climate do not currently pose particularly great risks to the population of the watershed, but that the combination of rapid urbanization and climate change will exacerbate those risks that do exist. In summer 2002, four three-person REU student teams applied the HERO vulnerability assessment protocol to the HERO-CM, HPO-HERO, and SOMBRHERO study areas, as well as to the Upper Penns Creek Watershed in central Pennsylvania, thereby facilitating further improvements to the protocol.

That iteration of the HERO vulnerability protocol was a result of two years of testing, constant re-evaluation, and critique. It attempted to provide guidance for the application of a set of standard methodologies to evaluate the vulnerability of natural and social systems to both short-term climate variability and long-term climate change (Figure 3). It reasoned that vulnerability is a function of exposure to various stressors caused by climate variability and change, the sensitivity of a system to these stressors (the degree to which a system will be affected adversely to a given degree of climate variability and change), and the ability of the system to adapt to these stressors (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage due to a given change in climate).

Under this framework, a vulnerable system would be one that is sensitive to modest changes in climate with the potential for substantial harmful effects, and one for which the ability to adapt is

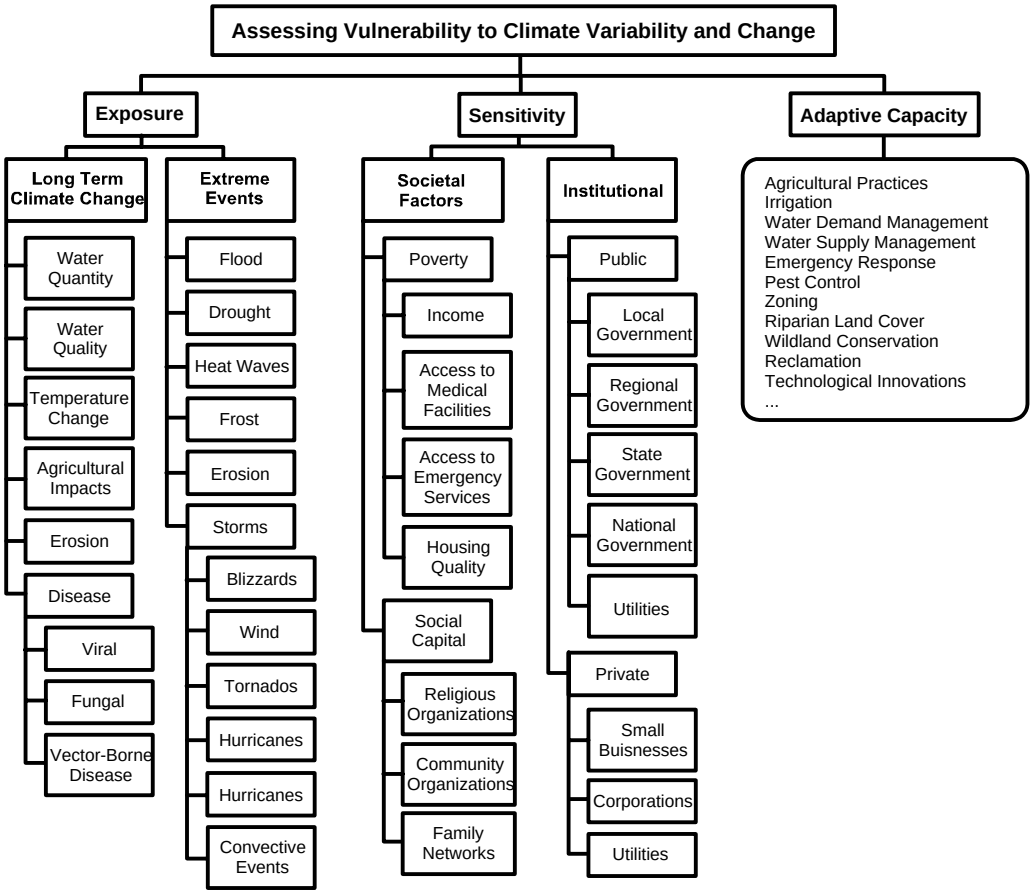


Figure 3: A hierarchical framework for a vulnerability assessment protocol

constrained. Hence, three main components of a HERO vulnerability protocol are exposure, sensitivity, and adaptation potential. Two important additional issues that are important in a vulnerability assessment are uncertainty and links to all scales of policy. Such a comprehensive vulnerability assessment protocol is a dynamic, evolving product, rather than a static framework.

Despite this progress, HERO investigators continued to evaluate this approach to vulnerability assessment. They concluded that the protocol was adequate for uncovering general trends in vulnerability and supporting cross-site comparison, but that it was inadequate for understanding the causes of local vulnerability. Consequently, in summer 2003 they extended the protocol to include qualitative components to complement the existing quantitative methods. The summer 2003 REU students learned how to gather and analyze qualitative data and subsequently interviewed community water system managers in their study areas. (The focus on community water systems narrowed the scope of their research, thus making it possible for them to complete the work in the six-week research period.) The findings suggested to HERO investigators that comprehensive vulnerability assessment requires both quantitative and qualitative research.

Knuth (2004) tested this idea by conducting a mixed-method vulnerability assessment in central Pennsylvania's Moshannon Creek Watershed. She found that integrating quantitative and qualitative vulnerability assessment methodologies resulted in a more complete representation of overall vulnerability than would have been possible using either protocol alone. Each methodology brought unique strengths to the assessment. The reductive character and spatial-display capability of quantitative research made it suitable for informing policy and cross-site comparison. The holistic nature of the qualitative, interview-based assessment allowed it to capture unique local characteristics and important trends in vulnerability. Mixed-methods application allowed each protocol's results to suggest improvements to the other's methods and conclusions, especially when the two methods approached similar facts from different perspectives. When the two protocols agreed, they identified key strengths of the analysis; when they disagreed, they identified weaknesses and suggested modifications to one or both of the protocols. The summer 2004 REU students will conduct research that continues to evolve the qualitative portion of the vulnerability protocol.

The HERO investigators also continued to mature the meta-protocol. Modifying a model developed by the Project for Public Spaces (http://www.pps.org) to evaluate the character and quality of places, HERO is using concepts displayed in Figure 3 to blend quantitative and qualitative aspects of vulnerability assessment (Figure 4). The diagram shows that vulnerability to drought (the center of the diagram and the target of the assessment) is a function of exposure, sensitivity, and adaptive capacity (the next ring out from the center). In the green ring outside these main components of vulnerability are a number of qualitative or difficult-to-measure concepts by which to judge vulnerability. This ring is the focus of qualitative research. The outermost (blue) ring shows the quantitative aspects of vulnerability to drought that are measurable by publicly available statistics or by research. Beneath the diagram (not shown), are brief explanations of exposure, sensitivity, and adaptive capacity and, more important, questions

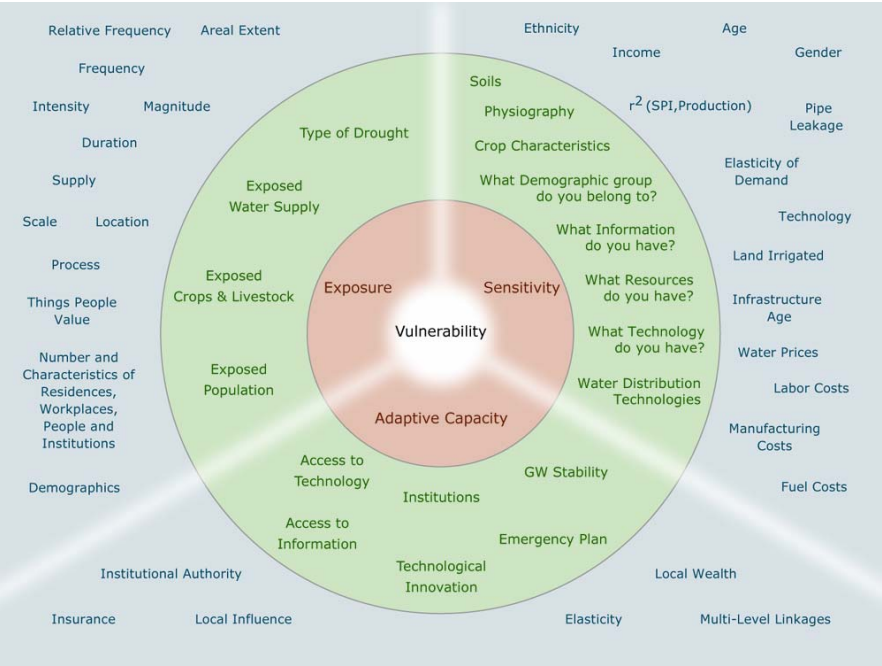


Figure 4. Prototype vulnerability assessment protocol diagram.

to consider when assessing these three components of vulnerability. This diagram is an incomplete work in progress—terms and concepts will be added, removed, and refined—but moves the project significantly closer to the goal of developing a user-friendly meta-protocol for assessing human-environment interactions over space and/or over time.

Intelligent Networking

In Years 1, 2, and 3, research on intelligent networking identified five system characteristics as important for supporting different-place (remote) collaboration:

- Facilitating dialogue—the ability to talk/chat while viewing and interacting with tools
- Group member behaviors—the ability to know what others were doing
- Drawing the group's attention—the ability to indicate objects, places, and regions and to alert others to the indications
- Private work—the ability to work out ideas individually before sharing them with others
- Asynchronous collaboration—the ability to save and share sessions and to initiate new analysis from any point

In Year 4, HEROINE investigators continued to build upon this foundation by applying these findings to development of remote collaboration tools and techniques detailed elsewhere in this report, including e-Delphi, e-Conferencing, and Codex. (E-Delphi, e-Conferencing, and Codex work in Year 4 were described in Section 1 of this report, "Project Activities.") Thus, the main "findings" were the successful application of these five characteristics to the process of collaboratory.

Proof of Concept

To be ready for testing the general HERO infrastructure—i.e., the protocols, data standards, and intelligent networking environment—the four HEROs continued building their local infrastructure. In addition, work began to test preliminary HERO protocols and each site actively engaged in the continued development of vulnerability and LUCC protocols. This section reports the results of the Year 4 activities documented in Section 1, "Project Activities" (and of necessity repeats some of that material for context).

HERO for Central Massachusetts (HERO-CM)

During 2003-2004, each of the HERO-CM tangible final products has generated interesting findings. Each of the points below related to the product above.

- Nick Malizia's research has found a mathematical solution to the Category Aggregation Problem (CAP). The CAP states that statistical analysis of a categorical variable can be very sensitive to the selection of the level of detail of the categories. Malizia's work shows how statistical results will behave as a function of aggregating many detailed

categories to fewer broader categories. The applicability of the technique is relevant in every field of scientific inquiry.

- Chris Lippitt's research shows a potential pitfall when a scientist attempt to assess the amount of land change by comparing two maps from different points in time. His method offers an approach that shows exactly how accurate the maps need to be in order for a scientist to conclude confidently that that the difference between two maps indicates true landscape change. Lippitt's work shows that the standard acceptable accuracy level of 85% correct is insufficient for most measurement of land change.
- Holden's research has found an efficient way to digitize maps using a combination of numerous software packages.
- Angwafo's and Bowers' work has shown that water resource managers are constrained by financial considerations so they can not even address immediate concerns, thus their opinion about climate change does not have a direct effect on their management style.
- Holden, Lippitt and Williams found an interesting method to measure the land change in Massachusetts over the last five decades.
- Malanson research has shown that simpler land change models perform as well and sometimes better than complex ones and that most researchers over estimate the accuracy of land change models.
- Shusas found a solution to a common blunder that tricks many scientists. Her method shows how to find systematic patterns among the categories in a transition matrix.

Susquehanna River Basin (SRB-) HERO

Year 4 local-area research at SRB-HERO focused on vulnerability, hydroclimatology, land-use/land-cover change (LUCC), and carbon. The 2004 REU students contributed to the evolution of the vulnerability assessment protocol by using a qualitative approach to assess the vulnerability of Centre County's community water systems to droughts and floods. They determined trends and indicators of sensitivity through fieldwork and by interviewing and surveying 15 community water system managers. Their results indicate that surface water systems are more vulnerable to climate change than groundwater systems are due to their direct exposure to atmospheric processes. Systems with more than one source, with backup capabilities, and with emergency plans are better prepared for system failures. Systems with archaic infrastructure and that employ managers with little experience, have little funding, or are situated in areas with environmental hazards are more vulnerable to hydroclimatic change.

Undergraduate student Sarah Knuth used the evolving vulnerability assessment protocol to assess the vulnerability of people and places in the Moshannon Creek Watershed to environmental hazards. The analysis combined quantitative and qualitative approaches to vulnerability assessment. Quantitative analysis showed that floodplain occupancy is considerable and that services critical to watershed function are concentrated in the most vulnerable areas. Interview-based qualitative analysis demonstrated that lack of awareness of this vulnerability increases vulnerability by decreasing response effectiveness; resource constraints at both local and county levels also increase vulnerability. Integration of the quantitative and qualitative analyses confirmed key strengths of the analyses, including the assessment of flood risk, technological hazards from roads, patterns of coping ability, and vulnerability of critical facilities.

Ph.D. student Rachel Kurtz developed a model to estimate total carbon fluxes for two ecoregions that intersect the SRB—the Northern Piedmont and the North Central Appalachians—by combining satellite-based LUCC estimates on an ecoregion scale with field-based biometric estimates of carbon. The total ecoregion carbon estimates showed a slight decrease in carbon storage in the North Central Appalachians during the period 1973-2000. This loss was mainly due to the timber harvest rotation, when aboveground biomass was removed and replaced by young forests. In contrast, the Northern Piedmont increased carbon storage from the early 1970s through the early 1990s, when urban expansion led to carbon loss. Although these trends are contrary to other estimates of carbon in the Northeast, the carbon storage estimates agree with current research, thereby implying that these trends only became evident because of the increased spatial and temporal resolution of the LUCC data used in this research. The results suggest that to understand the distribution of carbon sources and sinks, and therefore to develop sound carbon management policies, it is necessary to account for differences in LUCC at regional and sub-regional scales.

M.S. student Christopher Steuer inventoried and projected GHG emissions at Penn State's University Park Campus. The GHG emissions inventory simplified methods originally developed by the Intergovernmental Panel on Climate Change (IPCC) and applies them at the university level. Results of a ten-year inventory indicated that steam and electricity use are the primary sources of University Park's GHG emissions, leading to a 21.4 percent increase in emissions from 1990-99. Projections, which focused on future demand for these sources, suggested that emissions would increase to 56 percent over 1990 levels by 2012, despite current mitigation efforts. Continued increases in emissions over the projection period would result from construction of new campus buildings and increased electricity use among faculty, staff, and students.

The year 2003-2004 saw several other SRB-HERO student research projects:

- A high school student, mentored by two undergraduate students, conducted a quantitative vulnerability assessment of Bald Eagle Creek Watershed using the quantitative protocol. Findings were similar to previous findings for Spring Creek and Upper Penns Creek Watersheds.
- An undergraduate student assessed the impact of Centre County LUCC on songbird populations. She found the greatest impacts in deforested and fragmented lands.
- Two undergraduate students updated and improved the hydroclimatic database and associated graphics for Centre County. Their work shows that Centre County regularly experiences periods of drought and excessive wetness. Although these periods typically last for approximately one year, they can persist as long as a decade.
- A Ph.D. student is using a mixed-method approach to develop an agent-based model of community water system vulnerability to hydroclimatic change. He has found that the more vulnerable systems are the ones with greater surface water influence.
- Another Ph.D. student is using a mixed-method approach to develop a protocol for building climate impact scenarios for local-area research and assessment. Her findings to date have showed a mismatch between the data and information provided by climate modelers and the data and information that climate impacts researchers need. Her work will concentrate on resolving this mismatch.

Proof-of-concept research by SRB-HERO senior investigators involved advising the above studies and contributing to the all-HERO research, including work on vulnerability to drought, LUCC, and meta-protocol development. This research is described elsewhere in the report.

High Plains-Ogallala (HPO-) HERO

Research relevant to the HERO project in southwestern Kansas has included the following findings:

- By far most water use in the study area is for irrigation purposes; this differs significantly with water use in other study areas. Ninety-six percent of freshwater use in the study area is for irrigation.

- Unlike other HERO study sites, the standardized precipitation index (SPI) does not have a strong relationship with total agricultural productivity in the region. This is related to expansion of irrigation, post-1950. Prior to extensive irrigation, the productivity of this agricultural region was much more closely tied to precipitation: the area displayed greater sensitivity to drought when there was little irrigation.

- Land cover change in Gray county for the period 1985 - 2001 is dominated by crop rotation.

- Land enrollments in the Conservation Reserve Program (CRP) in Gray county were estimated to occupy 9% of the landscape by 2001, with early (1985 - 1992) CRP enrollments in areas with more limited groundwater supplies.

- Change detection analysis using Landsat TM data was able to document the amount and locations of cattle feedlot expansion (a doubling between 1992 and 2001)

- Agricultural land use/land cover change in Wichita county corresponds with changes to the groundwater resource. There was a switch away from irrigated crop production to dryland agriculture in areas where the remaining groundwater resource is too limited and/or too expensive to extract. (2003 thesis)

- Mirroring other parts of the country, farms have become larger and fewer in number, and specialization has increased. Improved agricultural technology, including crop varieties developed for dryland agriculture are becoming more important. Greater vertical integration has developed for some commodities, such as irrigated feed grains, feedlots, and packing plants. The processes of local change have played out differently in subparts of western Kansas. Water resource availability has played a very important role in determining within-region variations.

- Irrigated cropland in the study area expanded from about 50060 ha in 1950 to 420000 ha in 1969. Crops grown through time have changed with the expansion of irrigation. Even crops that are more drought tolerant are grown with use of irrigation water, along with

more water-demanding crops.

- Agricultural change includes the expansion of dairying into the study area. This activity may not be sustainable in the face of climate change, due to high demands for feed that requires relatively large water inputs.

- Two models of groundwater vulnerability, DRASTIC and LPI, yield generally similar results for Finney County, Kansas. (2002 thesis)

- Although not sustainable in the long term, there have been moves toward prolonging the life of the groundwater resource through increased conservation aided by changing technologies (*e.g.*, subsurface drip irrigation) and other management shifts (metering, crop varieties). Having undergone withdrawals sometimes at rates averaging 38cm/yr or more, but with recharge of less than 5 cm/yr (through most of the study area less than 2.5 cm/yr), more recent rates of decline have averaged less than 15 cm/yr (KGS 2000). An attitude of adaptability and resiliency also may help to decrease overall vulnerability of the region to climatic variability and change.

- Although much of the land base is unirrigated, irrigated agriculture and intensive livestock operations are the basis for much of the regional economy. These activities are not vulnerable to precipitation changes in the short term, but changes toward increased dryness could be a major problem as groundwater supplies are further depleted. In some locations, irrigated land has decreased already, with moves toward less water intensive crops and/or varieties ('dryland corn,' *e.g.*).

- Even though irrigated agriculture often is the focus of attention for the region, most of the land in the area is devoted to dryland crops and range. These lands are particularly vulnerable to periods of drought (or poorly timed rainfall). If accompanied by high energy prices (for water pumping) and/or low producer prices, the region would suffer with drought. In recent years, farmers in the region have seen dangerous declines in the ratio of receipts to costs.

- Public water systems rely exclusively on ground water, mostly from the Ogallala Aquifer with the deeper Dakota Aquifer providing a small amount in some cases. Compared to places where surface water plays a major role in providing drinking water, Southwest Kansas is much less vulnerable to climate change and variability. Climate events such as droughts affect drinking water supply indirectly, through their effects on other types of water usage, mainly irrigation.

- Interviews of community water system managers indicated that the resiliency of each community water system was related to natural and technological hazards, agricultural and community population impacts on infrastructures, and the education and experience of water system managers. Irrigation, population increases, and limited availability of water resources increase the community water systems' vulnerability. (REU work)

- Natural stresses on agriculturally-based socio-economic systems of the High Plains include drought, tornadoes, hail, and severe winter weather. The major concern is the capacity of the socio-economic system to adapt to declining groundwater resources. A number of characteristics that can be thought of as contributing to vulnerability, and those that may mitigate vulnerability or contribute to sustainability. Some may do both, as is the case with groundwater use: it mitigates vulnerability in the short term, but may undermine sustainability and contribute to vulnerability in the short term.

Southwest and Mexico Border Region HERO (SOMBRHERO)

Year 4 activities were focused on analysis of preliminary research findings and write up of initial draft papers. SOMBRHERO researchers chose in year 4 to hone in on environmental issues arising in urban areas of the region, with three of the papers in draft form focusing on Ambos Nogales. Two of these papers utilize land cover change information developed from the SOMBRHERO land use/cover change work conducted in Year 2 and Year 3. The first looks at the environmental inequities developing in Ambos Nogales related to uneven urban growth and water resource use. The second paper looks specifically at the impact of land cover change on dust pollution and draws additionally from leveraged funding of a NASA Space Science Grant for Undergraduate Research which was obtained during SOMBRHERO Year 3 activities. The third of the "urban" papers draws from the all information gained in the first three full years of research to conceptually discuss the range of climate impacts that might be felt in the Ambos Nogales region as well as the political-economic factors that mediate and exacerbate these impacts. Lastly, a fourth draft paper was established which draws on two years of summer REU work in the SOMBHERO study site to compare perceptions of vulnerability to climate change.

In addition to establishing papers from the initial three years of SOMBRHERO work, the SOMBRHERO 2003-04 year added two new graduate students to the main project, each undertaking new subprojects that contribute to the larger SOMBRHERO questions by focusing specifically on the community capacities and social dynamics within the study region. The first of these projects looks at the potential for community participation in watershed conservation and management in Ambos Nogales. After completing a literature review on water resource issues in the border region, graduate student Lisa Shipek began conducting interviews in the border region utilizing questions from the SOMBRHERO urban survey instrument developed during Year 2 and 3, as well as adding other more specific questions. Extensive fieldwork for this project is planned for Summer 2004, with project write up to occur during the 2004-05 school year. The ultimate goal is to evaluate the capacity of community based conservation to serve as an adaptive strategy to climate change.

The second new project, involves graduate student Paula Decker who is applying specifically social science frameworks to look at vulnerability to floods in urban areas, using Ambos Nogales as a case study. Until now, most of the SOMBRHERO research has couched vulnerability to climate change in terms of drought. Paula's work will begin to span the gamut of potential climate events. Initial work on this project began Spring 2004 and culminated in the draft of a conceptual paper on climate change and border cities. Preliminary fieldwork for this project begins Summer 2005. The ultimate goal is to evaluate how networks produce and ameliorate vulnerability to floods in Ambos Nogales, with particular attention to how these networks vary across the border and the role of researchers in these networks.

3. TRAINING AND DEVELOPMENT

Faculty, post-doctoral researchers, graduate students, undergraduate students, and others worked on HERO in Year 4. Various combinations of funds from HERO and related projects supported these individuals. In some cases, faculty and students contributed their time without financial support. Whatever the circumstances, these arrangements provided HERO with valuable help and, at the same time, supported student academic programs.

After the first four years of the project, nearly 100 people have no contributed significantly to HERO. An increasingly important focus for HERO is research participation by undergraduates. In Year 1, HERO applied for and received an NSF Research Experiences for Undergraduates (REU) Supplement. This supplement supported the activities of five women undergraduates—two at Penn State and one each at Clark, Kansas State, and Arizona. Four were Honors students and the fifth was a McNair Scholar. Four students presented illustrated papers at the Annual Meeting of the Association of American Geographers in Los Angeles.

In addition to the HERO REU Supplement, HERO-CM maintained its own undergraduate HERO-CM Fellowship Program. Six undergraduate students (one of whom was supported on the HERO REU Supplement) were chosen from a pool of highly qualified applicants after a campus-wide recruitment campaign. Working with project staff and faculty mentors, they contributed to the development of the data and informational infrastructure of HERO-CM in conjunction with their individual and/or team research projects. They also helped the HERO-CM team establish and test protocols that permitted data sharing and site comparisons among the HERO sites. A core effort of HERO-CM, this program will continue annually.

Spurred by the success of the HERO REU Supplement and HERO-CM efforts, HERO developed an REU Site. HERO devoted a considerable portion of its spring 2002 activities to prepare for the HERO REU Site. Twelve students—three each from Massachusetts, Pennsylvania, Kansas, and Arizona universities—attended a two-week short course at which they received training in the theory and method of human-environment interactions in general and vulnerability assessment in particular. After that, the students returned to their respective HEROs to apply the vulnerability assessment protocol, thereby testing the protocol and suggesting improvements to it. The three-person student teams not only collaborated with their mentors and colleagues at the four HEROs, but also interacted with the other REU students through the collaboratory. The highlight of the student collaboratory was weekly—and sometimes daily—videoconferences. NSF funded this highly innovative, distributed REU Site for one year and has since granted funding for an additional three years based on the success of this one-year pilot. Year 4 saw the 2003 REU site and planning for the 2004 REU site, which will commence at about the time this document is submitted.

University Faculty

Principal Investigator

Brent Yarnal, Professor of Geography and Director of the Center for Integrated Regional Assessment, Penn State. Yarnal's primary responsibilities are to direct overall project and SRB-HERO activities, to lead the all-HERO network-building activities, to oversee development of the vulnerability assessment protocol, and to run the HERO REU Site.

Co-Principal Investigators

Andrew Comrie, Associate Professor of Geography, University of Arizona. Originally an Investigator, Comrie shared oversight of the SOMBRHERO site in Year 2; in Year 3, he oversaw the site in Diana Liverman's absence. In Year 4, he became Co-Principal Investigator and guided SOMBRHERO. His primary responsibilities include environmental analysis, including data set development and analysis of climate and geospatial information.

William Easterling, Professor of Geography and Director of the Penn State Institutes of the Environment, Penn State. In Year 2, Easterling led the SRB-HERO effort in scale interaction and land-use change, especially as they relate to carbon fluxes. His duties as Director of the Penn State Institutes of the Environment required him to resign from HERO in Spring 2002.

Mark Gahegan, Professor of Geography and Associate Director of the GeoVISTA Center, Penn State. Gahegan is in charge of developing HEROINE database protocols, geocomputational methodologies, and GeoVISTA Studio.

C. Gregory Knight, Professor of Geography, Penn State. Knight is directing the SRB-HERO work on water resource/hydrologic vulnerability to climate and land-use change.

Diana Liverman, Professor of Geography, University of Arizona. In Year 2, Liverman shared oversight of the SOMBRHERO project and was in charge of human-environment methodology development, including community assessment and vulnerability index creation. During Year 3, she was Interim Dean of the College of Social and Behavioral Sciences and had limited input to HERO. In Year 4, she moved to Oxford University, where she directs the Environmental Change Institute, and turned over the reigns of SOMBRHERO to Andrew Comrie. Liverman has continued to work with the research team, even attending the Year 4 all-hands meeting.

Alan MacEachren, Professor of Geography and Director of the GeoVISTA Center, Penn State. MacEachren is overseeing the HEROINE geocollaboratory, Website development, and visualization efforts.

Billie Lee Turner II, Professor of Geography, Clark University. Turner guides the overall direction of HERO-CM, secures institutional support, and conducts and directs research on global change in local places.

Stephen White, Professor of Geography, Kansas State University. Until Year 2, White examined population redistribution, socio-economic drivers, and other exogenous and endogenous agents of change in southwestern Kansas. Midway through Year 2, he became Interim Dean of the College of Arts and Sciences and had limited input to HERO. In Year 4, he became Dean. John Harrington has directed CPO-HERO activities in his absence.

Investigators

Douglas Goodin, Associate Professor of Geography, Kansas State University. Goodin is working on remote sensing of land-cover change and assisting with the assessment of climatic variability.

John Harrington, Professor of Geography, Kansas State University. Harrington is informally directing CPO-HERO activities for Steven White. His main research tasks include examining links between climate variations and land use and land cover change. He will be the designated mentor for the HERO REU Site students in summer 2004.

Lisa Harrington, Associate Professor of Geography, Kansas State University. Harrington is looking at local measures of vulnerability, public opinion, and local perceptions of environmental change. She was the designated mentor for the HERO REU Site students in summer 2002.

David Kromm, Emeritus Professor of Geography, Kansas State University. Kromm is assessing the importance of resource availability, irrigation technology changes, and agricultural policy on land use change.

Max Lu, Assistant Professor of Geography, Kansas State University. Lu is looking at changes in the cattle feedlot industry and examining social and demographic measures of local change. He was the designated mentor for the HERO REU Site students in summer 2003.

Robert Merideth, Assistant Director, Udall Center for Studies in Public Policy, The University of Arizona. Merideth advises on bi-national environment and policy research and provides links to other ongoing projects and stakeholders in the region.

Colin Polsky, Assistant Professor of Geography, Clark University. Polsky has joined the HERO-CM team, specializing in vulnerability assessment. In Gil Pontius's absence in 2004-2005, he will lead Clark's HERO Fellows Program and will mentor the summer 2004 HERO REU students.

Robert Gilmore Pontius, Associate Professor of Geography, Clark University. Pontius is leading Clark's HERO Fellows Program, including the mentoring of the HERO REU students. He also conducts LUCC research at HERO-CM using GIS and statistical models. He is leading the all-HERO LUCC data storage and analysis efforts. He will be on sabbatical in 2004-2005; Colin Polsky will mentor the HERO REU students.

John Rogan, Assistant Professor of Geography, Clark University. Rogan has joined the HERO – CM team, specializing in monitoring LUCC using remote sensing.

Robert Varady, Deputy Director, Udall Center for Studies in Public Policy, The University of Arizona. Varady advises on environmental policy and environmental conflict resolution in the border region and in the Southwest and provides connections to regional and local communities of decision-makers.

Post-Doctoral and Other Research Associates

Jeremy Diem, Ph.D. 2000, Postdoctoral Research Associate, University of Arizona (50% of his support came from HERO/SOMBRHERO). Diem carried out geospatial environmental and social data library development, a vulnerability index review, and SOMBRHERO workshop organization in Year 1 and the beginning of Year 2. He is now a faculty member at Georgia State University.

Ke Chen, Ph.D., 1998, University of Western Michigan (HERO-CM; 100% of his support came from HERO). Chen worked on the HERO project during its first three years and was in charge of day-to-day project management of HERO-CM, coordinating HERO and HERO-CM activities in consultation with lead faculty and carrying out research for HERO-CM focusing on institutional and informational dimensions of regional sustainable development.

Rob Neff, M.S., 1997, Southern Illinois University, Ph.D. anticipated in fall 204, Penn State (100% of his support comes from HERO). Neff manages the day-to-day operations of the HERO project and staff. He also manages the SRB-HERO. His research is wide-ranging, with foci on vulnerability, transportation networks, and carbon.

Cynthia Sorrensen, Ph.D. 1998, Ohio State University; Assistant Social Research Scientist, University of Arizona. Sorrensen came to the project in August 2001 from California State University, Los Angeles where she was an Assistant Professor. She is in charge of day-to-day management of the SOMBRHERO project and is the lead on setting the research agenda at SOMBRHERO that focuses on impacts of drought and climate change and water resources, vegetation, and fire hazard.

Liem Tran, Ph.D. 1999, University of Hawaii (SRB-HERO; varying levels of his support came from HERO). Tran worked on the HERO project during its first three years. He worked with Shuang-Ye Wu on designing a meta-protocol and with Gil Pontius and others to develop protocol data requirements. He also initiated research on local decision-making and development that links quantitative and qualitative data collection and analysis.

Shuang-Ye Wu, Ph.D. 2000, Cambridge University (SRB-HERO; 50% of her support came in Year 1; 100% of her support came from HERO in Year 2; she is now an environmental consultant in the Washington, DC area). Wu helped develop the vulnerability assessment protocol, design a meta-protocol with Liem Tran, and develop and teach methodology

modules for the HERO REU short course. She contributed to logistical support for the HERO REU Site.

Graduate Research Assistants

Isaac Brewer, Ph.D. student, Penn State (Years 1 and 2, summer support from PNNL and academic year support from research sponsored by the GeoVISTA Center). Brewer worked at PNNL on the e-Notebook, making it an important part of the HERO collaboratory tool for the Website. During the academic year, he contributed to HERO without compensation, helping with e-Notebook, e-Delphi, and Web-based videoconferencing. He contributed to logistical support for the HERO REU Site.

Hong Gao, Ph.D. student, Kansas State University (Partial Year 2 support from HERO). Gao compiled socioeconomic and LULC data.

Alistair Geddes, Ph.D. student, Penn State University (Year 2 spring support from HERO). Geddes worked on land-use/land-cover research in the SRB-HERO, with emphasis on transportation development.

Diansheng Guo, Ph.D. student, Penn State University (Year 1 summer support from HERO). Guo worked on developing the capability to build links between the database and Web applications in visualization, geocomputation, and collaboratory.

Nathan Kettle, MA. student, Kansas State University (Year 3 support from Kansas State). Kettle conducted research on groundwater depletion and LUCC.

Ryan Kroemer, MA. student, Kansas State University (Partial Year 2 and 3 support from HERO). Kroemer conducted research on LULC and vulnerability. He also helped with the summer 2002 REU.

Rachel Kurtz, Ph.D. student, Penn State University (Years 2 and 3 tuition paid by HERO; all other support from USGS). Kurtz is a USGS employee who was assigned to HERO for the two years needed to fulfill residency requirements in Penn State's Ph.D. program in Geography. She worked working on land-use/land-cover and remote sensing analysis of the SRB-HERO, as well as on carbon fluxes associated with LUCC. She contributed to logistical support for the HERO REU Site. She continues to work on HERO LUCC research at USGS.

Steven LeDuc, M.S. student, Penn State University (Year 1 fall and spring support from HERO). LeDuc provided general support to the project during its startup phase.

Menzie McEachern, Ph.D. student, Clark University (Year 2 support by NSF-funded Center for the Integrated Study of the Human Dimensions of Global Environmental Change at Carnegie Mellon University). McEachern worked for the HERO-CM Fellowship Program as support staff in summer and as Teaching Assistant to the yearlong HERO course in fall and spring.

Brandi Nagle, M.S. student, Penn State University (spring Year 4 support from the Department of Geography, summer Year 4 support from HERO). Nagle compiled concept maps of human-environment relations in the four HERO study sites, as well as bibliographies of work conducted on human-environment relations in the SRB-HERO study site.

William Pike, M.S./Ph.D. student, Penn State University (Year 2 support from HERO, Year 3 summer and fall support from HERO; contributed time in spring). Pike mentored the HERO REU Supplement students during summer 2001 and helped build the SRB-HERO database. During Academic Year 2001-2002, Pike built the e-Delphi component of the collaboratory. He contributed to logistical support for the HERO REU Site. Although funded by the NSF GEON project, Pike continues to contribute to HERO, building Codex and maintaining e-Delphi.

Ryan Reker, MA. student, Kansas State University (Year 3 support from HERO). Reker conducted research on LULC and helped with the summer 2003 REU.

Reuben Rose-Redwood Penn State University (Year 1 fall and spring support from HERO). Rose-Redwood contributed to database development and general project support at the beginning of the project.

Anna Versluis, Ph.D. student, Clark University (Year 4 spring and summer support from HERO). Versluis provided general project support to the HERO faculty at Clark. Her interests are in human-environment interactions, spatial analysis, and complex systems.

Craig Williams, M.S. student, Penn State University (Year 1 summer support from HERO). Williams helped with Website development and maintenance, plus graphical support for the project.

Youfeng Wang, Ph.D. student, Kansas State University (Year 4 support from HERO). Wang has been collecting hydrogeological and agricultural data.

Jessica Whitehead, Ph.D. student, Penn State University (Year 4 support from HERO). Whitehead is developing a protocol for developing climate impact scenarios.

James Wood, M.A. student, Kansas State University (Year 1 support from HERO). Wood compiled data on LULC in the southwest Kansas study area and examined relationships between climate variability and land-use change.

Chaoqing Yu, Ph.D. student, Penn State University (Years 2, 3, and 4 support from HERO). Yu maintained the HERO Website in Years 2 and 3 and e-Notebook through Year 3. He coordinates HERO Web-based videoconferencing. His research involves building agent-based models of vulnerability to hydroclimatic change.

Research Experiences for Undergraduate (REU) Students and Other Undergraduate Researchers

2001 HERO REU Supplement students

Anna Brendle, Penn State University. Brendle served as the peer mentor for the 2002 HERO REU short course and for the SRB-HERO REU Site.
Andrea Lindblad, University of Arizona
Erin O'Brien, Kansas State University
Alissa Shirk, Penn State University
Emily Shusas, Clark University

2002 HERO REU Site students

Brenda Bonanno, University of Arizona
Mark Frischenmeyer, Kansas State University
Sarah Fuller, Penn State University
Sarah Hinojos, Kansas State University
Jeffrey Malanson, Clark University
Jamie Mohr, Clark University
Lucas Murrary, University of Arizona
Greg Reiter, University of Arizona
Jessica Schifano, Clark University
Emily Van Eman, Kansas State University
Stephen Weaver, Penn State University. Weaver served as the peer mentor for the 2003 HERO REU short course and for the SRB-HERO REU Site.
William Windle, Penn State University

2003 HERO REU Site students

Maatsi Angwafo, Clark University
Yasmin Bowers, Clark University
Dominic DeFazio, Penn State University
Brigid Dotson, University of Arizona
Mike Driessen, Kansas State University
Allyson Gatski (Jacobs), Penn State University. Jacobs will serve as the peer mentor for the 2004 HERO REU short course and for the 2004 SRB-HERO REU Site. She has also provided full-time staff support in the HERO Central Office spring and summer 2004.
Elizabeth Hultman, University of Arizona
David Kent, Clark University
Sarah Landan, University of Arizona
Tania Metz, Penn State University (supported by Penn State Student Research Opportunities Program for minorities)
Sam Montoia, Kansas State University
Darci Paull, Kansas State University. Paull will serve as the peer mentor for the 2004 HPO-

HERO REU Site.
Morgan Windram, Penn State University

2004 HERO REU Site students

Rebecca Alper, Clark University
Rosemary Daley, Penn State University
Steve Eddy, University of Arizona
Kristin Hamilton, Penn State University
Troy Hill, Clark University
Andy Hopp, Kansas State University
April Hulett, Penn State University
Miranda Leathers, Kansas State University
Rorik Peterson, Kansas State University
George Saliba, University of Arizona
Dale Sherwood, University of Arizona
Zo Tobi, Clark University

Other Undergraduate Researchers

Jessica Harper, Geography, Penn State University (spring 2004 intern). Harper compiled graphics from the SRB-HERO hydroclimatic database.

Matthew Heller, Penn State University (fall 2003 intern). Heller compiled a hydroclimatic database for the SRB-HERO.

Sarah Knuth, Earth Sciences, Penn State University (2003-2004 Honors thesis research). Knuth conducted a vulnerability assessment of the Moshannon Creek Watershed using the HERO quantitative and qualitative protocols.

Tim Menda, Geography, Penn State University (summer 2001 HERO support). Menda helped compile the Spring Creek Watershed database.

Jason Spangler, Geography, Penn State University (HERO support, spring 2003 through summer 2004). Spangler has covered many functions, ranging from Web development, to graphics, to database management, to modeling, to mentoring high school and undergraduate students.

Other Investigators

Martin Gutowski, Gould Center for Geographic Education and Outreach, Penn State (50% HERO support in Years 1 and 2). Gutowski helped develop the Oracle database for HERO and the tagging system for the datasets.

David Kirtland, USGS, USGS Global Change Research Program, Reston, Virginia. Kirtland coordinates the collaboration between USGS and HERO.

Thomas Loveland, USGS, EROS Data Center, Sioux Falls, South Dakota. Loveland is Principal Investigator on the Land Cover Trends project and chief link between USGS LUCC activities and HERO.

4. OUTREACH ACTIVITIES

Central Office Outreach

HERO has made substantial progress towards the goal of developing an international network of researchers working on local human-environment interactions. Work continues on the HERO Website (http://hero.geog.psu.edu).[2] Year 4 saw a complete overhaul and update of the Website.

In Year 1, network building concentrated on three activities, including initial Website development and interactions with the LUCC Programme and the nascent LTER social science community. Interaction with members of the LUCC Programme took place at international meetings, first in Belgium in January and then in Amsterdam in July. HERO became a LUCC endorsed project during Year 1.

Year 2 expanded on these activities and added the Sustainability Geoscope to the network of partners. HERO took part in biocomplexity incubation activities with the LTER social science network during Year 2. Personnel from HERO-CM and SRB-HERO took part in two workshops, one in Madison, Wisconsin aimed at LUCC modeling, and another in Phoenix, Arizona focused on analysis of demographic and historical data in human-environment research. One HERO researcher (Pontius) was co-organizer of the Madison workshop. An important Year 2 outreach activity involved the Sustainability Geoscope, housed at the Potsdam Institute for Climate Impacts Research (PIK). Similar to HERO, Geoscope plans to develop an international network of sites monitoring local sustainability. HERO was fortunate to become involved with Geoscope as they began conceptualizing this network. Hence, it is likely that HERO infrastructure will be foundational to the Sustainability Geoscope.

Outreach continued during Year 3, including participating in a workshop on methodologies and vulnerability at Harvard, which was co-organized by Harvard and PIK. Colin Polsky, a workshop organizer working at Harvard, joined the HERO-CM team in Fall 2003 as a Clark University faculty member. In addition, the HERO Central office has received inquiries from developing countries regarding the availability of vulnerability protocols and has responded by sharing preliminary results and publications.

Year 4 saw a maturing of these relationships and an expansion into other collaborations. HERO-CM and SRB-HERO personnel participated in an LTER social science meeting at Boston College that focused developing Open Source/Open Content tools for LUCC modeling and collaboration. The LTER social scientists are still in the planning, proposal writing, and overview paper-writing stages, but participation in these activities will result in the adoption of HERO infrastructure for facilitating future network-wide interaction. The Sustainability Geoscope held the first International Sustainability Geoscope Competition, sponsored by the Center for International Earth Science Information Network (CIESIN), the International Centre

[2] Because the Website is on a Penn State-owned server, University regulations require that the site have a "psu.edu" designation. University regulations also prohibit the use of "org," "com," or other such domain names attached to Penn State computers.

for Creativity, Innovation and Sustainability (ICIS), the International Human Dimensions Programme (IHDP), and the PIK. HERO Principal Investigator Brent Yarnal won the competition with a paper based on the HERO vision and became first "Architect of the Geoscope."

HERO continued building new partnerships in its efforts to expand the network of researchers working on human-environment interactions and who might use the HERO infrastructure. An important step was interaction with the organizers of the National Ecological Observatory Network (NEON). NEON is an infrastructure development project to develop a continent-wide set of ecological observatories with an explicit human-environment component. HERO personnel are taking leadership in building this human-environment component at both the national and regional scale.

Outreach by HEROINE and the HEROs

HEROINE's outreach efforts during Year 4 took several forms. Through its Web-based tools, particularly e-Delphi, HEROINE made its products available to a global audience. As noted earlier, organizations around the world have requested access to the e-Delphi system, and HEROINE personnel are assisting in the development of their activities. Team members are also collaborating with researchers in the GeoVISTA Center in the development of knowledge management tools, contributing expertise and software components to projects funded by NSF's Digital Government program and the Geosciences Network (GEON), among other agencies.

As reported in Year 3, HERO-CM is developing regional collaborations and partnerships with government agencies, research institutions, private sector organizations, and non-governmental organizations. These include the Massachusetts Geographic Information System (MASSGIS), Massachusetts Executive Office of Environmental Affairs, Massachusetts Department of Environmental Management, Massachusetts Department of Environmental Protection, Greater Worcester Land Trust, Massachusetts Audubon Society, Blackstone River Valley National Heritage Corridor, Quinebaug and Shetucket Rivers Valley National Heritage Corridor program, Massachusetts Institute for Social and Economic Research (MISER), Central Massachusetts Regional Planning Council, Central Massachusetts Regional Environmental Council (REC), Bureau of the Census (Regional Office), and New Ecology Incorporated. HERO-CM is asking these groups to contribute expertise to aspects of the project, to help train and supervise students, and to provide financial and in-kind support. HERO-CM also interacts with visiting scholars who show strong interest in HERO (e.g., Richard Rockwell, the leader of the Industrial Transformation Science Project of the International Human Dimensions Programme on Global Environmental Change [IHDP-IT]). Both Pontius and Chen have participated in various activities organized by local environmental NGOs (such as the Tatnuck Watershed Association and REC). Most recently, the HERO-CM team was asked by the City of Worchester to perform a GIS analysis of the impact of brownfields in the area, demonstrating the relevance of its most recent data collection and analysis efforts.

SRB-HERO investigators have worked on human dimensions of global change research in the SRB and the Mid-Atlantic Region for many years and, as a formal part of that research, have engaged in stakeholder outreach. At these spatial scales, their outreach efforts continue to touch literally dozens of institutions (including academe, federal government, state government, non-governmental environmental organizations, and corporations) and hundreds of individuals. SRB

Personnel are especially active in the Pennsylvania Consortium for Interdisciplinary Environmental Policy, a consortium of state government policymakers and 47 colleges and universities. The intensive investigation currently underway in Centre County, Pennsylvania is causing SRB-HERO personnel to turn their attention to their own backyards. The SRB-HERO research is focusing the team on local NGOs, starting with the Spring Creek Watershed Community, ClearWater Conservancy, and Penns Valley Conservation Association. The team is starting to work closely with the Centre County Planning Department and the Planning Department of the Centre Region Council of Governments, as well as planners in the local townships and boroughs. Significant interaction on global environmental change issues is developing with Leadership Centre County, a group dedicated to developing local leaders. Links are being forged with Penn State's Department of Landscape Architecture, which runs both the Watershed Stewardship Program and the Hamer Center for Community Design Assistance. The Hamer Center focuses on providing education and technical assistance related to land use and transportation, community and economic development, the environment and quality of life to local communities. SRB-HERO investigators continue to strengthen ties to local community water systems and emergency management.

HPO-HERO researchers have a history of collaboration with federal, state, regional, and local organizations with interests in the economic, natural resource, and social viability of southwestern Kansas; the research team is working to expand the network. Examples of collaborative links related to water resources include USGS and the High Plains Regional Ground Water Study, the Kansas Geologic Survey and their Atlas of the Kansas High Plains Aquifer, and the Director of the Southwest Kansas Groundwater Management District Number 3. Another example involves LUCC mapping: HPO-HERO team members are working with Kansas Applied Remote Sensing (KARS) researchers on additional funded projects. KARS staff members have put together three different statewide satellite-based land-cover maps. Team members have attended local meetings dealing with possible state mandated changes in rules and regulations associated with the use of ground water. The team continues to be interested in how internal and external voices help formulate policy that influences LUCC in the HPO-HERO area.

All of the SOMBRHERO Co-PIs have wide-ranging active research and professional agendas in the study region with broad relationships to SOMBRHERO. Team members have initiated and maintained affiliations with numerous governmental and non-governmental border groups working on human-environment issues (e.g., among many others, the North American Development Bank, the Border Environmental Cooperation Commission, and the Aurora Partnership, which focuses on the use of GIS and spatial decision-support systems and tools for environmental decision-making and management). They are also involved in a Dialogue on Water and Climate in the San Pedro River Basin, aimed at engaging stakeholders across the border into dialogue on water issues in the San Pedro watershed. They have also acquired a University of Arizona Faculty Small Grant to employ a geography graduate student in a pilot study to develop geovisualization techniques of the SOMBRHERO region. The student developed a border webpage to assess institutional links and a Web-atlas is forthcoming to facilitate visualization of SOMBRHERO research and results. We have worked with the Commission on Environmental Cooperation (CEC) in Montreal on a case study of transboundary water issues (i.e., hydrologic uncertainty, demand, institutional constraints, and water conflict) in the San Pedro and Santa Cruz river basins. A team member is Co-Chair of the Scientific Advisory Committee for the Inter-American Institute for Global Change. Another team member acquired a NASA Space Grant for Undergraduate Research to employ an undergraduate

(Summer 2002 REU student Lucas Murray) through the academic year to work on dust pollution in the Nogales region. This work also contributes to the remote sensing work done on the Nogales region. Team members are part of another major human-environment research project, the Climate Impact Assessment for the Southwest (CLIMAS) funded by NOAA, which focuses on the greater Arizona-New Mexico region and surrounding areas including northern Mexico. While the CLIMAS concentrates on climate variability and forecasting, pertinent links to SOMBRHERO include downscaled climate data, climate and health analyses, and sectoral vulnerability studies (e.g., urban water, ranching, forest fire). One team member recently finished a three-year study on impacts of climate variability in the Brazilian Amazon funded by NOAA, which addresses issues of drought and vulnerability. Though in a completely different ecosystem, this work conceptually overlaps with SOMBRHERO research on vulnerability.

5. CONTRIBUTIONS

Contributions within the Discipline

The principal disciplinary fields of the HERO project are Geography and the Human Dimensions of Global Environmental Change (HDGEC). HERO is contributing to Geography through the development of Geographic Information Science (GIScience) and human-environment geography—both major areas of emphasis within the discipline. Geography is also benefiting because of the visibility that it is gaining from the leadership role that HERO is taking in the HDGEC research community and in the larger global change research community. HERO is contributing to the HDGEC research community through the HERO infrastructure, which includes the protocols for global change in local places research, the development of GIScience tools for use by the HDGEC research community, and the network building aimed at bringing HDGEC researchers together.

Contributions to Other Disciplines

Other disciplines and areas of science are benefiting from HERO in two ways. First, human-environment studies are not a focus in most programs at NSF; they also tend to be secondary in social science and physical science programs at other federal agencies. (Note that a few programs, such as the Decision, Risk, and Management Science Program in the Social, Behavioral, and Economic Sciences Directorate and Dynamics of Coupled Natural and Human Systems in the interdisciplinary Biocomplexity in the Environment Program under Environmental Research and Education, explicitly address human-environment interactions.) By developing a focus on human-environment studies and by building infrastructure to support these studies, HERO is turning the spotlight on this important, but often neglected theme in modern science and agency missions. Second, the ideas behind the HERO project (i.e., infrastructure, monitoring, human-environment relations, global change in local places) appear to be catching on among the larger global change research community. As the United States Global Change Research Program (USGCRP)/Climate Change Science Program (CCSP) discusses its future role in American science and society, HERO and especially its ideas come up repeatedly as ideals to target. Large physical science programs, such as NEON (National Ecological Observatory Network) and CUAHSI (Consortium of Universities for the Advancement of Hydrological Sciences, Inc.), both funded through NSF, are focus explicitly on cyberinfrastructure and—to a lesser degree—on human-environment interactions. Even if HERO does not extend beyond the initial five years of the project, it appears that its ideas might persist through CCSP, NEON, CUAHSI, and other big science programs.

Contributions to Human Resource Development

On the one hand, HERO is developing a cadre of scientists imbued with knowledge about global change in local places and who know how to apply GIScience to solving these human-environment problems. On the other hand, HERO is helping scientists interested in GIScience to advance that science and, at the same time, to become familiar with human-environment problems. Furthermore, HERO is doing these things with a diverse group of undergraduate, graduate, and post-doctoral students, as well as professional staff and faculty. HERO investigators have included 37 women (39% of all participants in the project) and 11 minority researchers (12% of all participants).

Contributions to Research and Education

HERO is an infrastructural development project, so an important emphasis is the generation of physical, institutional, and information resources for scientists and students. The HERO collaboratory is a fundamental part of that infrastructure, providing a Web portal for human-environment researchers. The collaboratory is described in detail in the Research Activities portion of this report.

HERO also emphasizes developing a cadre of next-generation human-environment researchers. Through Year 4, the project has supported and/or sponsored 5 post-doctoral scholars, 20 graduate students, and 45 undergraduate researchers. The structure of the HERO REU Site (Yarnal and Neff, under review) provides an innovative approach to teaching collaborative, place-based human-environment research.

Contributions Beyond Science and Engineering

HERO infrastructure is helping to make it possible for scientists and decision-makers to understand the consequences of global environmental change on the people and places of their locale, as well as how that locale contributes to global environmental change. Such understanding will lead to informed local action and policy (at all levels) to facilitate local action. State and local governments and non-governmental organizations are starting to work with HERO investigators on these problems. For instance, HERO-CM investigators are working with local agencies to investigate the impacts of sprawl on the local environment, while SRB-HERO researchers are working with local and state officials to identify greenhouse gas emissions sources and to develop action plans to reduce those emissions.

6. COLLABORATORS

Collaborating Organizations

Clark University
Kansas State University
Pennsylvania State University
United States Geological Survey
University of Arizona

Other Contacts

As detailed in the report, we have had dozens of contacts—too many to list here. Nonetheless, a few significant ones should be mentioned:

- Pacific Northwest National Laboratories. PNNL developed the e-Notebook and hosted one of our graduate students to work on further development of that tool.

- The international Land Use Land Cover (LUCC) project. HERO is an endorsed project under that IGBP-IHDP sponsored umbrella project.

- The NSF-sponsored Long-Term Ecological Research (LTER) network. HERO is helping the network plan the infrastructure to allow them to add a social science component to that biophysically based network. A special emphasis of that collaboration is LUCC modeling.

- The Sustainability Geoscope, run by the Potsdam Institute for Climate Impact Research (PIK). HERO is helping PIK plan the Geoscope—especially its human-environment infrastructure.

- National Ecological Observatory Network (NEON). NEON is an infrastructure development project and will have an explicit human-environment component. HERO personnel are involved in early planning to insure that HERO's experience informs the NEON human-environment infrastructure.

- Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. (CUAHSI). Like NEON, CUAHSI is an infrastructure development project and will have an explicit human-environment component. HERO personnel are involved in early planning to insure that HERO's experience informs the CUAHSI human-environment infrastructure.