

Project Description

I. INTRODUCTION

The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) was founded in 2001 to develop a community science agenda and to design, to acquire funding, and to operate the infrastructure needed to advance that agenda. Many reports [1-6], primarily from the National Research Council, have recognized that advancing hydrologic science requires coordinated data collection drawing on the techniques of many scientific disciplines across larger spatial scales and for longer duration than traditional research projects. Such undertakings are beyond the scope of a single investigator or a small group of investigators and require a community effort.

The Consortium has grown to 107 members, 6 affiliate members, and 9 international affiliate members. Significant progress has been made since CUAHSI's inception in advancing our science agenda. Twenty-four teams developed river-basin scale research prospectuses [7] that have led to proposals to the National Science Foundation for Critical Zone Observatories (CZOs) and WATER and Environmental Research Systems (WATERS) Network test beds; the USGS, EPA, and NCDC have agreed to use CUAHSI-developed web services to simplify access to their data holdings; USGS has agreed to rent hydrologic instrumentation to CUAHSI member universities; two pilot synthesis activities have been funded to explore how meta-analysis of existing data by multi-disciplinary teams can advance hydrologic science. None of these activities would have happened without the efforts of CUAHSI.

Based upon a recently completed science agenda [8] and experience gained over the past 6 years, CUAHSI proposes to build on these accomplishments and, in this proposal, requests funding to continue operations for five years. The required infrastructure is divided into four mutually supportive projects: field facilities (observatories), instrumentation (Hydrologic Measurement Facility), informatics (Hydrologic Information System), and multi-disciplinary synthesis (National Center for Hydrologic Synthesis). These activities build the community's capacity to operate large-scale infrastructure as envisioned by the WATERS Network, as well as providing valuable services to the community and having intrinsic scientific merit. The major new initiatives are the development of a Community Hydrology Modeling Platform (CHyMP), which will assist in designing observatories and observatory networks, execution of community data campaigns as a test of the scientific value spatially intensive, coherent data collected as a community effort. In addition, CUAHSI proposes the establishment of a formal education and outreach program, and the development of user support services for software that is ready for release to the community. Biennial membership meetings will assess progress towards these goals.

Experience has shown that designing these complex facilities generally requires three distinct phases (conceptual, pilot, and developmental) before an operational facility is possible (Table 1). The conceptual phase results in a committee report that identifies needs and opportunities, but does not contain sufficient detail to define a multi-million dollar facility, as these infrastructure elements are envisioned. Rather, a pilot phase is required to scope out the facility more precisely and to determine the best approach to delivering a service. The HIS Phase 1 project (2004-2007) is an example of a pilot project that identified a technological approach (e.g., web services) to a set of specific requirements (a uniform interface to

Table 1. Current Status of CUAHSI Projects and Overview of Proposal Elements

Activity	Phase			
	Conceptual	Pilot	Developmental	Operational
Informatics				
<i>Data discovery and delivery</i>	CTR #2	HIS Phase 1	HIS Phase 2 1.5 Assessment	1.1 User Support
<i>Community Hydrologic Modeling Platform</i>	CTR #2 HIS Phase 2 NSF Scoping workshop 1.2 CHyMP Workshops*	<i>Platform 1 Pilot [e.g.] Platform 2 Pilot [e.g.] Comm. Model Pilot</i>	<i>Dependent upon Pilot Phase</i>	
<i>Hydrologic Data Center</i>	1.3 Data Curation Approaches	<i>Pilot Data Center</i>	<i>Dependent on Pilot Phase</i>	
<i>Virtual Observatories</i>	1.4 Example VO's	<i>VO's for initial CZO's</i>	<i>VO's for all CZO's</i>	<i>VO's for all field sites</i>
Instrumentation				
<i>Central Facility</i>	CTR#3 2.1 Sensor Workshops	HMF Pilot	<i>Instrumentation Development Ctr</i>	
<i>Modules/Nodes</i>	http://www.cuahsi.org/hmf/docs/Final-Node-Model-200705.pdf	GP/Feasibility Pilot BGC Sondes Node ET Node 2.3 Assessment	<i>Geophysics Feasibility Node</i>	<i>Specialized Geophysics Nodes</i>
Synthesis				
<i>Physical Center</i>	CTR #5	UIUC/UNH Projects 3.1 Summer Institutes 3.2 Assessment	<i>National Center for Hydrologic Synthesis</i>	
<i>Alternate Approaches</i>	3.3 Post-pilot Workshop	<i>Multiple Virtual Centers</i>	<i>Dependent on Pilot phase</i>	
Observatories				
<i>Hydrologic Observatories</i>	CTR #4,#6	CZO's	<i>Community Access</i>	<i>Network of CZO's</i>
<i>WATERS Network</i>	Design Documents 4.2 Further Development	4.1 Community Data Campaigns*	<i>Test-beds</i>	<i>MRE Construction</i>
Education and Outreach				
<i>Short Films</i>	---	Three Short Films Viz Competition	5.2 Resource Archive	<i>Peer-reviewed Resource Archive</i>
<i>Undergraduate and Graduate Education Support</i>	Conklin Committee Report	5.1 Prototype Lab manual 5.3 Pathfinder Fellowships	<i>Lab Manuals</i>	
<i>Professional Development</i>		2.2 EOL Fellowships 5.4 Cyberseminars		

Shaded: Completed or on-going activity; **Outlined**: numbered tasks included in this proposal; *Italics*: Activities to be proposed separately or subsequent activities CTR: CUAHSI Technical Report (<http://www.cuahsi.org/news.html>); GP: Geophysics; BGC: Biogeochemistry; ET: Evapotranspiration; *Additional information at <http://www.cuahsi.org/renewal-prop.html>.

access and to publish time series data). The pilot phase is succeeded by a developmental phase when specific tools and services are 'hardened' by testing them with a limited clientele to ensure reliability and operational readiness to serve the community. At this point, the necessary attributes of a facility are clear because its function has been precisely defined. The informatics and instrumentation effort has proceeded successfully along this path (Table 1). By contrast, we attempted to move from the conceptual phase

directly to an operational phase in the National Center for Hydrologic Synthesis, but were unsuccessful because the facility had not been sufficiently well defined.

The overall status of the CUAHSI projects is shown in Table 1. Shading indicates tasks that have been completed or are underway in related projects. Outlined activities are contained in this proposal with the numbers referring to task numbers in Section IV.

This proposal also requests funds for the continuation of CUAHSI's core corporate operations. The CUAHSI staff coordinates the projects, supports the governance committees and users groups that advise the projects and Board of Directors. In addition, CUAHSI will catalyze community efforts to achieve broader impacts in education, in outreach to citizens, and in engagement of the many federal, interstate, and state agencies who share an interest in water and water science.

After a brief review of CUAHSI's accomplishments during the past 5 years and its corporate structure, the current science vision of the hydrologic sciences community is presented. The body of the proposal describes a set of specific activities and services that will lay the intellectual foundation for the infrastructure needed to advance the scientific agenda of our community. The activities that have been chosen require community-level organization and, thus, can uniquely be done by a consortium such as CUAHSI. The proposed activities have been chosen as being both cost-effective and directly contributing to scientific understanding as well defining larger scale infrastructure needs.

II. RESULTS FROM PRIOR RESEARCH

CUAHSI has been funded first through a seed grant (EAR 02-33842) and then through a core grant that has included corporate operations, observatory development, synthesis center development, and standing committee support (EAR 03-26064). In addition, CUAHSI has collaborated on proposals for HIS Phase 1 (04-12975) and the HMF pilot project (04-47287). Results from these grants are presented in this section.

Community Science. Following the completion of the first CUAHSI Science Plan [9] and the initial design of the four project areas [10-13], CUAHSI offered small travel grants for eleven self-forming groups of scientists to write papers describing their vision for the future of hydrologic science, including the need for large-scale infrastructure. All these groups presented their thoughts to the community in a series of cyberseminars held during the fall of 2004; these are recorded and available on the CUAHSI website (<http://www.cuahsi.org/sem-vp.html>). Seven of these papers appeared in *Water Resources Research* between 2005 to 2007 [14-20]. These papers span a broad range of basic and applied science topics, including ecohydrology, hydrogeology, catchment hydrology, river restoration, floodplain management and remote sensing and involved 119 scientists in these teams as well as numerous graduate students and post-docs. During the development of the National Center for Hydrologic Synthesis at UC Berkeley, 10 short (two-page) views on the needs for hydrologic synthesis were solicited from 28 leading scientists in hydrology and affiliated disciplines. These also appeared in *Water Resources Research* [21-30]. These papers are being assembled in a single reprint volume, entitled *Envisioning the Future of Hydrologic Science*, for broader distribution.

The CUAHSI Science Plan was also updated over this period of time and released in 2007. *Hydrology of a Dynamic Earth* [8] describes a phased approach to research in hydrologic science over the next decade that has guided the development of this proposal. A team of 15 scientists contributed to this plan.

Hydrologic Information Systems. The goal of CUAHSI HIS is to enable easy and efficient access to hydrologic information on all components of the hydrologic cycle simultaneously through the federation of academic and government data sources. CUAHSI's role in the HIS has been to support the team of PI's, led by David Maidment, by helping with community surveys, providing community review of development priorities through a CUAHSI standing committee, coordinating with other CUAHSI projects, serving as liaison with federal data providers and representing HIS at Advisory Committee on Water Information (an intergovernmental panel) and with NSF programs, such as the LTER network office and NEON. Tangible results of this effort are a signed memorandum of understanding with the USGS on development of data services; CUAHSI is currently negotiating with EPA Office of Water and the National Climate Data Center for similar formal arrangements. CUAHSI has also coordinated the use of the WATERS test beds as beta-testers of the HIS software by organizing workshops and providing computer servers to each test-bed team. Interest in the HIS system for accessing data has also been expressed by the private sector, including consulting firms and ESRI, who has contributed software engineering services to the HIS project.

Hydrologic Measurement Facility. Access to modern instrumentation is an important requirement for any science. However, given the methodological breadth of hydrologic science and the harshness of environmental conditions often encountered in hydrologic studies, technical assistance in instrument selection and usage promises to significantly enhance hydrologic field studies. The pilot project has defined a distributed model for providing these services where an instrumentation node, hosted by an expert in this piece of equipment, is provided with the technician support to enable deployment of the instruments to projects selected through an open competition [31]. When the distributed model is implemented, CUAHSI will manage competition for the instruments to ensure community access and evaluate the performance of the node. This model is scalable and can be built incrementally. CUAHSI has supported this pilot project in its development of three white papers on instrumentation needs [32-34], and has provided funds for HMF-Geophysics deployments in 2006 and in 2007 to determine how the necessary services can be provided. In addition to the nodes, a Cooperative Research and Development Agreement (CRADA) was signed with the US Geological Survey to enable CUAHSI members to rent equipment from the USGS Hydrologic Instrumentation Facility (HIF), and a handbook of hydrologic field methods is being developed, initially as a special section of *WRR*.

Hydrologic Observatories. A major activity of the current grant was the development of a paper prototype of the Neuse Basin [35] that led to a large workshop entitled Hydrologic Observatories as a Community Resource in August, 2004 [36]. Prospectuses from 24 basins were submitted for this workshop that considered various aspects of observatories and observatory networks. These teams crossed traditional barriers, linking universities that were traditional competitors and departments that had never before collaborated. The concept of basin-scale observatories that brought together academic researchers with water resource managers was sufficiently compelling that many groups continued to plan observatories even after the NSF decided not to solicit proposals for hydrologic observatories. CUAHSI continued to pursue observatory development through two paths: incremental development through the Critical Zone Observatories (CZO), a joint effort with the other surface-earth programs, and the conceptual development of the WATer and Environmental and Research Systems (WATERS) Network, a joint CUAHSI and environmental engineering initiative to develop a project for funding through the Major Research Equipment Facilities and Construction Grant program. Several of the basins proposed for Hydrologic Observatories have become test beds for the WATERS Network and have applied to the

CZO solicitation. Three sites have been selected by NSF as CZO's, two of which were originally proposed as HO's. Some groups have also received funds for other sources to pursue their vision of a basin-scale observatory.

Hydrologic Synthesis. Hubbard and Hornberger [21] have defined hydrologic synthesis as “the integration (1) of knowledge from multiple, water-related disciplines, (2) across the molecular-to-process-to-basin scales of the hydrologic system, and (3) between theory, models, and observations.” CUAHSI developed a white paper describing a synthesis facility [10] and selected a partner for the development of a National Center for Hydrologic Synthesis. Although the resulting proposal was declined by the National Science Foundation, two synthesis activities were selected in 2007 to serve as pilot projects for the utility of this mode of research. The project at the University of Illinois (M. Sivapalan, PI) focuses on improving the predictability of water cycle dynamics through examination of patterns that emerge at different temporal and spatial scales. The processes that give rise to these patterns will be sought with particular attention to the role of the biosphere and humans in water cycle dynamics. The project at the University of New Hampshire (C. Vörösmarty, PI) focuses on the dynamic evolution of water and biogeochemical cycling at the regional scale in response to human and environmental forcings. This research will focus on a specific location (the northeastern US) over a 500-year period (1600-2100).

Education and Outreach. CUAHSI worked with the National Environmental Education and Training Foundation (NEETF) to develop a data base of water education and outreach programs for the use of the hydrologic science community in broadening the impact of their research. This database contains 365 commercial, federal, state and regional programs, and can be searched by theme, region, or education level [37]. CUAHSI also developed three short films for adult audiences to explain fundamental concepts of hydrologic science [38]. These videos will be used by the Coca Cola Company in their training programs on source-water protection. Thirty-nine cyberseminars, web-broadcast presentations, have been presented by CUAHSI since 2003. Some colleges and universities used the cyberseminars to anchor discussion groups. Generally, these have been effective and relatively inexpensive ways of to share scientific findings. A white paper has been developed by the CUAHSI Education and Outreach Standing Committee outlining activities for the next 5 years [39].

Corporate Management. During the past 5 years, there has been significant evolution in the corporate operations of CUAHSI as experience has been gained. The powers of the corporation are vested in a 15-member Board of Directors that is elected from the membership representatives (full members only) for staggered 3-year terms. Each year, the Board elects a Chair-Elect from its members, who serves 1 year in that position, and then becomes Chair for 1 year, and, finally, past Chair for one year. The Chair is compensated for 1 month of summer salary; Chair-Elect and Past-Chair receive one-half month of summer salary. The Board also elects two of their members to join the Chair-Elect, Chair, and Past Chair, to form the Executive Committee of the Board. The Board of Directors meets quarterly (twice physically and twice by conference call) and the Executive Committee meets weekly by telephone to transact business. The Board also elects a President, Secretary and Treasurer who are not members of the Board. Given CUAHSI's current size, one person serves as both President and Executive Director and is Principle Investigator of CUAHSI projects. The President, the Board, and particularly its Chairs, set the vision for CUAHSI and the operational policies for the corporation. The President/Executive Director has fiduciary responsibility for the corporation and is responsible for developing the corporate procedures to

implement these policies. The President also executes the strategies developed by the Board. The by-laws of CUAHSI are available at <http://www.cuahsi.org/by-laws.html>.

The CUAHSI by-laws also establish standing committees to develop the conceptual basis for infrastructure facilities, to review current projects from a community perspective, and to advise the Board on the direction and progress of these projects. Active standing committees are Education and Outreach (M. Conklin, UC Merced, Chair); Informatics (D. Lettenmaier, U. Washington, Chair), Instrumentation (R. Bales, UC Merced, Chair). In lieu of a standing committee on observatories, CUAHSI participates in a Coordinating Committee for WATERS test beds. CUAHSI nominees to that committee are Dave Goodrich (ARS, Tucson, AZ) and Jean Bahr (U. Wisconsin). The other standing committees (Science and Synthesis) are not populated at this time.

III. SCIENCE VISION

CUAHSI's science plan [8] defines the focus of hydrologic science as developing a systematic understanding of *continental water dynamics*—that part of the global hydrologic cycle acting over and on the continental land masses and involving the dynamic interaction of water and related processes within the critical zone. At the most general level, continental water dynamics requires analysis of fluxes and stores of water throughout the continent, of the interactions water experiences along pathways through and among these stores, and of the velocity and travel time along these pathways. These four fundamental properties—stores, fluxes, flowpaths and residence time of water—link hydrology with biogeochemistry, ecology, climatology, geomorphology, oceanography, and social/behavioral sciences. Understanding these properties of continental water dynamics will enable better prediction of direct and indirect effects of climate change and human activities on water resources and the environment.

Three challenges have been identified by CUAHSI in its science plan as the top priority in the coming decade:

1. **Linking the hydrosphere and the biosphere.** Recent research in ecohydrology, the interface between hydrology and terrestrial ecology, has shown that interactions among biological, soil, and hydrologic processes are strong and adaptive. Traditional views of a one-way hydrologic forcing of the biological system do not capture these interactions and adaptations. Soil moisture, a poorly measured store of water, has emerged as the “gatekeeper” linking atmospheric, biological, and hydrologic processes
2. **Scaling hydrologic, biogeochemical, and geomorphic processes.** Current understanding of these linked processes comes from laboratory simulations under controlled conditions and field studies at relatively small scale. How these processes combine in a predictable way to control macroscale processes or if these process are *not* predictable from small-scale processes is not known. In other words, are macroscale processes the result of emergent behavior, and if so what are their properties?
3. **Predicting the effects of climate change and human population on water resources.** With the understanding developed under the first two challenges, we can more reliably make these predictions. A fundamental goal of hydrologic science is to be able to predict the response of water and the critical zone to climate and human perturbations to a level of confidence approaching those now possible for atmospheric and ocean systems, despite the heterogeneous nature of the continental environment.

To comprehensively address these challenges requires coordinated scientific investigation and large-scale infrastructure that extends from a plot or hillslope, across scale to the continent. Community-level science is a necessary complement to PI-based science to accomplish this multi-scale, multi-disciplinary research.

Three phases are proposed to advance this science agenda: (1) *Establishing benchmarks of current understanding* through the use of simulation models on “digital observatories” constructed from existing data records (including remotely sensed data and paleodata), that is supported through a community modeling platform (2) *Testing generality of understanding* through cross-site comparisons using measurement campaigns of limited duration which build on information from fixed-place-based observations of longer duration, and (3) *understanding long-term response* of hydrologic systems to climate and human impacts through the establishment of an expanded network of place-based observatories. The first two phases are the focus on this proposal (Tasks 1.2 and 4.1) and lay the foundation for achieving the third phase through the development of Critical Zone Observatories and the WATERS Network.

IV. PROJECT TASKS

The proposed tasks advance each of the infrastructure elements towards operational status. As shown in Table 1, each activity contributes to a specific development phase. The experience and information gained from these activities are essential to the operation of effective large-scale infrastructure, as proposed for the WATERS Network. Progress towards this goal of community infrastructure will be assessed by **biennial CUAHSI All-Scientists meetings**. The first of these will be held in August 2008 using funds from the current project. This proposal requests funds for subsequent meetings in 2010 and 2012. The focus of these meetings is community facilities and the science that is done at these meetings. We envision a meeting comparable to the Long-Term Ecological Research (LTER) network’s All Scientists meeting with a focus on networking among colleagues and graduate students, and presentation of the latest science. All tasks other than the biennial CUAHSI All-Scientists meeting are organized by infrastructure element.

1. Information Services

The foundation for community science is data sharing. Therefore CUAHSI leads from the development of information services. The first task, User Support Services, is the initial step towards an operational hydrologic data services center; it completes the development cycle by deploying software developed by the HIS Phase 2 project to the user community. Three additional tasks are at the conceptual stage: defining a community hydrologic modeling platform, determining approaches for data curation services, and exploring approaches to making observatory data more accessible to the community. Finally, funds are requested to support the Informatics Standing Committee to assess progress on funded informatics projects.

Task 1.1 HIS User Support Services

Objective: To determine the most efficient way to support a federated data system; to explore modes of data curation for field studies; and to develop data description standards beyond standard meta-data to enable outside scientists to understand what a particular data series is intended to represent

Approach: The HIS project is a developmental project, not one that can provide user-support services to the community. We propose to hire 1 person who has a master’s degree in hydrologic science with strong

computer science skills to assist those field studies that wish to join the CUAHSI data federation as an ‘affiliated observatory.’ For the first two years of this project, approximately half of their time will be devoted to this activity. This position will be located at CUAHSI Headquarters to assess whether a support facility remote from the developmental centers (currently at Univ. of Texas, San Diego Supercomputing Center, Drexel, and University of South Carolina) is feasible. The support person will work closely with the HIS team initially to learn the software packages, but ultimately will provide input to the HIS team on software performance.

Task 1.2 Community Hydrologic Modeling Platform (CHyMP)

Objective: To develop a common platform for the efficient construction of hydrologic and biogeochemical models at multiple scales for observatory design, for resource assessments, and for decision support tools and to enable the development of community models of the hydrologic cycle

Background: Community modeling—the development, distribution and technical support of common simulation code—has a rich tradition in the atmospheric and oceanic sciences and has proven quite effective in those disciplines. CUAHSI believes that such a community modeling effort in terrestrial hydrology will similarly enable major advances in hydrological science that are simply not possible in its absence. Without a substantial community modeling program in hydrology, many simulation tools will remain fragmented by and within disciplines (e.g. groundwater models, unsaturated zone models, rainfall-runoff models, floodplain hydraulic models, etc.), or in the proprietary domain of the author. This scenario often requires researchers to rewrite component code that already exists, or to rely on existing code without significant technical support. As simulation models are becoming increasingly integral to hydrologic research, these inefficiencies are arguably undermining advances within our science.

Approach: A scoping workshop will be held during the winter or spring of 2008 to develop a structure for this effort. In this proposal, we request funds to hold two community workshops to lay out the conceptual basis for community modeling efforts. The reports from these workshops will a detailed set of specifications and requirements for the development and operation of a Community Hydrologic Modeling Platform.

The first workshop, *Blueprint for a CHyMP*, will refine the concept for CHyMP including its attributes and components. Participants in on-going community modeling efforts such as Earth Surface Modeling Framework [40], NCAR’s Community Land Model [41], the Global Land Data Assimilation System [42], the Community Surface Dynamic Modeling System [43-45], USGS’s Modular Modeling System [46] and GSFLOW [47] will be invited to the workshop; other participants are expected from universities, NSF, USGS, NCAR, NASA, NWS, NOAA and other federal agencies, as well as international participants.

To focus this workshop, we propose the goal of the CHyMP to be the development of a full water cycle model. This model would include explicit coupling of snow, surface waters, unsaturated zone, groundwater flow and surface energy balance components. The platform should support activities at multiple scales, for example, in spatially-distributed form for watershed-scale applications, and as a grid-scale model for larger-scale applications. Common features could include the following capabilities:

- Assimilation or other use of in situ, aircraft and remote sensing measurements from testbed and future observatories
- Utilization and integration with the HIS in a seamless manner

- “Swappable” components with standard interfaces
- Ease of linkage to components from other disciplines, e.g. biogeochemistry and ecology

A number of approaches could be followed to achieve these goals including

1. *Couple existing models.* The general model could be a collection of existing hydrologic models linked by an interface, much like models are linked together on the Earth System Modeling Framework[40] developed by NCAR, using technologies such as OpenMI [48].
2. *Revise existing models.* Several existing hydrologic models provide many of the capabilities needed for a general model, and with modification they may be suitable. For example, MIKESHE developed by DHI [49] has been widely used to represent groundwater and surface water. Land surface hydrology is represented in the Community Climate System Model [50] and it is possible that this package could be extended to meet the needs of hydrologic researchers.
3. *Develop a new approach.* The needs of the community may be better served by developing a new model than by retrofitting old ones. As an example, multiphysics modeling software is a relatively recent development that has the flexibility to represent a range of processes that is much broader than any existing hydrologic model. Both commercial examples [51-53] and open source codes [54] are available.

The second workshop, *Hardware and Software Issues for the CHyMP*, will explore technical issues associated with the development, maintenance and support of a CHyMP. Participants will include software and hardware engineers, model developers and users; technical support professionals; invited participants from other community efforts such as the ESMF, NCAR, CSDMS, GLDAS and from NCAR and other agencies. Topics to be discussed at this workshop include CHyMP coding standards, strategies for linking model components, computation coupling, computational storage, interoperability, technical support and access to NSF CSL.

Further information on CHyMP is available at http://www.cuahsi.org/renewal_prop.html.

Task 1.3. Approaches to Data Curation

Objective: To determine efficient and effective approaches for data curation

Approach: The Earth Sciences Division of NSF has a data policy that calls for preservation and open access to data collected from projects it funds [55]. The development of metadata catalogs, as needed to implement the CUAHSI HIS federation system, is a first step towards curation. However, it is probably not sufficient. The hydrologist hired for User Support (Task 1.1) will devote approximately 50% of his or her time during Year 1 of the project towards working on approaches that a hydrologic data service center could take for providing a range of curation services, up to and including data archiving. This effort will coordinate with HIS Phase 2 and with on-going cyberinfrastructure projects in the geosciences, such as GEON [56], the WATERS Network CI design, and the broader environmental sciences, including NEON [57] and Ecological Society of America [58].

Task 1.4 Virtual Observatories

Objective: To better document data sets collected at environmental observatories and to deepen understanding of physical settings of observatories for the broader scientific community, and, thus, to encourage utilization and collaboration at these observatories

Approach: Beginning in Year 2 of the project, after the first three Critical Zone Observatories have been operational for about 2 years, CUAHSI will work with one of the CZO's to develop web resources to introduce scientists not associated with the CZO to the site. These resources must go beyond simply posting data about the site to explaining the context for this data collection: why were these data collected? What did the program staff believe that these data represented? Such documentation takes considerable effort and will require collaboration with the CZO staff. This task will explore various approaches, from static 'observatory manuals' that provide documentation to 3-D fly-throughs based upon local DEM's (or using Google Earth or Microsoft Virtual Earth interfaces) to immersive environments allowing users to explore the site virtually. The objective of this two-year, half-time effort is to explore possibilities that could grow into a pilot project.

Task 1.5 Assessment of Informatics Projects

Objective: To provide community input and evaluation of priorities of HIS project and eventual CHyMP projects.

Approach: Travel and administrative support for standing committee.

2. Instrumentation

Delivery of geophysics services and development of other instrumentation services will be pursued in other proposals to be submitted by CUAHSI. In this proposal, we request funds for annual instrumentation workshops to keep abreast of latest developments in the field and for support of a standing committee to enable the node model [31] to operate. For professional development, we also propose to institute a visiting faculty program for hydrologic scientists at the National Center for Atmospheric Research's Earth Observing Laboratory.

Task 2.1 Sensor and Sensor Network Workshops

Objective: To assemble community experience in the deployment of new sensor and sensor networking technologies to inform observatory design and to diffuse knowledge of new techniques to the broader community

Approach: Workshops will be held at the rate of 1 per year to explore different emerging technologies of interest to hydrologic science community. Workshops will typically contain training or other hands-on activities so participants can learn new technologies.

Task 2.2 CUAHSI Fellowship at NCAR Earth Observing Laboratory

Objective: To encourage collaboration between observationally oriented atmospheric and hydrologic scientists and to inform the hydrologic science community about the operation and utility of community-based central instrumentation facility.

Approach: Funds are requested to partially subsidize a sabbatical stay for a hydrologic scientist at EOL; NCAR will commit approximately \$35,000 (gross) during FY08 and will consider an annual match of CUAHSI resources if the visit proves successful. Applications for this position will be evaluated annually by a panel jointly appointed by UCAR and CUAHSI.

Task 2.3 Support for Node Model and Assessment of HMF Activities

Objective: To negotiate usage rules with affiliated nodes, to select technologies to be proposed as CUAHSI nodes; to work with NSF on allocation of deployment funds; and to select non-NSF grantees for instrumentation access

Approach: Travel and administrative support for standing committee is requested.

3. Synthesis

Two synthesis activities, one at the University of Illinois and the second at the University of New Hampshire, were recently funded by the NSF to explore the utility of synthesis in hydrologic science. These activities stem from a CUAHSI technical report [11] describing synthesis for hydrologic science. CUAHSI has been asked by the PI's to evaluate these activities through interviews with the scientists involved in the activities. In addition, CUAHSI would like to update its technical report on synthesis through a community workshop to be held during the second year of this project (Year 3 of the synthesis projects).

Task 3.1 Summer Institutes

Objective: To expose young scientists and graduate students to new theories and worldviews emerging from synthesis activities at UNH and UIUC.

Approach: Intensive week-long seminars hosted by various partner institutes for young faculty, post-docs and graduate students as annual events beginning in 2009 (Year 3 of Synthesis Projects). Applications for travel support for 25 people will be reviewed by CUAHSI standing committees and synthesis PI's.

Task 3.2 Evaluation of Existing Synthesis Activities

Objective: To determine satisfaction of participants and the advantages of different organization of synthesis activities

Approach: CUAHSI staff will conduct periodic surveys and an exit interview with participants and apply metrics from the National Center for Ecological Analysis and Synthesis [59] to assess effectiveness of UNH and UIUC education activities.

Task 3.3 Community Workshop on Hydrologic Synthesis

Objective: To determine the form and nature of a synthesis center for hydrologic science, other surficial earth sciences, and environmental engineering given the results of the initial synthesis efforts, other synthesis and water centers, the existence of CZO's, and the status of WATERSNet development.

Approach: A community workshop with interested parties from a range of disciplines to examine centralized physical versus a distributed virtual facility and to develop governance policies for such a facility.

4. Observatories

Observatories that will collect coordinated, multi-scale, and multi-disciplinary data for community use is the heart of the vision that CUAHSI is striving to attain. We propose to advance this objective by continuing CUAHSI engagement in the WATERS Network design and, in the largest activity in this

proposal, to undertake a data-collection campaign to test many of the fundamental precepts of a community observatory.

Task 4.1 Community Data Campaigns

Objective: To test synergies arising from coordinated community data sets by collecting spatially intensive data on two parts of the hydrologic cycle (stream discharge and groundwater fluxes); to test utility of systematic data collection from a network of sites by repeating measurements at three locations of different geology, glacial history, vegetation, and climate; and to test power of data sharing by tracking utilization of publically available data sets

Approach: Two complementary campaigns are proposed: the Mountain Flow Observation Campaign (MFLOW) that will test alternative mechanistic explanations for flow routing in mountain streams and the Multi-scale Measurement of Groundwater Flow into Channels (SEEP) that will test controls on groundwater flux to streams. After an initial organization and planning period during Year 1 (refine hypotheses, determine standard methods, recruit participants), one site will be sampled during each of Years 2-4, and a data synthesis effort during Year 5. In each case, a model based upon the null hypothesis will be constructed prior to data collection to provide a benchmark against which to judge improved understanding resulting from the campaign. We initially plan on sampling the three CZO's (Kings River, CA; Boulder Creek, CO; Juniata River, PA) during Years 2 to 4; all three site PI's support the planned campaigns.

MFLOW will collect cross-sectional flow field of a 20-km stream reach at longitudinal intervals of 2 channel widths and feature-based 2D- and 3D-flow field measurements (around outcrops, steps, pools, and other features that cause flow convergence or divergence), measured by a variety of techniques depending upon local conditions (e.g., mechanical or electromagnetic flow meters, acoustic Doppler velocimeters, or acoustic Doppler current profilers). The stream reach should span multiple channel types, such as cascade, step-pool, plan bed and riffle pool units. The data set will be sufficiently specific to enable testing of diverse algorithms for predicting the flow field in a nonuniform channel with instream flow obstructions, as commonly found in mountain and upland channels.

SEEP will use the discharge data (a secondary product of MFLOW) to infer groundwater discharge from net differences in streamflow between successive gaging points. This initial assessment will identify reaches for placing seepage instrumentation (drive-point piezometers, pan-and-bag seepage meters, electronic seepage meters, temperature profiles, etc. as appropriate for site conditions). The hydrogeologic setting will be characterized by describing bed morphology, quantifying distribution and grain size of bedload, and describing stratigraphy. The central hypothesis of SEEP is that the magnitude and distribution of ground water discharge to streams will be controlled by the geometries and properties of specific hydrologic and geologic settings. Some examples of potential controls that need to be tested in different hydrogeologic settings are as follows. Shallow streambed slopes will be characterized by a greater degree in spatial heterogeneity of groundwater fluxes than steep slopes. Immature streams will be characterized by more spatial heterogeneity in groundwater fluxes than mature streams and urbanized streams. Thinly mantled streambeds will be more variable in fluxes than streambeds with thick overburden. Topographic relief will tend to focus flow and increase the spatial variability of flux distribution. While these predictions are heuristic, variability itself is not yet defined. What is the extent

of flux heterogeneity? At what scales does variability occur? How do the definitions and scales differ in various physical settings?

These campaigns will be widely advertised to attract participants for collecting the core data set and to enable others to build on these data sets with complementary measurements (e.g., steady-state tracer injections for delineation of hyporheic zone, shallow geophysical measurements of groundwater table). Two CUAHSI Board members (Greg Pasternack (UC Davis) for MFLOW and Wendy Graham (Florida) for SEEP) will organize the initial planning meeting, which will be open to the community. From these meetings, a campaign leader will be chosen and receive compensation for developing the design. Funds will also be provided to the host sites for local logistical planning and assemblage of baseline data sets. Funds are also requested for equipment rental (for example, through the CUAHSI-USGS agreement) and travel support for graduate students. All data collected under this campaign will be made public as soon as possible after quality assurance through the CUAHSI HIS program. Additional information on SEEP and MFLOW is available at <http://www.cuahsi.org/renewal-prop.html>.

Task 4.2 CUAHSI Support for WATERS Network

Objective: To provide hydrologic science perspective on design of WATERS MRE Project

Approach: Because the Conceptual Design Review will happen during the first year of this project (and potentially later), salary support is requested to enable a CUAHSI community member to remain engaged in this activity. Document revision and preparation will be required. Following the CDR, a different funding source will support development of documents for the Project Design Review.

5. Education and Outreach

The vision of the CUAHSI education and outreach effort is to empower our community of scientists and educators to more effectively transfer advances in hydrologic science to students, policy makers and citizens such that all make scientifically informed and sound choices concerning water-related issues affecting society.

CUAHSI's E&O program will provide community members with support and opportunities to integrate their research with highly effective teaching and communication of hydrologic science to a broader audience. CUAHSI's motivation for action is influenced by the national agenda to increase American competitiveness in STEM disciplines, in particular the hydrologic sciences; the increased need for citizens to understand water issues, resources and management; and a desire to ensure the results of hydrologic research are applied in the most efficient and effective manner. The need for better understanding of water issues is undeniable. Worldwide, 6000 children under the age of five die every day because of unsafe water and sanitation; 1.1 billion people in developing countries have inadequate access to safe drinking water. Water-related diseases are the single largest cause of health-related death in the world. Water quality and availability is a growing concern in this country, not just in developing countries.

Students need to be trained in hydrologic science and engineering to meet the challenge of the growing water quality and availability problems. Likewise, the public needs to have raised awareness of the seriousness of water quality and availability problems and the essential importance of hydrologic science in addressing them—this is the most compelling rationale for a public science education effort.

CUAHSI proposes to hire a PhD-level education coordinator with assessment capabilities to lead these efforts. Because the field of water education is vast, we propose to focus initially on undergraduate and graduate education and to build on our initial efforts at public outreach with short videos.

Task 5.1 Case Studies in Hydrology Education

Objective: To develop modular case studies to enrich theoretical courses and to develop modular laboratory and field exercises for data collection

Approach: Building on the experiences of Modular Curriculum for Hydrologic Advancement [60] CUAHSI will host a web-based portal to host and disseminate case studies, which will include assessment tools [e.g., 61] and teaching guides. Pedagogical standards will be developed through a workshop to be held in Year 1. As these standards are finalized, new case studies and lab/field exercises will be solicited and reviewed by an editorial board. Newly submitted case studies will be reviewed by an editorial board according to those standards. Accepted case studies will be posted to the portal and assigned an identification number (such as a formal DOI) to permit authors to receive credit for their efforts. Current lab and field manuals are discipline-specific [e.g., 62]; this effort will assemble a manual that covers all of hydrology. This effort complements existing activities of the CUAHSI HMF on developing publication outlets for hydrologic methods.

Task 5.2 Media Bank

Objective: To develop a resource archive for model visualizations, animations, and video of hydrologic phenomena and concepts.

Approach: Through graduate student competitions and unsolicited contributions, CUAHSI will develop a database of video products that will contain sufficient metadata to enable their discovery and to document the content of the video. The E&O Coordinator will develop guidelines for describing video content that must be adhered to for the video to be posted to the archive.

Task 5.3 CUAHSI Pathfinder Fellowships

Objective: To enhance communication among different parts of the hydrologic science community and to improve the appreciation for different field settings and for different approaches to hydrologic science issues by exposing graduate students to significantly different field environments than their primary study site or to provide an opportunity to work with research groups using significantly different modeling approaches

Approach: Grants would provide travel support for a graduate student to make an extended visit (1 to 3 months) to a field site or with a research group as part of a masters or PhD program. A stipend of up to \$5000 would be offered to defray the expense of the visit. Grants would be awarded through an application process. Evaluation criteria would include how different the proposed location or group is to the home institution and the approach for integrating this experience into the candidate's graduate research.

Task 5.4 CyberSeminars

Objective: To provide free access to the latest findings in hydrology through web access to research seminars and to provide an archive of these lectures

Approach: Building on the success of the current cyberseminar series, CUAHSI proposes to continue these series at the rate of approximately 5 seminars per semester. A seminar planner, generally from the CUAHSI Board, will develop a roster of speakers, which will be widely advertised. The cost of these cyberseminars (including recording) is approximately \$700 each.

V. BROADER IMPACTS

The proposed activities both advance the community agenda for hydrologic science by developing the knowledge required to operate large-scale infrastructure effectively and benefit society by making the products of hydrologic science research—data, model results as contained in visualizations, and resulting knowledge—more accessible. The project will permit effective engagement with the “mission agencies” of the federal government with water responsibilities (e.g., USGS, USFS) to leverage the science investments of those agencies for the use of the academic research community. This kind of engagement is possible only with a consortium like CUAHSI. A number of the activities in this proposal will directly contribute to undergraduate and graduate education. The CUAHSI biennial meetings and many of the workshops proposed here will specifically support graduate student attendance.

VI. MANAGEMENT PLAN

Richard Hooper, President and Executive Director of CUAHSI, will serve as PI of the project and coordinate activities between CUAHSI staff, the CUAHSI Board, Standing Committees and sub-awardees. The CUAHSI Chair-Elect, Chair, and Past Chair serve as co-PI’s on this project in an ex officio capacity. Currently these positions are filled by Efi Foufoula (U Minnesota), Claire Welty (UMBC) and Wendy Graham (U Florida).

The CUAHSI staff consists of a senior project manager, David Kirschtel, who has experience in the development in the NEON MRE Project, a full-time communications manager, Conrad Matiuk, who also serves as web master for CUAHSI, a company controller (Jessica Annadale), and an administrative assistant (Nigadel Jordan). Paul Thrasher, a certified public accountant, provides accounting oversight and business systems review on a consulting basis. The staff will be augmented by an Education and Outreach Coordinator and by Software Support specialist. An organizational chart is shown in Figure 1.

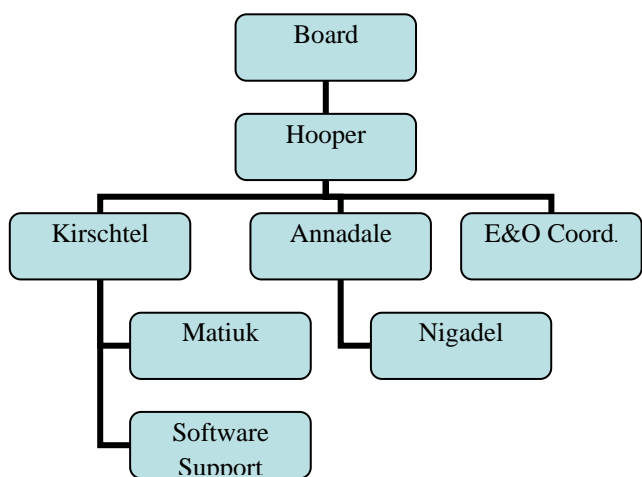


Figure 1. CUAHSI Organizational Chart

Outreach Coordinator and by Software Support specialist. An organizational chart is shown in Figure 1.

Pilot and developmental projects are operating under awards directly from NSF so the day-to-day operation of those projects is the responsibility of the respective PI’s. CUAHSI provides oversight (through standing committees), coordination among the projects, and logistical support for workshops, competitions, and standing committee meetings.

Figure 2 shows a timeline for all the tasks listed in the project as well as the biennial membership meeting. That meeting serves as an integrating mechanisms for this various tasks as progress on each

task towards the overall goal of effective infrastructure is evaluated. A large portion of staff time is devoted to coordination of the tasks, and providing oversight, in the form of users committees and standing committees. Staff also assists in workshop organization, logistics and completion of workshop reports.

Sub-awards to leaders of the community campaigns given the level of effort required to organize these activities. All other pilot or developmental projects (HIS, HMF, any new projects for CHyMP) will be separately proposed with their own PIs. CUAHSI responsibility is one of coordination and oversight.

Year	2008			2009			2010			2011			2012			2013	
Quarter	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	
0. Biennial Meeting								*							*		
1.1 User Support			/				/			/			/			/	
1.2 CHyMP	*				*		/										
1.3 Data Curation							/										
1.4 Virt Obs													/				
2.1 Sensor Wksh		*				*			*		*		*				
2.2 EOL Flwshp																	
2.3 HMF Support																	
3.1 Sum. Inst.				*				*		*		*		*			
3.2 Assessment					/			/									
3.3 Wrkshp						*											
4.1 Campaign	Planning						Deploymnt #1			Deploymnt #2			Deploymnt #3		Synthesis		
4.2 WATERS																	
5.1 Case Studies	*		/				/		/		/		/		/		
5.2 Media Bank	*		/				/		/		/		/		/		
5.3 Flwshp																	
5.4 Cyberseminar																	

*** Workshop or other Milestone; / Deliverable**

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