CONSORTIUM OF UNIVERSITIES FOR THE ADVANCEMENT OF HYDROLOGIC SCIENCE, INC.

TECHNICAL REPORT #5

CUAHSI

universities allied for water research

A NATIONAL CENTER FOR HYDROLOGIC SYNTHESIS

SCIENTIFIC OBJECTIVES, STRUCTURE, AND IMPLEMENTATION

A report of a CUAHSI workshop held in Santa Barbara, California, July 10-12, 2003

NOVEMBER 2003

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EXECUTIVE SUMMARY

SYNTHESIS

(OED): the process or result of building up separate elements,
especially ideas, into a connected whole, especially into a theory or system

(Webster): the combination of parts or elements into a whole

The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) convened a three-day meeting of its Standing Committee on the Hydrologic Synthesis Center at the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, CA on July 10-12, 2003. At this meeting, the Standing Committee was asked to determine the optimal configuration and characteristics of a hydrologic science synthesis center and to prepare a request for proposals (RFP) that CUAHSI could issue to solicit a host for a synthesis facility. This white paper is the committee report of that meeting. A draft RFP was also prepared, but was later modified to become a memorandum requesting a statement of interest to partner with CUAHSI as host of the synthesis center. The memorandum is available from CUAHSI.

This white paper report, developed from the July workshop, brings together the rationale, motivation, and objectives behind the hydrologic synthesis concept and provides additional background to the request for a Statement of Interest.

At the July meeting, the Standing Committee decided to form two subcommittees, one to write the draft RFP and the other to write the committee report. It also identified issues for discussion with the CUAHSI officers and Executive Committee. On July 11, the Standing Committee met with the Executive Committee and discussed conceptual issues related to the synthesis center and procedural issues related to the RFP. Jim Reichman, Director of NCEAS, made a presentation to the joint group.

The Standing Committee outlined a process to issue the RFP according a schedule that began with the draft workshop outcome, a draft RFP to be reviewed by the Executive Committee and then by the hydrologic science community before being released for the selection process. Subsequent to completion of the first draft, the RFP was extensively reviewed and underwent several modifications. Eventually it became, instead, a request for a statement of interest to partner with CUAHSI. The request will be released in January 2004. The current goal is to complete selection of the partner by early fall 2004.

Other topics discussed at the July meeting were: interrelationships among CUAHSI program elements; selection of the director; schedule for competition; proposal review process; community support and building a strong hydrologic science community; success factors for a center; conflict of interest management; and management and coordination of CUAHSI activities, centers, and programs. The product of the meeting was the draft RFP, a draft version of this report on the synthesis center, and a set of minutes for the meeting.

The purpose of this report is to provide an up-to-date document on the scientific objectives, structure, and implementation of a National Center for Hydrologic Synthesis (NCHS). The report brings together the rationale, motivation, and objectives behind the hydrologic synthesis concept and provides additional background to the request for a statement of interest. It will serve as the basic document on hydrologic synthesis for comment and reference by the hydrologic science community. It replaces a previous CUAHSI white paper on hydrologic synthesis, and will be made available to all on the CUAHSI web site.

The members and chair of the Standing Committee were appointed by the CUAHSI Executive Committee. Below are the names of committee members, and a list of CUAHSI officers and members of the Executive Committee who participated in the second day of the July workshop.

CHAIR

Neil Grigg, Colorado State University

MEMBERS

Elizabeth Boyer, State University of New York
Jeff Dozier, University of California, Santa Barbara
Nancy Grimm, Arizona State University
Venkat Lakshmi, University of South Carolina
Upmanu Lall, Columbia University
Dennis McLaughlin, MIT
Ying Fan Reinfelder, Rutgers University
Yoram Rubin, University of California, Berkeley (observer)
David Tarboton, Utah State University
Charles Vorosmarty, University of New Hampshire

OTHER MEETING ATTENDEES

Doug Alsdorf, CUAHSI, Secretary of the Corporation
Wendy Graham, CUAHSI, Member, Executive Committee
Rick Hooper, CUAHSI, Executive Director
Ken Potter, CUAHSI, Member, Executive Committee
Jorge Ramirez, CUAHSI, Member, Executive Committee
Yoram Rubin, CUAHSI, Member, Board of Directors
Frank Schwartz, CUAHSI, Member, Executive Committee
Claire Welty, CUAHSI, Treasurer of the Corporation
John Wilson, CUAHSI, Chair, Board of Directors

INTRODUCTION

THE NEED FOR HYDROLOGIC SYNTHESIS

Hydrologic science is a rapidly expanding interdisciplinary field that connects climate, Earth, and life sciences, and links them to health and society. Hydrologic science processes interact nonlinearly across many scales in space and time, leading to complex space-time patterns. These patterns may correspond to simple underlying rules or laws, but this is not directly evident from the integration of models of the component unit processes. Whether we seek to understand and predict the transport of contaminants through the subsurface, or the underlying mechanisms of observed changes in the frequency of droughts and floods, a synthesis of knowledge (observations and their interpretation in a theoretical framework) from diverse environments, disciplines, and observational scales is needed to explain the emergent patterns. Hydrologic synthesis is critical for the advancement of the science to support integrated water resources management in the face of anthropogenic and natural change, population growth, and economically and environmentally sustainable resource management.

As these integrated perspectives evolve, one is faced with large quantities of disparate data and concepts that are being developed in increasingly specialized disciplinary contexts. A venue for systems thinking and comparative analysis that can stimulate new ways of designing observation systems and synthesizing hydrologic laws could revolutionize hydrologic science and help it attain its maximum potential as a collaborative field of science that contributes to the acceleration of scientific progress and the sustainable development of human society.

The global water cycle is a dominant factor in the redistribution of energy in the climate system. Climate science has typically been defined as an intersection of atmospheric and ocean sciences, treating terrestrial processes as a boundary condition. Hydrology traditionally focused on terrestrial processes and treated weather and climate, geomorphology, ecology, and even human modification of the land as exogenous processes. The field of terrestrial hydrology, as represented by organization into professional societies, groups, and journals, has been fragmented by domain (e.g., surface, groundwater, polar), by approach (e.g., physical, chemical, stochastic), and by area of application (e.g., contaminant transport, floods). While individuals will continue to define advances in these sub-areas, a communal response is necessary to address the scientific challenges posed, for instance, by the rapid rate of local and global anthropogenic change.

Process-level understanding of the hydrologic sciences has advanced to the point where it is ripe for synthesis in a contemplative and integrative environment through the application of modern cyberinfrastructure. This opens new possibilities for a vastly increased understanding of the water and associated biogeochemical cycles from local to global scales, which would lead to applications for improved water resources management and to integrated education.

Recognizing the importance of water to life and to Earth systems, the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) seeks to advance hydrologic science in the 21st century through a broad-based program of observations and research. CUAHSI (http://www.cuahsi.org) has evolved a science and implementation plan through a series of workshops, meetings, and other collaborative exercises. A primary purpose of CUAHSI is to help develop basic programs and infrastructure to support community research. The infrastructure elements include a system of hydrologic observatories, a hydrologic information system, a hydrologic measurement technology facility, and a hydrologic synthesis center. The synthesis center is intended to play a critical role in the development of CUAHSI programs and infrastructure by providing a venue

for the formulation of hydrologic science questions and research initiatives through a synthesis (or cross-cutting analysis) of existing information and theories. Thus, it would also provide a vehicle to coordinate and assess the products from the other infrastructure elements and to provide direction for future science programs and infrastructure needs. Given this context, the mission of the proposed National Center for Hydrologic Synthesis (NCHS) is to:

- Promote the articulation of a community vision for the future of hydrologic science;
- Cultivate an interdisciplinary research culture of collaboration and cooperation; and
- Offer new opportunities to cooperate in attacking specific scientific challenges.

BACKGROUND AND OBJECTIVES

Hydrologic science traditionally has been a somewhat fragmented accumulation of knowledge about complex, multifaceted, interdisciplinary phenomena, the components of which all pertain to water. Recent decades have seen a movement within the hydrologic science community toward comprehensive research endeavors, such that the interfaces among the sub-specialties of hydrologic science have become the frontiers of the science and not the boundary conditions of its sub-fields. However, the advancement of science on these frontiers is not efficient. The venues available for such activities are either dedicated to other realms of science or are transitory in nature. The hydrologic science community does not have access to the same modern observational, data synthesis, and cyberinfrastructure technology available to other fields. In other words, hydrologic science on its modern frontiers now relies on targets of opportunity, and uses only a small portion of the available modern technology. Overcoming this impediment is the primary motivation for HydroView, CUAHSI's proposed program of infrastructure support for hydrologic science that includes hydrologic observatories, hydrologic information systems, and a Hydrologic Measurement Technology facility. The CUAHSI program with the greatest potential to change the way that hydrologic science is conducted is a permanent facility for the synthesis of ideas across the broad spectrum of specialties encompassed by hydrologic science. It is for this reason that CUAHSI proposes the establishment of a NCHS. With such a facility as its matrix or mortar, CUAHSI programs will constitute a formidable structure for the advancement of the science.

During January through March 2002, CUAHSI conducted six regional workshops at which faculty from its member universities and selected scientists from outside the consortium family met to develop ideas for input to CUAHSI's science planning process. At each of these workshops, it was apparent that the workshops themselves were serving as ad hoc forums for synthesis of ideas among individuals who often had little or no history of collaboration. A consensus evolved from these workshops that a permanent facility at which hydrologic scientists could meet in person with support for data access, visualization, and exploration would serve to unify the community and enhance its capability to address the broader questions, which to date have remained largely beyond its grasp.

The ecological community has such a facility, the National Center for Ecological Analysis and Synthesis (NCEAS), in Santa Barbara, California. Because ecology is at one of the frontiers of hydrologic science, several hydrologists active in preparing CUAHSI's science plan have had the opportunity to participate in activities at NCEAS and have found the experience very rewarding. Ecological science and hydrologic science also share a similar history, with both historically relying on individual investigators exploring their own field sites or running their own computer models. Therefore, the NCEAS activities and infrastructure have been taken as the starting point for the development of plans for providing similar experiences for hydrologic scientists working on a broad spectrum of issues.

A draft white paper on the synthesis center concept was then prepared, presented, and debated at a CUAHSI membership meeting at Snowbird, Utah in August 2002, at which

point the concept of a synthesis center was formally adopted as part of the CUAHSI overall science plan. The CUAHSI membership resolved that the structure and location of the synthesis center be selected through an open, peer-reviewed process. CUAHSI membership at the Snowbird meeting resolved that the synthesis center serve as a physical base for activities of the following types:

- Meetings and workshops
- Working groups
- Visitors, including post doctoral fellows, sabbatarians, and teachers in residence
- Educational and outreach functions
- Research applications
- Synthesis activities derived from the Hydrologic Information Systems initiative

The Snowbird workshop recommended that the white paper be revised to address the recommendations of the review group.

Following the Snowbird meeting, a CUAHSI science agenda was developed that articulated the key elements of the CUAHSI program as Hydrologic Synthesis, Hydrologic Observatories, Hydrologic Information Systems, and Measurement Technology, all of which we now put under the umbrella of HydroView. The Snowbird meeting and science agenda thus confirmed the need for synthesis to be facilitated through the establishment of a National Center for Hydrologic Synthesis (NCHS).

In June 2003, CUAHSI's core proposal for the initiation of CUAHSI activities was funded by the National Science Foundation (NSF). In addition to the core and other activities, this proposal included funding of additional steps towards the development of a synthesis center. In July 2003, the Standing Committee held a workshop on the Hydrologic Synthesis Center at NCEAS in Santa Barbara. The committee was asked to determine the configuration for the synthesis center and to prepare a request for proposals (RFP) that CUAHSI could issue to solicit a host for the synthesis facility. After the meeting, the format of the RFP was changed to a request for a statement of interest to partner with CUAHSI as a host of the NCHS. This white paper report, developed from the July 2003 workshop, brings together the rationale, motivation, and objectives behind the hydrologic synthesis concept and provides additional background to the request for a statement of interest developed by this workshop.

SCIENTIFIC OBJECTIVES OF A NATIONAL CENTER FOR HYDROLOGIC SYNTHESIS

WHY IS SYNTHESIS NEEDED?

Over the last few decades, hydrologic science has grown to encompass scientists and engineers from a diverse array of fields, and information and knowledge that span every branch of the Earth sciences and some of the biological sciences. Efforts are needed to unify and consolidate the hydrologic science community as well as the vast amount of hydrologic information toward the goals of achieving a higher quality of scientific research and answering questions that have greater societal importance. Specifically, the hydrologic community requires research synthesis for the following reasons:

1. Hydrologic science, by nature, is multidisciplinary. Through the water cycle, hydrology connects the atmosphere with the land, the land with the ocean, and the biota within, including humans. Thus, hydrologic research has been conducted by scientists and engineers from a diverse array of disciplines and fields. The researchers belong to different organizations, attend different professional meetings, and publish their results in different professional journals. This fragmentation makes it difficult for the community as a whole to address larger hydrologic science questions that cut across the disciplinary boundaries. Well-coordinated and more than just casual interactions among the leaders of diverse disciplines and fields are needed to overcome this community fragmentation.

2. The extent and diversity of hydrologic data, information, and knowledge hinder synthesis. It is not practical for individuals to attend the many meetings and read the many journals that bear on hydrologic sciences. Ideas and findings that potentially apply to other sub-fields may not travel beyond the meeting room walls or journal covers. Synthesis research is needed to collect, consolidate, organize, extract, and distill the knowledge and ideas that transcend disciplinary boundaries and allow us to infer general patterns, principles, and concepts.

3. Along with the growth and explosion of hydrologic knowledge, cutting-edge research inevitably becomes highly specialized and focused. This specialization manifests itself not only in terms of disciplines and aspects of a particular problem, but also in both spatial and temporal scales of investigation. Since global and regional processes are the outcomes of complex, nonlinear interactions of local processes, the hydrologic community faces the formidable task of understanding the relevance of a particular phenomenon at a particular scale to various processes at another scale. This type of research is fundamental to the advancement of hydrologic science as a whole, and is best accomplished by focused and intensive interactions among scientists with insights into dominant processes at a range of scales.

4. Hydrologic science has arguably the strongest societal relevance among all the Earth science disciplines because a sustainable society depends on abundant and clean water while avoiding the hazards related to too much water. To best manage this precious resource, dialogues are needed at the community level between the natural scientists engaged in understanding the Earth's hydrologic system and the social scientists engaged in building a sustainable society. Synthesis of knowledge between the two groups can better inform the hydrologic community of the most pressing societal needs and standing issues, and provide the management community with sound science-based decision support.

WHY IS A CENTER NEEDED?

Hydrologic synthesis of the scope envisioned above requires sustained and intense interactions among diverse experts drawn from the breadth of the hydrologic science community, as well as the other Earth sciences and relevant biological and social sciences. One could argue that the existing venues of communication and collaboration such as meetings and workshops, journals, and electronic communications are sufficient to achieve the above synthesis goals. But, how often do we hydrologic scientists attend an American Geophysical Union professional meeting, hear an exciting talk, initiate a conversation, and speak of collaboration, only to return to our home institution, become submerged in our daily responsibilities, and set the idea of collaboration aside? It appears that a new mechanism of collaboration and contemplation is needed that allows scientists to escape their daily routines and come together to one location with face-to-face interaction over an extended period and with all necessary logistic and technical support.

The concept of the "working group," pioneered by NCEAS, has proven to be an extremely successful model for such a mechanism. It brings together a moderate number of diversely experienced scientists to contemplate a specific challenge for synthesis by relieving them of daily routines by gathering them in one room at a central facility for several days at a time and over the course of a few years. The value of this approach is reflected in the number of benchmark publications that have come out of NCEAS working groups. According to NCEAS' record, these publications are more likely to have multiple authors, and more likely to appear in journals such as *Nature* and *Science*, as compared to the "business as usual" publications by the same authors. Therefore, it is clear that the most compelling reason for a hydrologic science synthesis center is to provide a mechanism and exciting environment for "big science" and "think tank" activities crucial to pushing forward the frontiers of hydrologic science.

While the working groups have proven to be the most exciting element of NCEAS operation, their postdoctoral fellows program is equally compelling. Young scientists interested in "big science" questions are drawn from all over the world to the center where they are supported and encouraged to participate in working groups and interact with the best thinkers in the field of ecology. They participate in research at the national and international level and benefit from multiple mentors. Such a mechanism for training the future leaders of the ecological field was nonexistent before NCEAS. According to NCEAS' record, postdoctoral fellows from the center are more likely to obtain the best academic and government jobs. Therefore, the second most compelling reason for a hydrologic sciences synthesis center is that it provides a mechanism and an exciting place for better training of young scientists and cultivating future leaders of our field.

The third reason for hydrologic science synthesis center is the need for the hydrologic research community to provide the public with hydrologic science education, outreach, and management-decision support. Again, NCEAS serves as one model. Its *Kids Do Ecology* program instructs K-12 students in ecologic appreciation. Its *Undergraduate and Graduate Interns* program supports undergraduate and graduate student participation in data analysis and synthesis research, providing an opportunity for them to work with top scientists, gain research experience, and acquire a "large picture" view of the field of ecology. Its outreach staff facilitates information dissemination aimed at influencing local, regional, and national policy. All these functions are important missions of the scientific research community, and a hydrologic science synthesis center with similar functions is an ideal mechanism for fulfilling these missions at the community level.

The fourth reason for a hydrologic science synthesis center is to indirectly support so-called high-risk, exploratory, or new and emerging research that may have great potential but cannot be funded through the conventional channels.

The fifth reason is that a center such as NCEAS makes doing science easy. Its permanent staff arranges for international travel and visa application, housing, and data archiving and analysis, and provides computational support, graphics preparation, and technical writing. This logistic and technical support, together with the fact that the visiting scientists are away from the daily distractions of home, cre-

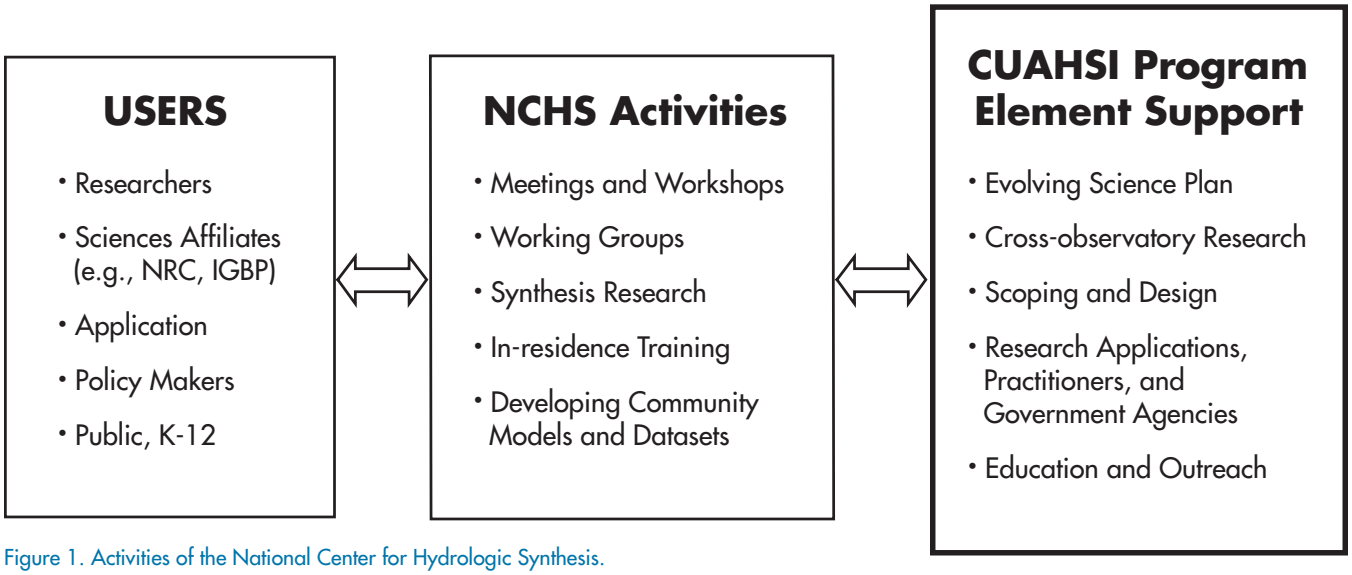

Figure 1. Activities of the National Center for Hydrologic Synthesis.

ates the carefree environment required for contemplating complex synthesis issues.

WHAT WILL A SYNTHESIS CENTER ACHIEVE?

A number of directions and approaches to hydrologic science research will be fostered by a center devoted to hydrologic synthesis. These directions include projects whose scale will surpass the typical single principal investigator single level hydrologic science research that up until now has been the norm. The center will enable a new type of hydrologic science inquiry that will come about only through collaborations among a diverse population of scientists and policy makers. Research directions will reflect the most recent findings from various national and international workshops and steering committees such as the U.S. Global Change Research Program (USGCRP) New Science Initiative on the Global Water Cycle (http://www.usgcrp.gov/usgcrp/ProgramElements/water.htm) and various committee reports from the National Research Council. Some examples follow.

Uncovering Feedbacks and Emergent Properties: This area recognizes that water plays a vital role in virtually all aspects of the global environment and is tightly coupled with the cycling of chemical species, especially nutrients. Interactions are decidedly two-way. Changes cascade through the system, and non-linearities and thresholds are common. Water management now figures prominently in the analysis. The classification of system-wide properties is not defined merely by the sum of the individual parts, but by their interactions. It is insufficient, then, to view the system as a simple aggregation of local-scale processes. It instead requires appropriately cast, systems-wide, and interdisciplinary analysis.

> *Examples of Supporting Questions: How is the water cycle linked together? What are its key sensitivities to change? What thresholds are there to change? What elements of the system create positive feedbacks to climate change? Which ones create negative feedbacks? How do human activities influence the state of the water cycle?*

Hydrological Dynamics: Variability and Change: This conceptual area involves the notion of change, arising from both natural and anthropogenic factors. The time domain of the effort must necessarily encompass the contemporary time frame where defining the state of the water cycle has greatest societal relevance. But understanding of observed present-day dynamics is also informed by dynamics occurring over geological and historical domains. These retrospective analyses are necessary to place the contemporary state of the water cycle in proper perspective, establish the direction and rates of contemporary change, and draw inferences about the future.

Examples of Supporting Questions: What are the key factors operating today in defining the state of the hydrosphere? Are these anthropogenic or natural? What is the relative magnitude of variability and change in the present-day water cycle versus the past? What are the implications for the future of water resource management?

Hydrologic Science Across Scales: How do hydrologic and related science behaviors scale across both space and time? While observations can be made at, literally, any scale of interest—from the lab bench over seconds, to geographic regions (using remote sensing) over decades, to the globe over millennia (from ice core records)—the great challenge lies in developing a mutually consistent picture from the concurrent analysis of these differently scaled measurements. Consistency must move toward full mass- and energy-conserving principles over all scales, and across all hydrologic settings and environments.

Examples of Supporting Questions: Do process-level field measurements support or refute dynamics observed over broader spatial and temporal domains? Under what conditions do continental-scale features of the water cycle become apparent? In individual watershed measurements? Are current techniques sufficient for producing a scalable, mutually consistent picture of hydrologic science?

Interdisciplinary Hydrology: The watershed is a natural unit for the study of the interaction among physical, chemical, and biological processes in the fields of biology, biogeochemistry, geology, and geomorphology. However, the traditions of scientific training both in the United and abroad are impediments to interdisciplinary research. Common data sets and research topics are required to catalyze interactions amongst traditional disciplines. The interdisciplinary view also requires development of a concrete language to share among the participating sciences. It also needs common data sets, tools, and case studies.

Examples of Supporting Questions: What are the major linkages in and controls on the terrestrial water and biogeochemical cycles that are mediated by physical climate and biogeochemistry, biology, and social systems? Is there evidence for co-evolution of terrestrial hydrologic and vegetative systems?

Hydrologic Science for Policy: Although there is, in fact, great concern about the state of our water resources, except for some notable and incomplete examples (e.g., U.S. National Assessment), we still need tools and mechanisms to inform the policy process. The proposed hydrologic synthesis center would make an ideal setting for the translation of state-of-the-art hydrologic scientific knowledge to the management and policy communities, while at the same time soliciting input from those communities for the direction of CUAHSI synthesis studies and other activities.

Examples of Supporting Questions: What are the key U.S. and global water management and policy imperatives? What are the effective mechanisms for catalyzing a fruitful exchange between the water sciences, water management, and policy communities? How can uncertainties be expressed by hydrologists, used meaningfully by decision-makers, and conveyed to the public?

Hydrologic Science Education at the Undergraduate and Graduate Levels: Because physical hydrology has traditionally been taught in the civil engineering or geology departments on university campuses, students who decide to pursue hydrologic science normally are required to take a heavy load of courses to justify the degrees they receive, rather than to achieve a broad-based hydrologic science education. Is there a need to formulate a coherent curriculum for hydrologic science education that is centered on the needs of the evolving discipline and yet recognizes the fact that hydrologic science will remain as a program or emphasis within the traditional departmental boundaries? If the answer is yes, then what would be the core curriculum? What are appropriate basic requirements in math, physics, chemistry, biology, geology, and sociology, etc., for cultivating a new generation of hydrologic scientists who are well versed in the languages of sister sciences? A working group consisting of scientists from all the relevant disciplines is an ideal way to address this important issue that will certainly impact the future of the hydrologic sciences community.

CENTER MISSION AND GOALS

The mission of the National Center for Hydrologic Synthesis is to advance hydrologic science and its contributions to society by:

- Promoting the creation of a vision for the future of hydrologic science;
- Cultivating an interdisciplinary research culture of collaboration and cooperation; and
- Offering new opportunities to cooperate in attacking specific problems of broad interest in the field that have significant social and scientific relevance.

The center will seek to achieve the following goals:

- To provide a venue for groups to meet and conduct interdisciplinary planning, synthesis, and results dissemination covering issues ranging from fundamental research to water resources applications to education and outreach, facilitated by access to data and models;
- To provide facilities and support for individual visiting scholars to conduct synthesis of data and knowledge, leading to increased understanding of the complex interactions among the components of hydrologic science;
- To provide an opportunity for recent Ph.D.s to work collaboratively with each other and with mentors towards new lines of discovery in the field, unconstrained by the usual institutional expectations; and
- To facilitate the interaction among the various CUAHSI programs and activities, including the updating and evolution of the CUAHSI community science agenda.

CENTER ELEMENTS AND ACTIVITIES

The NCHS will fulfill its mission through participation of individual members of the hydrologic science community rather than through a permanent staff. The staff's role will be to facilitate the activities of external participants rather than to perform internal research and synthesis themselves. Following the NCEAS model, the center activities will consist of, but not be limited to, the following elements: (i) working groups, (ii) workshops, (iii) post-doctoral fellows, (iv) sabbatical fellows, and (v) graduate and undergraduate interns.

WORKING GROUPS

The most successful activity in NCEAS is the working group, and it will also be the centerpiece of our hydrologic science synthesis center activities. Working groups will be formed at the initiative of the hydrologic science community to address problems of synthesis across disciplines and scales. Such problems might include integration and interpretation of large hydrologic science data sets (especially those produced through the activities of large-scale cooperative hydrologic science projects), major theoretical problems of wide interest, cooperative modeling and programming issues, resolution of controversies over hydrologic process understanding, or current issues in water resources management. Projects will be formulated by groups within the hydrologic science community and will be selected on the basis of proposals submitted to the center's Science Advisory Committee (discussed later). Following the NCEAS model, the working groups can range from eight to twelve persons who will meet at the center for two to five days each visit. Working groups will be funded for periods from one to several years, and for meetings of one to two weeks, two or three times a year. Funding will be provided for transportation to the center, expenses while at the center, and incidental expenses such as computing and publication costs. Funding could be solicited for a post-doctoral fellow to cooperate with the working group. Working groups would normally be expected to produce peer-reviewed publications as a result of their activities, but other products, such as software, could be developed. Working groups also might find it useful to hold workshops periodically to broaden input and to develop consensus on the ideas that they are pursuing.

WORKSHOPS

One of the primary objectives of CUAHSI is to bring together a rather fragmented community that has migrated to hydrologic science from a variety of disciplines to formulate and focus upon a common set of critical scientific problems and societal issues. Initial CUAHSI workshops have proved highly successful in this regard and this momentum should be maintained. This can be accomplished through a regular series of workshops. The workshops will differ from the working groups in that they will be attended by a diverse group, will deal with broad issues of common interest to the community, and will typically be a one-time event. The center will provide funding for transportation and expenses for the workshops. Workshops can be initiated either through action of the CUAHSI Executive Committee, through initiative of one of the working groups, or through competitive proposals from the community.

POST-DOCTORAL FELLOWS

The second most successful element of NCEAS is the postdoctoral fellows. Postdoctoral fellows will be selected through competitive applications and will reside at the center. A normal post-doc tenure will be two years, with the possibility of application for an extension for a third year. The post-doctoral fellows could be selected from proposals in response to solicitations associated with working groups, or from proposals for projects originated by the applicants. Proposals would be expected to be in the areas of hydrologic science synthesis and analysis, rather than field or laboratory

projects. Salary, travel costs, and relatively minor research expenses will be covered. Post-doctoral fellows will be expected to select a mentor from among the members of the center's Science Advisory Board, the leaders of the working groups, or the sabbatical fellows.

SABBATICAL FELLOWS

Sabbatical fellows will reside at the center and will also be selected through competitive applications. The fellows will be expected to spend the majority of their sabbatical in residence at the center. The center will provide up to half salary, a housing allowance, and an office equipped with computing facilities appropriate for the fellows' research needs. Preference will be given to sabbatical proposals emphasizing problems of broad interest to the hydrologic science community and/or collaborating with a working group or a post-doctoral fellow. Peer reviewed papers and books will be expected of each sabbatical fellow.

GRADUATE AND UNDERGRADUATE INTERNS

Undergraduate and graduate students can apply for on-site or off-site internships attached to particular working groups, workshops, or sabbatical fellows, and involved in data analysis and synthesis or education and outreach activities.

POTENTIAL SYNERGIES

The greatest synergy between the center and other elements of CUAHSI's HydroView Program is with the Hydrologic Information Systems (HIS) element. Indeed, HIS already encompasses most of the cyberinfrastructure-related activities at NCEAS. In this area, NCEAS is an imperfect model. The hydrologic science synthesis center will use HIS products rather than duplicate them.

Synthesis opportunities also abound with respect to each of the other CUAHSI program elements. For example, it is anticipated that each of the CUAHSI Hydrologic Observatories will have some facility for the synthesis of its data and theoretical constructs. However, there will be questions addressed in the programs of each of the observatories that are broader in scope and impact than just the region or hydrologic setting that the individual observatory represents. In particular, there will be questions that are continental to global in scale as the basis for the observatories functioning as a network rather than an aggregation of individual studies. Synthesis of findings and data pertinent to these large-scale questions can be conducted effectively by working groups sponsored by the center.

The CUAHSI Hydrologic Measurement Technology (HMT) program will be active in the development of new advanced instruments and measurement systems. Such cutting edge science might well benefit from working groups constituted jointly by the center and HMT.

The center would be an ideal facility for the support of CUAHSI activities pertaining to education and outreach. Working groups could be convened to scope out and develop materials and strategies to address the multitude of audiences that could benefit from such activities.

The CUAHSI program of research applications could benefit from the inclusion of members of the applications segment of the hydrologic community on many of the center working groups. Participation by application-oriented members would provide research scientists with better knowledge and understanding of the real world problems and would give the applied members better understanding of the relevance and the potential limitations of new science and technologies as they become available for use.

DELIVERABLES

The primary products of center activities will be a steady flow of refereed publications, workshop proceedings, monograph series, short-course materials, synthesized data sets, and web-based products. Furthermore, we expect to see more multiple-author and benchmark articles appearing in higher-level scientific journals such as *Nature* and *Science*. However, the most beneficial deliverable will be that it may change the ways hydrologic scientists conduct research by promoting cross-subdisciplines and cross-scale interactions that will lead to answers to larger questions in hydrologic science.

CENTER ORGANIZATION, STRUCTURE, AND SUPPORTS

Following the NCEAS model, we anticipate that the center should include an administrative group, a science advisory board, a scientific support group, a technical support group, and a logistic support group.

ADMINISTRATION

The administration may be comprised of three persons: the director, associate director, and an administrative assistant. This group will be responsible for the overall management of the center, for planning its activities in conjunction with the center's Science Advisory Board, for developing its sources of funding, and for networking with the hydrologic science community. The center director would report directly to, and the center's performance would be evaluated by, the CUAHSI Executive Director.

The most crucial member of the center will be the director, who will set the tone of cooperation and mutual support that will be necessary to the center's success. The director should be a known and respected member of the community who also must have the interpersonal skills and the scientific savvy to foster the interdisciplinary studies that will be the backbone of the center's scientific programs. On the other hand, the director must have restraint so that he or she does not, and is not perceived to, control the agenda of the center to the detriment of the broader community. Ideally, the director would also have managerial experience and talent so that both the day-to-day operation of the center would be effective, and its long-term vision would be guaranteed by the development of a high quality business plan. Following the NCEAS model, in order to attract a pool of qualified applicants, the center director might be provided with open term of office and a tenured faculty appointment at a center-affiliated university.

The associate director will serve as the primary assistant to the director, and will serve in the director's stead when the director is absent from the center. The associate director should be hired to complement the director's strengths and weaknesses.

The administrative assistant will serve as the third-ranking official for the center, but he or she will have no supervisory responsibilities when either the director and/or the associate director are present. The primary role of the assistant is to work closely with the scientists and the working groups to assure the success of their endeavors. This individual should have experience in group dynamics and also would serve as the primary liaison between the administrators and the working groups, sabbatical fellows, post-docs and other scholars.

SCIENCE ADVISORY BOARD

The Science Advisory Board (SAB) may be comprised of 15 to 20 members from a wide spectrum of hydrologic science sub-disciplines. Its primary functions would be to advise the director on a variety of topics, and to review proposals for center scientific activities (working groups, workshops, post-doctoral fellows, sabbatical fellows).

Mechanisms for determining board membership might involve community nomination and voting, existing SAB nomination and voting (as at NCEAS), and appointment by CUAHSI Executive Committee. Board members serve two to three year terms, and at the end of each year, one-third of the board will be replaced.

One of the primary missions of the SAB is to provide a flexible and speedy funding process that can meet the synthesis needs of the community. A set of principles that captures

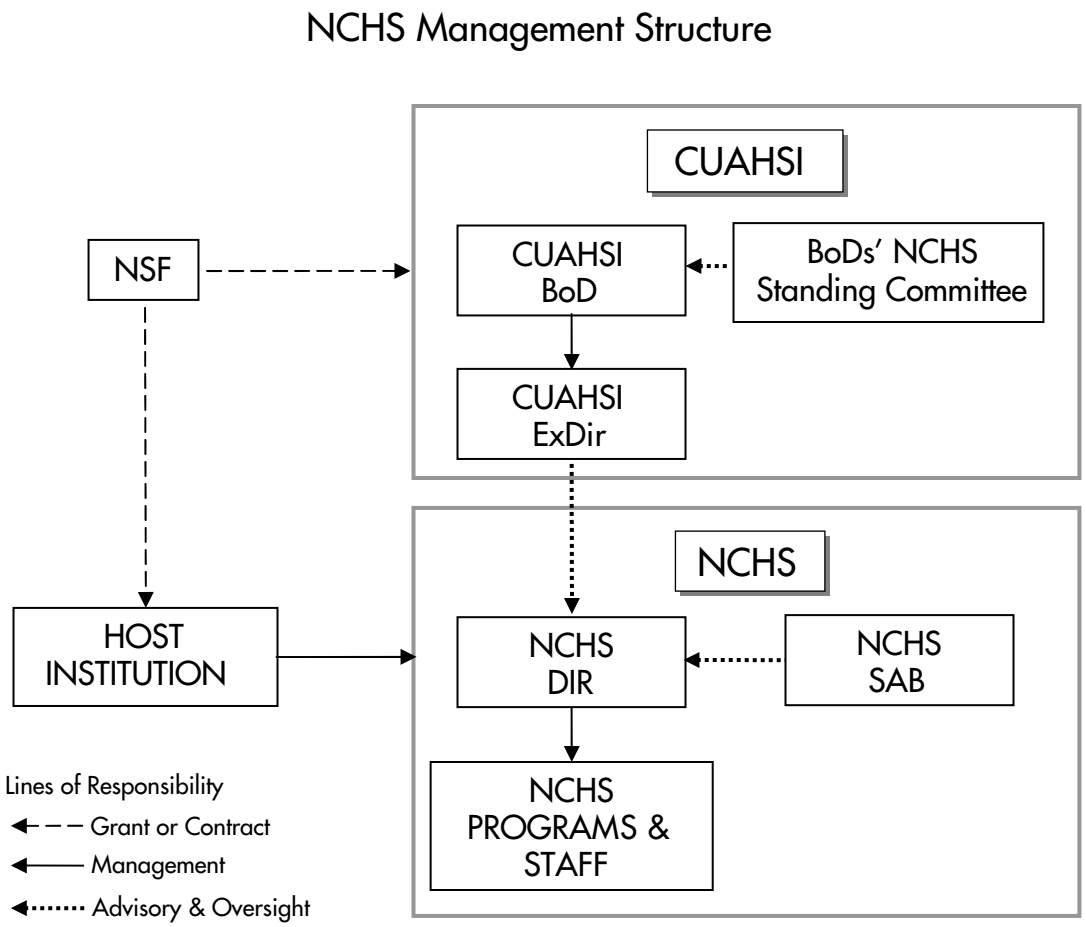

Figure 2. The National Center for Hydrologic Synthesis management structure.

some of the flexibility and quality assurance, similar to that used by NCEAS, will guide the director and the board in the funding process. These principles will ensure that the funding process for all programs at the center be transparent. All proposals will be considered through a formal in-house review system that provides written feedback to the investigators.

SCIENTIFIC SUPPORT

The scientific support group may be comprised of 5 to 10 staff members. The group would provide support for center projects throughout the life of each project. It would facilitate the activities of the working groups, assist the resident scholars, prepare reports and outreach materials, and organize workshops, conferences, and training courses hosted

by the center. It would also provide technical writing support and would have responsibility for the preparation of workshop and conference reports and training and outreach materials. One or two members of the group would serve as liaisons for education, outreach, and research application functions of the center.

TECHNICAL SUPPORT

All center activities will be supported by an in-house cyberinfrastructure group. The group will consist of about five people trained in computer science and technology. Technical personnel will support the various working groups and resident researchers in their needs for data retrieval, analyses, computation, and presentation. This group will be closely linked with the CUAHSI Hydrologic Information Systems (HIS) program. Key support services include:

- Desktop computing support and systems and network administration;
- A scientific programmer and technology consultant to help working group members and resident researchers access the hydrologic models, analysis routines, and data sets required for their studies;
- Regularly renewable funding for desktop technology and software licensing;
- Capacity to employ common computing functions such as statistics, GIS and remote sensing, visualization, and commonly used hydrologic models;
- A database server with sufficient space for storing general project file directories;
- High-speed Internet communications capabilities;
- Access to the scalable database server at HIS with multi-terrabyte storage capacity for storing larger datasets;
- Access to high-performance computing facilities;
- Access to a relational database system at HIS for more formal data storage when needed; and
- Access to electronic library resources including subscriptions to electronic journals.

LOGISTICAL SUPPORT

Three secretarial positions would be required to support activities at the center. In addition, one clerical position would be needed to handle the travel arrangements for the program participants. A bookkeeper would be needed to work with CUAHSI accounting staff and with center management to make sure that the center's finances are properly allocated. One custodian would be needed to keep the facilities functioning, clean, and orderly.

CENTER FACILITIES

The physical facilities required to house the National Center for Hydrologic Synthesis are a building or a wing/floor of a building, its furnishings, and equipment.

NCEAS, an operation similar to the one described above, is located on the third floor of an office building in downtown Santa Barbara, California, occupying almost 11,000 square feet. However, a workshop convened to determine the needs of NCEAS before it was established estimated that approximately 20,000 square feet would be needed to carry out its mission. The reason for the difference between the workshop plan and the built facility is the decision not to include a 100-seat auditorium. Thus, approximately 8,000 square feet will be assumed to satisfy the initial needs of the hydrologic center.

The facility itself should be designed or remodeled so that the natural interaction of resident scholars and visitors is encouraged while still offering solitude for those times when the creative urge needs to be satisfied without interruption.

NCHS's location will be a major determinant of its success. While not required, it would best be located near a university campus with a major program in hydrologic science so that natural synergies between the university and the center can be fostered. Some of the possible synergies will involve the participation of undergraduates and graduate students, in the activities of the center either in work-study programs or as junior participants in the center working groups. The university's faculty will also benefit from ease of access to center programs and collaboration with its resident scholars. The center will benefit from the interaction with the local university faculty and through sharing of facilities such as libraries and internet capacities. The ideal locale would be one where the local university is a node on Internet II or soon will be, for access to this latest expansion in bandwidth could offer significant advantages.

On the other hand, the center should not be located directly on a university campus in order to minimize perceptions of the center being a captive of a host university's particular agenda for hydrologic science. Modest geographic isolation from a host university campus also provides some insulation from the daily routine for the local faculty when they participate in activities of the center. NCEAS's location eight miles from the University of California at Santa Barbara has been shown to be an optimal geographic attribute.

Other locale characteristics that would help fulfill the center's mission are location in a town where the climate and the ambiance are pleasant to visit and to live. The climate should not be too extreme in any season as the center will be in operation year round. The local area should offer a pleasant and reasonably priced choice of housing for resident scholars and staff, and have comfortable and cost effective lodging for transient participants in the working groups and workshops. A reasonable choice in cuisine among the local restaurants is also highly desirable. Lastly, the center should not be so isolated from an airport that it deters participation in work groups and workshops.

The center should be furnished in a pleasant, functional, and comfortable manner with adequate space and storage for those who will spend significant portions of their time therein. Each office and conference room, as well as the lounge, should have adequate equipment to serve as a stimulus to accomplishing the center mission. Once again, NCEAS can serve as an initial model, as it features computers of various types so that each visiting scholar has access to his or her operating system of choice in his or her office space. Furthermore, NCEAS has two computer laboratories where all resident scholars and visitors have ready access to a variety of other more specialized machines. Each NCEAS conference room is networked into the LAN with multiple sockets for full participation of all working group members.

Finally, the NCEAS lounge is a focal point of interactions among those who participate in NCEAS activities. It is laid out so that several discussion groups can be active at any given time while enjoying comfortable furnishings, access to white boards, and readily available refreshments.

IMPLEMENTATION PROCESS

CUAHSI should seek a partner to initiate, manage, and operate the NCHS. The center, to be hosted by the partner institution, will be funded by submitting an unsolicited proposal to NSF and/or other governmental agencies. NSF will conduct a standard review of the proposal, which will succeed or fail on its merits.

To ensure that all potential host institutions have a fair opportunity to partner with CUAHSI, the consortium has devised a pre-proposal preparation process and review procedure that includes submission of a statement of interest to partner with CUAHSI and, upon selection for consideration, a final pre-proposal. CUAHSI will form an internal review team to review, rank, and recommend the statements of interest. The CUAHSI Executive Committee will consider these reviews and recommendations and select up to four finalists be invited to submit pre-proposals to CUAHSI. Following site visits, a CUAHSI review team will rank and recommend the pre-proposals to the CUAHSI Executive Committee, which will select one pre-proposal as the basis for our submission to NSF for evaluation and potential funding. CUAHSI management will work with the selected partner institution to prepare the collaborative proposal.

A memorandum (with an extensive addendum) has been prepared by the Standing Committee on the Hydrologic Synthesis Center containing detailed information on the preparation of statements of interest for partnering with CUAHSI, finalists' preparation of pre-proposals, budget information, and review procedures.

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TECHNICAL REPORT *#5*

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