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

TECHNICAL REPORT #7

CUAHSI
universities allied for water research

DESIGNING HYDROLOGIC OBSERVATORIES AS A COMMUNITY SERVICE

Report of a Workshop held at
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INTRODUCTION

Recognizing the limitations of the current modes of field research, the hydrologic science community, through the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), has been exploring the utility of large-scale infrastructure to make fundamental advances in its science. Having identified the interfaces between traditional sub-disciplines of hydrology (such as groundwater and surface water or the land surface and atmosphere) and between hydrology and closely related disciplines (such as biogeochemistry, geomorphology, and ecology) as the most promising areas of research (Smith et al., 2002), the fundamental requirement to advance the science is *to collect coherent, multidisciplinary data at multiple spatial scales.* Although large environmental data sets currently exist, they are often are incoherent—streams gaged in one location, observation wells monitored in another location, chemical and biological measurements taken in a third location—so that hypotheses cannot be tested. Where more-integrated studies are performed, such as at Long-Term Ecological Research sites or at study sites run by federal science agencies, they are often at a small scale (order of tens of square kilometers) and in headwater locations. Studies of larger-scale phenomena (e.g., regional groundwater and river exchange) and of human influences on these systems are difficult or impossible.

To overcome these limitations, the concept of *hydrologic observatories (HOs)* emerged, envisioned as calibrated river basins with an area on the order of 10,000 km^2. Although never before achieved, technological advances in instrumentation, cyberinfrastructure, and remote sensing make this vision possible today. Ideally, basins will be chosen where extensive data sets have already been collected and where research, monitoring, and assessment activities are ongoing. By strategically investing in additional data collection and adding infrastructure to make the site accessible to non-local researchers, the vision for hydrologic observatories could be achieved at a feasible budget.

These HOs would be supported with three additional program elements: informatics, instrumentation, and synthesis. Collectively, the program is known as HydroView, the first comprehensive, large-scale infrastructure for hydrologic science.

CUAHSI received a grant from the National Science Foundation (NSF) to further develop the hydrologic observatory concept by performing a "paper prototype" study of the Neuse River, North Carolina (Reckhow et al., 2004) using a large team of scientists both local to the basin and from across the country. The central challenge faced by this team was balancing the "network" aspects of HOs (i.e., how commonalities among HOs were defined and enforced) and "local" aspects of HOs (i.e., how the observatory design team (ODT) for an HO was able to advance its own research agenda). Ultimately, this team rejected a common set of design questions as impractical, at least for the initial few HOs, and instead endorsed a characterization of the site, defined to be the mass, fluxes, flowpaths, and residence-time distribution of water, sediment, nutrients, and contaminants across a range of spatial scales. This characterization is believed to be fundamental to a broad class of hypotheses, and, hence, useful to the community. Although the ODT is free to design around a locally chosen set of hypotheses, it must provide the community with the data and models that provide this characterization. These data and models form the "core data" and are the community data product that will be freely available to everyone with no first-publication rights.

Selection of the first HOs, therefore, shifted from an emphasis on response to a common set of design questions to a demonstration that the core data set proposed by the ODT will, in fact, be useful to the broad community. A central metric of success for an HO will be the number of scientists *outside the ODT* who perform research at the site. Further description of the findings of the Neuse Prototype study is included in the Background section of the report.

STRUCTURE OF THE WORKSHOP

Following the release of the draft Neuse report in June 2004, a two-day workshop was convened to further develop these concepts. The workshop was structured around marketing potential HO basins to the community. What were the attributes, including physical setting, existing infrastructure, and local community support, that would make this site attractive to researchers from across the country and around the world to travel there? Research "prospectuses," limited to 10 pages, were solicited from the community and posted on the CUAHSI web site. A total of 24 prospectuses were submitted from teams around the country (Table 1).

Table 1. List of potential HO basins proposed by the community

Alaskan North Slope/ Kuparuk
High Plains Aquifer
Apalachicola, Chattahoochee, Flint
Flathead River Basin
Illinois River Basin
Connecticut River
Great Salt Lake Basin
Mississippi Embayment
Delaware River
Pacific Northwest
Mississippi Headwaters/ Red River
Greater Santee River Basin
Rio Grande
Ozarks Plateau
Sierra Nevada
Platte River Basin
Potomac River
Spokane River Basin
Republican River/High Plains Aquifer
Susquehanna River Basin
San Antonio/Guadalupe
Suwannee River
South Platte River
Yazoo River Basin

The first day of the workshop consisted of presentations to the entire group of the Neuse Paper Prototype, a discussion of the design status of the other HydroView elements, and an update from the National Science Foundation about the HO competition schedule. In the afternoon, a poster session was held to allow the participants to discuss the various sites. This was followed by an election of a network of five HOs by the participants. This election forced an active consideration by the participants of what they wanted in an HO network and emphasized the community nature of the HOs—these are sites to be used by the entire community and not simply research sites for the ODT. This network has no meaning beyond this workshop, does not imply endorsement by CUAHSI, and was simply a way to construct a specific, albeit hypothetical, network for consideration on the second day of the workshop. The five basins elected to the hypothetical network were the Potomac, Suwannee, Illinois, Great Salt Lake, and Pacific Northwest (Willamette/Deschutes).

Two sets of break-out sessions were held on the second day. The first set considered each of the chosen basins and addressed the following topics:

1. The Neuse Prototype Report concludes that a useful characterization of an HO would be describing the mass, flux, flowpath, and residence time of water, sediment, nutrients, and contaminants. This report assumes that the ODT will propose a series of conceptual models across scale to estimate these characteristics. What do you need, as someone not familiar with the HO site, to be able to utilize this information? Will this characterization be useful to your research?

2. The Neuse Report did not include much on energy budgets. Although point measurements of radiation, for example, will be part of micrometeorological stations and enhanced observing arrays, constructing an energy budget of a complex terrain at large scale is a complex undertaking, but critical to understanding climate and hydrologic interactions. What kind of energy measurements should be part of core data (as opposed to investigator-driven science projects) or, conversely, what proportion of the core data budget should be allocated to energy measurements?

3. What "static" information (e.g., land use/land cover, digital elevation models) do you expect to be available at an HO? How frequently should these be updated?

4. HO core data will necessarily include standard hydrologic time series of precipitation, snowpack water equivalents, discharge, groundwater levels, and water quality data (although their number, spatial orientation, etc. is subject to design). Fewer "standard" data will also be included, such as NEXRAD space-time series, time series of NDVI or other remotely sensed data, and more exotic water-quality indicators (dual isotopes of nitrogen, DNA sequences of pathogens). What proportion of the core-data budget should be devoted to "pushing the envelope" and developing non-standard data series or should these efforts be reserved for the science projects performed at the HO? What are the guidelines you can provide to determine suitability for inclusion of a data type in core data from this perspective?

The second set of break-out sessions considered the five selected basins as a network and were organized by five science topics: Understanding hydrologic extremes, fate and transport of contaminants, biogeochemistry, hydrologic influences on ecosystem functioning, and sustainability of water resources. The topics addressed by this set of break-out groups were:

1. Although each HO will be individually designed, the Neuse Report concludes that the data can be integrated at the level of the four fundamental characteristics of the basin (mass, flux, flowpath, and residence time of water, sediment, nutrients, and contaminants). Do you agree that integration can occur at this level?

2. All core data will be collected according to published protocols. These protocols will be made as uniform as possible across HOs, given variations in local conditions. While this is sufficient for data comparability at some level, integrating data series across very different sites is always difficult. Must CUAHSI develop a set of cross-observatory hypotheses to design an effective network of HOs? If so, how should such a set of hypotheses be chosen? As an NSF-run competition? By a CUAHSI committee?

3. A set of five HOs were presented to you as a network. How effective were these sites at addressing your science topic? Would you choose a different set of five sites from the 24 prospectuses? If so, which ones and why? If not, is this set acceptable for the questions or do you not have enough information to decide? What other information do you need?

Each break-out session was held in duplicate to allow for smaller groups and, thus, to encourage more discussion. Discussion leaders were identified and reporters recorded the findings of the group. In this report, the duplicate group reports are combined.

Finally, four focus groups were formed during a working lunch to consider the following topics concerned with implementing HOs:

- Evaluation criteria for HO proposals
- Management structure of HOs
- Metrics of success for HOs
- Data collection protocols and standards

Although there was not sufficient time to come to consensus on all of these issues, the reports of the breakout and focus groups give a sense of the community's feelings and concerns. The intent of this report is to record these findings so that future discussions of these complex issues will be better informed.

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BACKGROUND

The development of large-scale environmental observatories to advance scientific inquiry into a broad range of problems from climate change effects to eutrophication to loss of biodiversity has been the subject of debate in the United States during the past five years. The larger scale of these field facilities will revolutionize the science in two important ways:

- *direct study of intrinsically large-scale phenomena* such as exchange of groundwater and surface water at the river-basin scale
- *easier testing of transferability of concepts* developed from small-scale studies by providing a broader range of well-characterized locations

Hydrologic scientists bring a unique perspective to developing large-scale environmental observatories by applying the hydrologic cycle as an organizing principle to landscape-scale studies. Applying the concepts of conservation of mass and energy budgets allows for quantitative tests of our understanding at these large scales. From this perspective, the catchment emerges as a natural unit of the landscape, with boundary conditions that are convenient for hypothesis testing and model development. Because water serves as a solvent, as a transport vector, and as a critical factor in determining species distribution, the catchment is a meaningful landscape unit for a broad range of disciplines beyond physical hydrology including geomorphology, biogeochemistry, and ecology.

SCIENCE VISION

Through a series of community workshops, CUAHSI has identified an integrated set of infrastructure elements, called HydroView, to support hydrologic observatories as well as the community at large. Hydroview consists of informatics, instrumentation, and synthesis facilities (Figure 1).

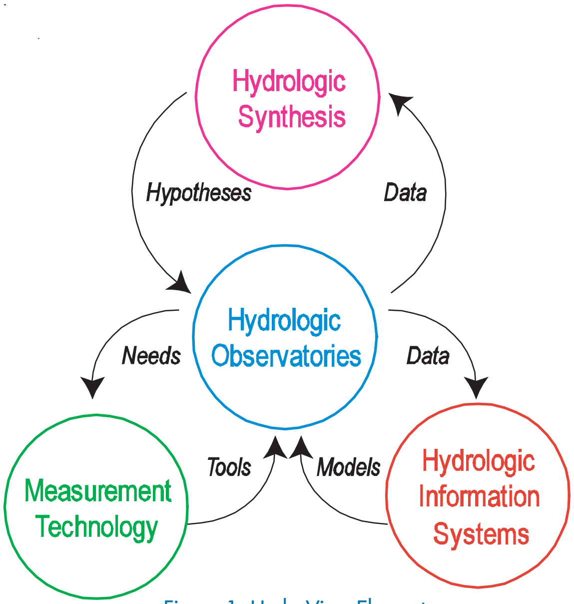

Figure 1. HydroView Elements

The goal of HydroView is to dramatically advance society's ability to estimate the terrestrial distribution of water and associated biogeochemical elements at any scale. This step forward requires innovative scientific concepts, measurements, and models. HydroView will take this step by implementing an unprecedented observing strategy focused on critical environments. The focus on observations arises from the recognition that hydrologic science has many concepts and models of these concepts that have not yet been rigorously tested. The integrated, multi-scale data to be collected at hydrologic observatories will provide the more powerful test required to advance the science.

Through a series of community workshops, CUAHSI has identified improving the predictive understanding of the following five science topics as the top priority:

- Linking hydrologic and biogeochemical cycles
- Sustainability of water resources
- Hydrologic and ecosystem interactions
- Hydrologic extremes
- Fate and transport of chemical and biological contaminants

Each of these topics can be addressed by three cross-cutting themes:
- Forcing, feedbacks, and coupling
- Scaling
- Prediction and limits to predictability

The integrated data collected hydrologic observatories will address all of these topics in a cost-effective manner because of the degree of overlap in the data required. Consider, for example, the measurement of evapotranspiration. Currently, an ecologist measures water flow in the xylem of a tree in one place, a hydrologist measures soil moisture and energy fluxes in another place, and an atmospheric scientist uses an eddy covariance tower to estimate evapotranspiration in a third place. By bringing these measurements together in one place, each can still pursue his or her scientific question, but the power to test which factors control evapotranspiration is vastly increased by the redundancy of the measurements. Furthermore, measurement of carbon dioxide concentrations on the eddy covariance tower can be added at a small incremental cost, but the ecologist or carbon modeler also has all the hydrologic data at her disposal to place those carbon fluxes into a larger context. This is the power of integrated data.

DESIGN CONCEPTS

Core Data

A significant challenge in the design of hydrologic observatories is the designation of "core data," defined as data that provide a characterization of the catchment that is useful for a broad range of questions. However, any characterization that is truly hypothesis-independent could easily consist of tens of thousands of physical, chemical, and biological measurements that are taken continuously in time and space. Because this is clearly not feasible with limited resources, any feasible characterization will necessarily be dependent upon the hypotheses considered. Of course, there is a spectrum of dependence. If one considers a three-dimensional space whose axes are spatial coverage of data, temporal frequency of sampling, and resolution of the data, where the orientation of the axes has the most complete coverage, highest frequency and highest resolution at the origin, then data near the origin are less hypothesis-dependent and data farther from the origin are more hypothesis-dependent (Figure 2a).

For example, radar reflectance, which can be interpreted as precipitation rates, have complete spatial coverage and a high sampling frequency, placing them near the origin in the x-y plane, but may have a coarse spatial resolution, placing it somewhat up the z-axis. LIDAR measurements of topography are high resolution and have complete spatial coverage, but are measured only infrequently; while, soil moisture measurements made by a TDR probe may have high resolution and high temporal frequency, but a very limited spatial extent.

Viewed in this manner, the challenge in the design of a hydrologic observatory is determining the boundary between core data and investigator data (Figure 2b).

Many multidisciplinary environmental networks have foundered on the definition of core data. A simple concatenation of each scientist's wish list for data rapidly becomes infeasible. On the other hand, how is the utility of any feasible data set for advancing the science determined?

In the prototype study, we recognized that virtually all hypotheses that we considered required the characterization of four basic properties of the catchment, where each property refers not only to water, but also to sediment, nutrients, and contaminants:
- Mass in each "store"
- Residence time within stores
- Fluxes between stores
- Flowpaths among the stores

In all cases, "stores" refers not only to surface and subsurface areas of the catchment, but also the atmosphere. In our discussions of the Neuse basin, we considered the control volume to be the entire catchment area in the horizontal dimensions and extending 1 km below land surface to 15 km above land surface in the vertical.

Therefore, our proposed definition of "core data" is those data that contribute to the quantitative estimation of these properties at a range of spatial scales. Particularly at large scales,

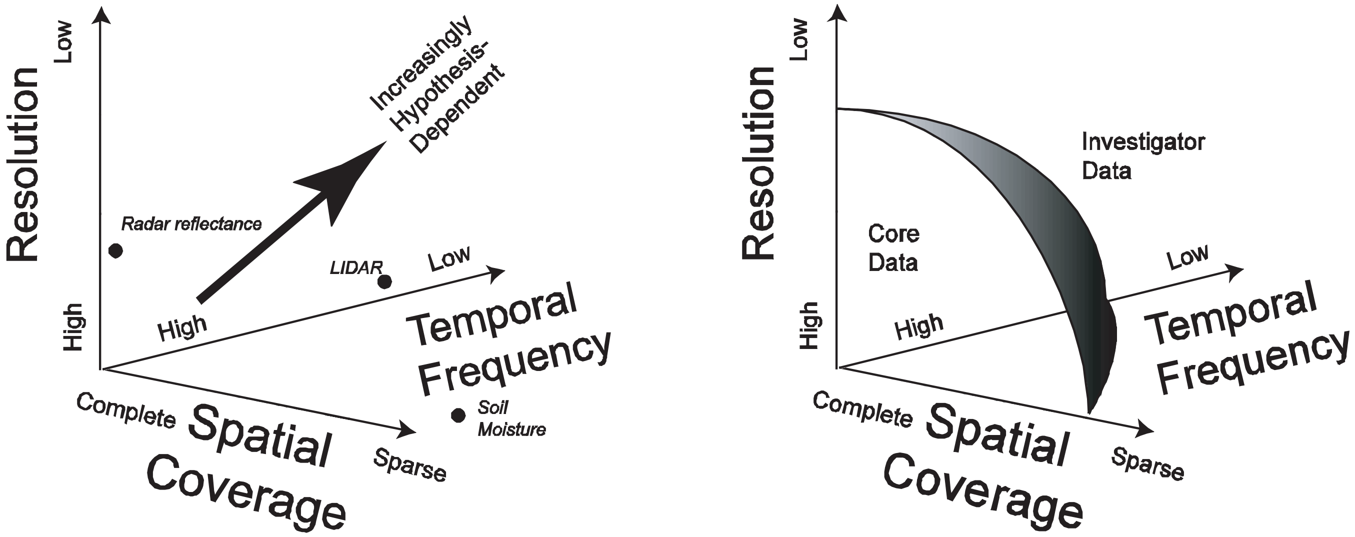

Figure 2. (a) Spectrum of hypothesis dependence. (b) Boundary between core data and investigator data.

these properties cannot be directly measured and must be inferred. We recognize that, in many cases, estimating these properties is a challenging research topic in its own right.

Hydrologic Observatories as Community Resources

To justify the level of investment a hydrologic observatory will require (our base scenario was an annual operating budget of US$3M and a capital budget of US$10M), these facilities must serve as community resources attracting a large number of scientists across a range of disciplines. To ensure high usage, the following design principles were adopted:

1. *A professional staff*, headed by a PhD-level scientist, will operate the hydrologic observatory. This staff is accountable to the community through a CUAHSI governing body.
2. *Core data* will be immediately available to everyone using a common data model across all hydrologic observatories. The primary duties of the observatory staff will be to collect the core data and to populate the common data model.
3. *Site access* will be on an equal basis for all scientists, subject only to coordination constraints among existing projects. The observatory staff will provide site coordination, secure necessary permits, and enforce any permit restrictions.
4. *Local support* will be provided to make the site attractive to remote investigators including laboratory facilities, field vehicles and other logistical support. Professional staff will assist in collection of investigator data where resources permit.

Size and Scope of Hydrologic Observatories

Hydrologic observatories must be of a sufficient size to permit the examination of all interfaces in the hydrologic cycle, including the land-surface and atmospheric interface. The minimum size for studying mesoscale atmospheric processes is on the order of 10,000 km^2, roughly two orders of magnitude larger than typical instrumented basins. This design size is not meant to be a rigid constraint. In some settings, particularly in the arid western United States, significantly larger basins must be considered. In other settings, such as the West Coast, smaller parallel basins must be used. Elsewhere, topographic divides have little hydrologic meaning and effective basins must be defined by groundwater divides. In all cases, the critical factor is the choice of boundaries that enable estimation of the four fundamental properties listed above in the most efficient and most precise manner.

A national network of hydrologic observatories is also envisioned. This will require a coordination of effort to ensure comparability of data. A common data model, common protocols, and metadata standards will be required for this effort to succeed. These tasks will require substantial investment and coordination with government science agencies, such as the U.S. Geological Survey, U.S. Forest Service, the USDA Agricultural Research Service, and National Resource Conservation Service. The prospect is daunting, but advances in informatics and technology services make this feasible. The CUAHSI Hydrologic Information Systems group is currently at work on the data model and anticipates that a prototype will be available well in advance of the establishment of the first hydrologic observatory.

Although our current focus is on the United States, the data model and all data protocols will be made available to all interested parties through our web site. We seek to coordinate our efforts with studies in other nations and to work closely with groups such as the International Association of Hydrologic Science's Prediction in Ungaged Basins (PUB) initiative.

Observatory Design Team

Given the design concepts and broad science topics described above, an observatory design team's role is to pick a set of hypotheses of interest to them and to define a data set that will test those hypotheses. If our contention is correct, these hypotheses will require the estimation of the four fundamental catchment properties described above. The observatory design team must articulate how to delineate the basin into stores (e.g., the number of vertical layers, horizontal compartments), designate which data are required to estimate these properties, and propose an analytical approach to convert the data into estimates of these properties. These data become the core data, which are the community product. Presumably, these data alone will not be sufficient to test the hypotheses and additional data will be collected. These additional data are "first publication" data that the investigator retains the right to publish, although they will be released to the public after a specified period.

In this manner, the observatory design team performs a community service (by defining the core data), and receives an incentive for that service (the ability to advance their own science with first-publication rights to critical data). In this way, we are also assured that the data are sufficient to answer *some* scientific questions. The core data, it must be stressed, are made immediately available to all scientists.

The observatory design team develops a specific work plan for the collection of the core data. This work plan is subject to review by a CUAHSI governing body to ensure compliance with network data standards and completeness. CUAHSI may add additional parameters to enhance data comparability across observatories, but the observatory design team will be assured of getting the data necessary for their hypotheses. The approved work plan is then given to the Observatory Staff to execute. The observatory design team does not control the collection or access to the core data. Periodic meetings between the Observatory Staff and the design team will be necessary to assess progress.

EVALUATION CRITERIA

Because the design approach allows for local variation and encourages creativity on the part of the observatory design team, criteria for evaluating proposals for hydrologic observatories are needed. We have developed the following criteria:

1. *Hypotheses posed.* Do the design hypotheses address at least three of the five priority topic areas? Are the cross-cutting themes addressed? Are the hypotheses interdisciplinary? Are they innovative and exciting?
2. *Design.* Does the design provide estimates of the fundamental catchment properties across a range of spatial scales, including the entire basin (or basins)? How are intensively instrumented sub-basins combined with more extensive survey or synoptic data? What proportion of the data funded by this effort will be designated as "core data"? Is the design justified through quantitative analysis? Are benchmarks specified to gage increase in understand-

ing through this effort? Is there the adaptive use of models to guide field data collection?

3. *Existing data.* How are existing data (including those collected at research sites and monitoring data collected by government agencies) leveraged in the design? Is full advantage taken of them?
4. *Institutional support.* Is there evidence of active support by government agencies and non-governmental organizations in the hydrologic observatory? Do stakeholder groups, such as basin commissions, support the effort and will they assist with access to private lands and other permitting issues?
5. *Education and outreach opportunities.* Have these opportunities been identified and is there a credible plan for pursuing these opportunities?

Although CUAHSI will not make funding decisions (such decisions are reserved by the funding agencies), these criteria capture the key aspects which we believe are necessary for the successful operation of a hydrologic observatory.

CONCLUSIONS

At the outset of this prototyping effort, a more centralized approach was envisioned for HO design. However, the complexity and myriad peculiarities of individual basins render such an approach ineffective. Instead, we determined that design teams who are intimately familiar with the basin are needed to design the core data collection, but that these data must be cast in terms of transferable, fundamental properties of the catchment. The design challenge becomes one of balancing the interests of the observatory design team with the network requirements of comparable data.

As of this writing (August 2004), a pilot network of five observatories are planned for funding. The first two observatories will begin operation in the fall of 2005, followed by a third in 2008, a fourth in 2009, and a fifth in 2010. This staggered implementation will allow operational experience to be gained and will help to ensure the success of hydrologic observatories in meeting the goals we have set for them.

REPORTS OF HO BREAKOUT GROUPS

POTOMAC RIVER BASIN

The Potomac design team members provided an overview of this proposed HO, highlighting the inclusion of a large urban area, fringe watersheds that drain to Chesapeake Bay, and heterogeneity in physiography that make the HO unique. Observatories where numerous detailed studies have previously been carried out (such as the Potomac) have a clear advantage on start-up because baseline data have already been established. A conceptual model for observatory can build on previous studies as a starting point, for example the USGS Potomac NAQWA study. Some decisions about the choice of what will be considered as core data may be dependent on the conceptual model developed for the HO. One of the most challenging problems for the Potomac is to quantify the fluxes of sediments and nutrients to the Chesapeake Bay and determining their land-based sources. Recommended core data will most likely include the need to calculate fluxes of water and associated constituents leaving the study area, which requires measurements of flow rates and concentrations at outlets. In this case, sampling protocols cannot rely solely on baseline sampling and will also need to include event-based monitoring because a large fraction of total load is associated with the largest flow events. A conceptual model should include planning for measurement of attributes that will be useful in characterizing fluxes as well as in developing predictive capability.

Two principal features that will make an HO attractive as a community resource are (a) the richness and availability of baseline data sets, and (b) other attributes such as the physical facilities that make it a desirable place to work.

Regions characterized by spatially rich data sets such as the Potomac may be able to utilize information to begin to address the question of scale. Starting at a scale at which there are well-defined data sets and understood governing principles in the basin, one could test the idea of moving across scales (scaling up) in the HO. One example is the availability of high-resolution LIDAR in selected areas, with a topographic resolution of 1 m. Small urban channel hydrologic models need this as input, but for the entire Potomac this may not be necessary. It may be feasible to obtain LIDAR for selected other areas of the basin and an appropriately-developed conceptual model would dictate where to do that. Deciding how to allocate resources for expensive data collection over a large region will be a challenge; allocation of resources will be expected to be part of the HO proposal.

An example of data that could be used in cross-observatory testing might be Nexrad data (the next generation of radar) to address the question of whether a standard protocol could be developed to link Nexrad data with actual ground-based precipitation amounts across a variety of regional hydrologic conditions. In this case, Nexrad data could be considered essential core data and resources could be allocated to filling in existing networks.

Attributes that will be key to attracting researchers to work in an observatory include interesting or unique physical features (e.g., geology, climate patterns, long-term gaging records; dense networks of instrumentation in place), good researchers to work with at the host facilities, easy access (roads, airports, proximity to participating schools), and good brick-and-mortar facilities being available to researchers. Facilities include dormitories, a central or central-plus-satellite field offices housing field equipment, and a computer/modeling/study center where researchers can interact. Facilities should also have the ability to host visiting groups for training and lectures. Plans for the HO need to include providing access to field vehicles (vans, boats as appropriate) and technicians to maintain equipment and collect core data. In some cases it may be possible to take advantage of existing but underutilized facilities of several member universities. In large-basin HOs such as the Potomac, it seems as though satellite field facilities would be essential since it would be a five-hour drive from one end of the basin to the other. Insofar as an operating model is concerned, CUAHSI may want to look to the LTERs or field biological stations as examples. In many cases, the PI needs to raise funds to travel to the stations but the stations would provide some basic support services such as sample analysis.

The question of QA/QC of the core data was also discussed. Presumably, the HO facility will provide this function and also post new data as soon as possible. The HO field office should also provide access to sites and study areas, such as private property, and help identify public vs private lands. Handicap accessibility should be taken into consideration from the beginning in designing new facilities. This would include field vehicles and handicapped-accessible labs.

HOs as a Network

The break-out group felt that the network of HOs should be as diverse as possible to best represent continental variability in climate, geology, vegetation, and land use, particularly if the objective is to address hydrologic issues of national significance. Relevant considerations include spanning the range of physiographic types and topographic structure, natural water stores, and understanding of chemical and biological as well as physical processes. The general theme of quantifying stores, fluxes and pathways for water, energy and water-transported constituents is fundamental and an appropriate cross-cutting theme for the observatories. In general, larger basins such as the ones represented at the workshop (most much larger than 10,000 km^2) are preferable to smaller basins because there is a better opportunity to answer more of a variety of questions and incorporate a suite of nested/paired sub-basin designs within the large basins. In addition, the choice of large basins would encourage mesoscale climate modelers to be involved as participants.

The group was of the opinion that the five observatories selected as a strawman sample network from this meeting would make a workable network, but that there could be other equally plausible locations chosen to form a network backbone. Concern was expressed regarding how a network will be put in place if the observatories are chosen one-at-a-time—this would make optimizing a best set difficult.

Careful thought needs to be given to what kinds of questions will be appropriate to address across all HOs and how these questions will be formulated and adopted/evaluated by the HOs. Example cross-HO problems might include: (1) quantifying land surface-climate feedback and (2) evaluating the sustainability of water resources. These are challenging problems across the continent that would be expected to have various components of the hydrologic cycle play a more prominent role that others depending on the region in which the problems are being evaluated. The HOs and key questions also need to be selected so that there is visible payoff in results in five to ten years such that the value of the observatories is apparent to the funders. Concern was expressed as to whether there would be enough funds allocated in the HO budgets to answer cross- network questions, in addition to questions that may be more regionally-specific.

The collection of core data and connection of the HOs as a cyber-network of nodes is also of fundamental importance to the network concept. Collection of a common data set should be linked to a conceptual model and be driven be answering a specified set of questions that are relevant across all HOs. Using the tools being developed by the HIS team will allow one-stop shopping for modelers seeking high-quality data sets at one or more HOs, which will greatly expand the pool of researchers using the observatories beyond those involved in field work.

ILLINOIS RIVER BASIN

This group tried to address two questions: (1) How can we network HOs? and (2) How do HOs attract outside researchers? We used the Illinois River Basin as an example for discussion, but looked for solutions that would be generally applicable.

Networking study sites can suffer from two opposite problems: study sites can become isolated or so many resources are devoted to coordination that scientific inquiry is not advanced. (LTERs perhaps suffered from the former and NAWQA from the latter.) A balance needs to be struck between networking and science needs.

To assist networking, overarching questions should be posed. CUAHSI plays an important role in identifying questions that cross cut sites. Common equipment and data collection protocols have frequently been mentioned to improve networking. Nonetheless, some data collection needs will be site specific. To this end, the core data set could consist of two parts: (1) core data for comparison across sites and (2) core data to assist individual site investigators that propose work at a given site. Our group thought CUAHSI should provide a template for the former data set before proposals are submitted, rather than individual groups coming up with slightly different versions of shared (core) data.

Some common themes show up on everyone's list of attributes to attract "outside" researchers to an HO. For example, researchers will want professional technical staff to help deploy instruments, ease of access to existing instruments and data, student facilities so that they can stay at the site for a period (good logistics, low cost or free), and an atmosphere that encourages multidisciplinary research.

Our group tried to identify additional strategies to encourage off-site researchers to propose work at an HO. Land access for field research was one of the top concerns. Field research is often plagued by lack of access, vandalism, or interruptions in data collection due to changes in access. We'd like to see the HO provide a map showing location of study areas, what the access would be, how safe the equipment would be, and existing data. HOs should be responsible for obtaining permits and permission for property use, informing appropriate authorities, and keeping local researchers and the general populace informed.

Another possible inhibition of traveling to another site for field research is the concern that your expertise is already available at the site, and additional contributions aren't needed. HOs should encourage additional collaboration by suggesting data gaps, posting questions (on the web or listservs), and visiting other campuses to talk about possible research.

Another avenue to consider is suggesting that researchers do comparative studies between their own field site and the HO. An example from the Illinois River Basin is comparing different agricultural practices in Illinois and Nebraska. Some collaboration that does not involve external funding could also be encouraged (experiments of opportunity).

We would like to see HOs with high levels of outside collaboration receive additional funding for support services. This would encourage the time-consuming outreach necessary to bring about collaboration.

SUWANNEE RIVER BASIN

This group addressed five questions about how an observatory will function as a part of a network and what attributes will make an observatory a true community resource. The group used their proposed basin as a specific example for discussions, but focused on attributes and features that could be used for any proposed observatory.

HOs as a Community Resource

1a. What are the attributes of an effective conceptual model?

An effective conceptual model:
- should be useful in designing experiments and testing hypotheses
- should be flexible, adaptive
- should be modified as data are collected in an iterative way
- should support research at multiple scales
- may include paired watersheds
- should address some site specific issues also
- should include history of land use and climate

1b. Will core data, without a conceptual model or, alternately, a conceptual model that isn't meaningful to you, provide an effective baseline characterization of the site to enable you to conduct your research more efficiently than going to a different field site? Is this advantage great enough to overcome disadvantages of the site (e.g., distance)?

A conceptual model is as important as the core data for PIs to develop and test new hypotheses.

2. Are there critical services that the HO should provide, beyond the core data, to make it an attractive place to work?

Basic requirements include field vehicles, laboratory space for setting up and testing field equipment, chemical laboratory facilities to analyze water samples, mobile chemical labs for field use, meeting rooms, sample storage facilities (including refrigeration), computers and dataloggers.

We assumed that much of the equipment would be made available through the Hydrologic Measurement Facility or would be provided by the PI.

Providing staff to assist with field studies is **critical**. Staff should be able to assist with site access, liaison with other local state, federal, or nongovernmental organizations that may provide equipment, lab facilities, or expertise in different research areas. It would be beneficial to have a pool of students who could be used for intensive field campaigns.

3. What kind of energy measurements should be part of core data (as opposed to investigator-driven science projects)? Conversely, what proportion of the core data budget should be allocated to energy measurements?

Core data should include micrometeorological measurements of ET (Eddy covariance and/or Bowen ratio) in representative land use settings. Short and long-wave net radiation should also be measured. Water vapor and carbon fluxes should be included in Eddy Covariance system. Measurements of sap flux in representative vegetation types would also be valuable. Energy-budget measurements should also include soil-moisture and soil water-pressure measurements to estimate evapotransporation (ET) from subsurface measurements. Lower atmosphere boundary-layer measurements should be included that would provide a link to general circulation models (GCM) grids. The measurement network should be designed to link with satellite remote-sensing approaches for estimating ET. Depending on the HO, energy exchanges with deeper groundwater and geothermal budgets may also be critical core data.

The percentage of the core budget allocated to monitoring the energy budget would depend on the prioritization of this task relative to the conceptual model for the HO but should not exceed 10%.

4. What "static" information do you expect to be available at an HO? How frequently should these be updated?

Static information should include:
- Compilation of all existing and published data on land use/land cover, hydraulic properties of soils and aquifers.
- LIDAR topographic map of the HO
- Hydraulic properties of soils (including saturated hydraulic conductivity and water retention functions) for representative soils
- Hydraulic properties of aquifers including hydraulic conductivity and storativity
- Groundwater age dating

The goal would be to populate the geovolume database to the best ability. A database of all static measurements made in various studies in the HO should be developed and constantly updated. More detail should be provided in focus areas determined from conceptual model. Updates of static data would depend on developments in technologies or measurement devices and research requirements.

5. What proportion of the core-data budget should be devoted to "pushing the envelope" and developing non-standard data? How would the suitability of these efforts be determined?

Less than 5% of core-data funds should be devoted to cutting-edge technologies and high-risk data collection. Funds allocated to this kind of work should be allocated to "proof-of-concept" work, through a competitive process driven by individual PIs judged by an independent advisory panel, perhaps organized by CUAHSI. Additionally, staff at HOs should try to obtain external funds for these kinds of projects.

HOs as a Network

1a. How effective was this network at addressing your science topic?

HOs did not seem to emphasize impact of urban areas on hydrology. The selected network could address urban issues across US. Selected network seemed to sample a range of climate, land use, and geology and appeared to be representative. The group did not have time to address other science topics.

1b. Would you choose a different set of 5 sites from the 24 prospectuses?

Some suggested Alaska should be included in the network because of its sensitivity to global change while others suggested arid regions are even more sensitive to global change. The purpose of the network should be to increase the scale of the research; geographical criteria not necessarily as appropriate as range of scientific questions (e.g. global change, urbanization).

2. Must CUAHSI develop cross-observatory hypotheses to design an effective network?

CUAHSI should develop a set of hypotheses. Many hypotheses should be transferable among observatories; however, each HO should not be required to work on every hypothesis. The hypotheses should be provided for general guidelines. Data collection and analyses should formulate new hypotheses that were not considered prior to data collection. Fundamental measurements often imply cross-network hypotheses.

3. Is the Neuse "flux/store/pathways" paradigm effective for integration across the network?

The Neuse paradigm is effective at a minimum. It may not be detailed enough in some cases; therefore, *we must make sure we address processes within boxes and have appropriate control volumes.*

GREAT SALT LAKE BASIN

Like the other groups, this group addressed five questions about how an observatory will function as a part of a network and what attributes will make an observatory a true community resource. The group used their proposed basin as a specific example for discussions, but focused on attributes and features that could be used for any proposed observatory.

1. What are the attributes of an effective conceptual model? Will core data, without a conceptual model or, alternately, a conceptual model that isn't meaningful to you, provide an effective baseline characterization of the site to enable you to conduct your research more efficiently than going to a different field site? Is this advantage great enough to overcome disadvantages of the site (e.g., distance)?

Despite some confusion, most agreed that the scale of this site's conceptual model should be a transect from lake to ridge crest. This was likely to reasonably capture the essential hydrology of the site, and yet was general enough to be adaptable most research projects. Further, some recognized that a generalized conceptual model of the site would greatly aid in interpreting results, particularly when testing models and concepts across a network of sites. The group agreed that it was essential to include any impacts of water management within the conceptual model. All the proposed HO's (except perhaps Alaska) likely are affected to greater or lesser extent by water management. Explicitly including management will facilitate the transfer of HO science to society.

2. Are there critical services that the HO should provide, beyond the core data, to make it an attractive place to work?

The group identified the following facilities as essential:
- Affordable housing near field sites
- Field vehicles
- Lab space for basic analyses
- Professional staff

The group identified the need for professional staff to assist with the following:
- Collection core data
- Consultation with (prospective) PIs regarding experimental design (e.g., sampling locations) appropriate to specific basin.
- Acquisition of appropriate access, permits, etc. to sampling sites.

In addition, to promote collaboration, the host institution should provide the following:
- Hosting of annual meetings for all users of facility to promote collaborations and identify links among projects. CUAHSI should host similar meetings at national professional meetings for all users of all sites.
- Host institution should allow visiting graduate students to enroll in appropriate courses so that graduate students from other institutions may continue their education while being present to collect data. Classes open to the community might attract others to the HO just for the opportunity to take specialized classes not available at their home institution. This could be part of the HO's educational outreach.

3. What kind of energy measurements should be part of core data (as opposed to investigator-driven science projects)? Conversely, what proportion of the core data budget should be allocated to energy measurements?

Energy measurements are critical and offer an opportunity for an HO of develop a novel resource—extensively gaged basins already exist, but a well designed HO could be the first site to accurately close the energy budget. This would be attractive to many researchers, such as those whose interests depend on, for example, ET. This is the type of infrastructure that would both attract external researchers and yield novel core data that would be essential to inter-basin comparisons of energy budgets. The group noted that in addition to installing new sensors (e.g., eddy towers), some existing sensors may need to be upgraded. And there should be plans to complement ground-based point measurements with regionally averaged, remotely sensed data. However, energy measurements off all types may be difficult at the Salt Lake HO due to the steep gradients. Finally, the group noted that it was essential that the HO reach out to NCAR and other agencies to inquire about cooperative efforts in this important area.

4. What "static" information do you expect to be available at an HO? How frequently should these be updated?

Critical data essential to attract external researchers include:
- Basic GIS data layers for land use, etc. that includes both present-day and as much historical data as possible.
- LIDAR
- Repository for archived samples of both water and cores.

5. What proportion of the core-data budget should be devoted to "pushing the envelope" and developing non-standard data? How would the suitability of these efforts be determined?

The group thought that the infrastructure for much of the core data likely already exists (e.g., stream gages, wells). To the extent that this infrastructure is supplemented, the installation design should be defined by the science drivers. At Salt Lake, supplemental gages, for example, should be focused along the proposed transect. The group suggested that the HO investigate the use of the new generation of low-cost micro-sensor technologies as an alternative to traditional sampling protocols, such as the use of embedded micro-pressure transducers rather than full-blown USGS-type stream gages.

The group thought that installation of additional equipment to collect traditional data was less likely to have immediate payback in results than would be obtained by devoting funds toward installing equipment to collect more cutting-edge types of data. The group thought that the HO should consider what emerging data types are likely to become "standard" over the next decade. For example, ten years ago, eddy towers might have been considered cutting-edge", whereas many now consider them standard. Other emerging data types that may be applicable to the Salt Lake HO include groundwater age and novel isotopes (e.g., nitrogen).

The definition of the core data set should consider those that might bring researchers from other disciplines to the site. For example, sediment transport data might attract geomorphologists while nutrient cycle data (e.g., carbon, nitrogen) could appeal to biogeochemists.

PACIFIC NORTHWEST BASINS

The Pacific Northwest Observatory group tried to address two main issues: (1) How will individual HOs function as part of a network and (2) What attributes make an individual HO a community resource. The group used the proposed Willamette/Deschutes paired basin design as an example for these discussions.

HOs as a Network

The exact location of observatories is not as important as the science the site will enable.

Energy budgets, in addition to being of scientific value, are also an important piece of information when comparing different observatories.

HOs as a Community Resource

To make these sites a useful resource, a critical service will be student and training support.

Some example core data include:
- Input precipitation (snow/rain)
- Hydrologic Fluxes (sublimation/ ET)
- Storage/Flows
- Water quality parameters (TMDL constituents)
- DEM (LiDAR)

Land Cover/ Land Use

Other data that would be useful for the PNW observatory are delineating the rain/snow boundary and employing transects along elevational and directional gradients.

REPORTS OF SCIENCE TOPIC GROUPS

BIOGEOCHEMISTRY

The group's focus included formulation of the statement that the understanding of biogeochemical cycles will aid in understanding the hydrology of the observatories.

Core Data

Identification of what should be designated core data was the primary discussion topic of the breakout group. Many in the group are interested in understanding the stores, fluxes and mass balances of biologically important major elements. They would like to use the core data to estimate budgets. The group believed that collection of a broad set of core data will allow integration across the network to determine the mass, fluxes, flow paths and residence times. Additional integration can be achieved by nested watershed sampling design in every watershed to facilitate scaling studies.

Measurements of water quality are of great importance to those in this breakout group. Most in the group believed that convincing the HO community of the need to measure water quality was one of our primary charges if the HOs are to serve our needs.

Core data identified by the group included:
- Major ions
- Dissolved organic carbon
- Major nutrients
- Silica
- Total suspended solids
- Isotopes of water
- Microbiological measurements

Data collection should be directed at development of high capital investment, low personnel measurements of much of the core data. Development of novel ways of data collection will require close cooperation with those involved in the Hydrologic Measurement Facility (HMF). For example, the measurement of nitrate needs to be faster and cheaper. Development of better methods, possibly remotely sensed or remotely collected nitrate data, in collaboration with the HMF facility, will provide a great service to the biogeochemical community represented among the attendees of the breakout group.

Design of the core data and infrastructure of the hydrologic observatories to serve the biogeochemical studies of those in the hydrologic community would require sampling and analysis of water-quality samples in a variety of media in addition to streams, such as groundwater, throughfall, and rainfall.

Observatory design should probably include an intensively instrumented sub-basin of approximately 1 km^2 at each site. Nested designs at every HO site will facilitate cross-observatory comparisons and assist in the determination of universal scaling laws.

The HOs should be designed to provide a sample archive, with samples collected and preserved in such fashion to make them useful for biogeochemical analysis in the future. The HO should include infrastructure to ensure the core sampling is conducted routinely and broadly and that the samples are preserved appropriately. Funds to provide core services of for sampling and analysis should be included as part of every observatory.

The group estimated that approximately 10,000 samples for biogeochemical analysis should be collected and analyzed annually at every observatory. The group estimated that approximately $1M of the annual operating budgets should be directed towards the sampling and analysis of the biogeochemical samples. The group did not come to a conclusion about how much of the capital costs should be reserved for biogeochemical facilities. The group thought, however, these required a significant investment of funds.

Non-data Facilities

The group was in agreement that providing places for long and short term students stays would enhance the usefulness of the HOs. Training for students in field sampling and analytical techniques would also enhance the usefulness of the HOs.

Additional Questions Discussed by the Group

- What does biogeochemistry tell about flow?
- What are the concentration/discharge relationships?
- Determine the differences and similarities of the chemical and hydrographic dynamics in different systems at different scales. What do these tell us about flow paths? This question implies sampling at a variety of scales and over different events.

ECOLOGY

The group did not discuss the specific questions but rather began with a discussion of the parameters that should be addressed by a network and if the selected pseudo-network addressed those parameters. Some of the types of parameters or characteristics of a network included: urban, agricultural, and natural ecosystems and upland aquatic zones. In addition, at each HO or across the network there needs to be a gradient of precipitation (wet/dry), temperature (hot/cold), environmental, and setting (continental/marine/boreal). Other important considerations are the steepness of the gradient and temporal variation.

The group thinks that a regionalization scheme as a way to determine the location of a network was not a good starting point. The selection process must be hypothesis driven with those questions informing the development of a network. For hydrologic and ecosystem interactions these questions should address the ecology/hydrology interface. Collaboration between the ecological and hydrological communities should be pursued with questions that address the impact of ecological processes on hydrologic processes. An interaction between proposed NEON observatories and CUAHSI HOs may be the best way to proceed because there may be a certain amount of redundancy in the two approaches. The group felt that HOs must incorporate measures that are traditionally ecological. Examples of these kinds of data included:

- Nutrient cycling
- Land use/land cover
- C3 vs. C4 plants
- Precipitation recycling by plants

The group discussed some of the questions they considered to cut across several of the sub-disciplines of hydrology, including hydrologic and ecosystems interactions. The group felt that societal relevance should be the ultimate driver. Some of the cross-cutting themes included:

- Water resource management
- Water supply
- Water quality
- Land use changes
- Climatic variability

The hydrologic community must be challenged to address new objectives with innovative approaches (i.e., beyond the normal ways of doing business such as increased numbers of stream gages). The group suggested that some of these objectives include:

- Higher-resolution land use and land cover data
- Better understanding of the distribution of temperature including micro- temperature profiles
- Better understanding of energy budgets
- Ecological-hydrological connections and the human impact on those interactions
- Extreme events
- Impacts of exotic species on hydrological processes
- Disease sites and vectors as related to hydrology
- Disturbance events such as massive forest die off as affected by changes in hydrologic processes
- Changes in hydrologic parameters caused by ecological disturbance

The group thought that HOs need to address the collection of new ecological data that could be used for advancing the knowledge of ecosystem-hydrology interaction. The network broad definitions, however, should be used for defining science questions. Each HO needs to develop its own approach to answering those questions.

The group felt that the HO network must emphasize human interaction with ecological and hydrological systems, integrate existing data throughout the system and from other sources, have good management, and be smaller than those HOs that are presently proposed.

SUSTAINABILITY

This session initially spent some brief time discussing and defining sustainability. For the purposes of this break-out group, sustainability was broadly defined as the ability of water resources to meet intended uses.

1. Effectiveness of the pseudo-network

The five selected HOs forming the network were assessed for their ability to meet science topics of interest to the audience members of this group. Some science topics could not be adequately addressed by the pseudo-network (e.g., insufficient latitudinal variation in each of the selected HOs to address climate science questions). Additionally, groundwater sustainability seemed to be a pervasive problem in that the selected HOs may not have demonstrated how robust they could quantify that aspect of the hydrologic budget.

The sustainability context was believed to be a socioeconomic as well hydrogeologic issue and, therefore, a political appreciation of the HO network outcome is important. For example, “What political settings exist at each HO?” or “How might political or socioeconomic research be addressed by the HO network?”

Planning issues, directed at sustainability issues, could be addressed via a conference/workshop prior to the ultimate selection of individual HOs or the entire network. A workshop dedicated to political, social, and economic science appropriate and applicable to the HOs is warranted.

To determine the suitability of the selected HOs and the pseudo network to be effective in meeting science topics, the HOs and science topics were tabulated (Table 2), and each HO was ranked (1 = low, 3 = high) as to how they met the needs of a particular science topic. Ideally, the HO network would be effective if there were at least two or three 3’s in all rows of Table 2.

Overall, the general sentiment was that an appropriate network of five HOs can address the major sustainability issues and that the proposed pseudo-network is workable. Does the pseudo-network address sustainability? The reality is that the five HO candidates comprising the pseudo-network, nor the pseudo-network itself, probably were not selected (in the voting process) with an emphasis on sustainability. Thus, this criterion will require clear delineation, documentation, and metrics if it is to be used as one of the pillars for selection of an HO or the HO network.

The workgroup developed a list of the major challenges facing the sustainability issue for the HOs which are as follows:

Major challenges in socio/political water management
- Sustainable groundwater extraction/use
- Surface water quality visa-vise agriculture, industry, mining
- Optimization of water utility within western (or eastern) water law
- Flood, hurricanes, natural strategies/science needs
- Effects of climate change on critical processes; supplies, ecosystems, people
- Urbanization issues/effects on water supply/quality
- Irrigated agriculture
- Drought
- Reservoir management
- Constraining State laws/water rights
- Conservation practices/programs

Table 2. Rating of HO Pseudo Network

	PNW	GSL	Illinois	Suwannee	Potomac	Comment
Sustainable GW extraction/use	2	2-3	2-3	2	1	
Surface water quality visa-vise Ag, Industry, Mining	2	2	3	3	3	
Optimization of water utility within western water law	3	3	0	2	0	west vs. east
Flood, hurricanes, natural strategies/ science needs	1	1	1	3	3	
Effects of climate change on critical processes; supplies	2-3	3	3	2	2	sea-level change
Urbanization issues/effects on water supply/quality	2	3	3	1	3	
Irrigated agriculture	3	3	1	3	1	
Drought	2	3	2-3	2	2	

Core data required to support major challenges
- Regional long-term stores, fluxes
- Project future demand on water; support these requirements
- Capture extreme events with societal impact
- Uses of water within basin: ecological; human
- Instream flow history
- Water quality vulnerability/susceptibility assessment
- Projected water demands
- Instream flow rights
- Waste water/return flows
- Demographics

The discussion on this topic went back and forth between the actual core data needs and the science hypotheses that they could address. Example scientific questions are as follows:

The group strongly believed that a CUAHSI Workshop on integrating social science/economic data gathering in HOs was necessary prior to the HO selections to insure that sustainability issues are adequately addressed. For example, “How should policy and management be incorporated in HOs?”

Global hypotheses and research questions
- Ecosystem water demand - Are ecosystems on a downward trend/spiral? How susceptible to stresses are the ecosystems (global change)?
- Changing public interest in water issues – How does the public affect the sustainability of water resources?
- Water limitations to growth – Is water truly a limit to growth? What are the local expressions, responses, or lack of interest/response?
- Political context by region/HO (varies significantly) – How is the political body represented by the HO geography open to management?
- Human factor data collection as changes (incentives vs. regulation promoting sustainability) occur: Political changes could entail experiments (possibility)
- Historic reconstruction/trajectory – Can HO data be used to recreate pre-human influence hydrographs?

Can data integration occur?

For integration of all HO data to occur, socioeconomic data will be necessary to add to the core data (four fundamental characteristics) to effectively address broader issues of sustainability. This means that it is important that social sciences are involved in each HO. Sustainability interest groups (physical-social sciences) will be necessary in each HO in order for effective data integration to occur across the network.

Data scales must be appropriate for each area and discipline. These scales will need to be clearly delineated and details on their scalability should be known (as for hydrologic scalability issues).

HO groups working on sustainability will need to work with HIS teams to incorporate socio-economic data. Ultimately, the HOs and the HO network should be viewed as platforms from which social scientists can perform non-hydrologic and non-CUAHSI research (demographics, health, etc.).

HYDROLOGIC EXTREMES

Discussion in began with a review to determine what was meant by "extremes"—some suggested that any abrupt change in condition, whether in vegetation cover, ecosystem characteristics, anoxic events, mass wasting events, etc. should be included. It was recommended that one approach is to think of land and vegetation as the "substrate" and water as the "change agent." Focus was placed primarily on extremes defined as the tails of the frequency distributions of precipitation, streamflow, or other hydrologic parameters, with consequent effects on ecosystems considered as a secondary impact. It was pointed out that hydrometeorology is only one of the drivers that may result in extreme events, and that a proper assessment of causative mechanisms also requires understanding of the physiographic and geologic controls on watershed hydrologic response, the impacts of anthropogenic modification of the landscape, and direct intervention in the hydrologic system, for example, by impoundment and diversion of flows, construction of levees and other flood control structures. Furthermore, there are cascading series of events that may generate extreme consequences. For example, forest fires may alter precipitation-runoff relationships by creating hydrophobic soil layers and also increasing the likelihood of mass wasting, thus allowing triggering of catastrophic debris flows even if the associated precipitation event is not extreme.

Other components of the conceptual framework for studying hydrologic extremes include a focus on the consequences of the timing and sequencing of events, the joint probabilities of less extreme events that may combine synergistically to trigger an extreme response, the tendency of extremes to occur in association with large-scale cyclical patterns (e.g., ENSO), the possibility of secular trends in climate or of land-surface characteristics that might cause long-term alteration of frequency distributions for hydrologic extremes, and the relative importance of hydrologic extremes with respect to the long-term cumulative flux of water, sediment, nutrients or contaminants. For example, the 1993 floods in the upper Mississippi drainage caused very large nutrient and contaminant loads. Economic and planning aspects of floods and droughts are clearly important and require social-science input, as the workgroups discussing sustainability of water supply also recommended. Important issues of allocation under conditions of shortage are related to the reigning legal doctrine—for example, prior appropriation vs. riparian rights —and to the cultural norms for resolving disputes.

If hydrologic extremes are characterized as opposite tails of the frequency distribution—floods and droughts—we need to recognize that floods and droughts are different in fundamental ways and that the attempt to design a monitoring protocol requires an understanding of those differences. Floods are short-lived and often develop rapidly, requiring rapid and flexible response in order to collect adequate data to describe them. In many cases it may not be physically possible to put people on site while the flood is in progress, and even if it is possible to reach the site it may not be possible to make the relevant measurements, either because of the physical difficulty of measurement or the speed with which the parameters to be measured change. Conversely, droughts develop slowly and are recognized as extreme only by virtue of their duration. The extent to which a drought is "extreme" is a function of the shortage of precipitation to replenish supplies, the water demand exerted by natural processes and human uses, and the buffering capacity of the water supply system. Adequate monitoring requires characterization of spatially extensive patterns of atmospheric conditions, energy budgets, vegetation condition, snow and its ablation, soil moisture, ground water, and stream flow, as well as fluxes across all of the relevant interfaces. Detailed hydrogeologic mapping to characterize groundwater systems will be expensive, but important in understanding drought influences. Although droughts may not require the rapid response that is needed for floods, they may require a much longer time base of sequential observations, because of a relatively long time lag between the precipitation deficiency and the drought response of the basin.

It is important to quantify uncertainty measures explicitly in all observed states and fluxes.

1. Is the selected pseudo-network of five Hydrologic Observatories effective to address the issue of hydrologic extremes? If not, are there other combinations you would recommend?

a. Floods: There was general agreement that this network adequately represents the range of precipitation extremes and mechanisms of runoff generation. There was some sentiment favoring the inclusion of an Arctic site to capture processes and patterns that are dominant in cold regions, and a suggestion that this might be substituted for one of the two western sites or one of the two mid-latitude sites. One person suggested that it would also be desirable to include a site affected by the southwestern monsoon. Another suggested that we should seek to study areas where naturally occurring extremes have largely been eliminated by management activities, chiefly through dam construction. Members of group A felt that five sites might not be enough to capture the range of conditions associated with hydrologic extremes; members of group B felt that they would be adequate if the area of inquiry were confined to the continental United States.

Additional recommendations are that we should develop protocols for assessing changes in frequency of floods over time as a function of human influence on the hydrologic system and on geomorphology, and that we should seek to examine gradients of hydrologic response to the same storms under conditions of differing physiography and geology. We should also recognize the spectrum of flood-generating mechanisms (e.g., convection cells, tropical cyclones, rain-on-snow) and make sure that the network includes as many of these as possible. Scaling issues are also important, and different response mechanisms may be responsible for the most extreme events at different spatial scales—for example, intensity associated with convection may be dominant in small drainage areas, whereas a large fraction of basin area contributing at lower flux rates may be dominant at large drainage areas. The full-flood hydrograph is of concern at all scales.

Many scientists typically think of floods in the context of channel networks, but what about other kinds of hydrologic settings – e.g. karst or wetland environments? Also, what about mechanisms that are not easily studied in the continental United States, for example, glacial outburst floods?

b. Droughts: The time scales of interest are on the order of many decades, several years, within year, and within season, depending on climatic regime and human biological adaptation. With respect to droughts, it is not as clear that we have enough basic information to assess whether any particular network is adequate. Groundwater reservoirs typically have 20-30 times the storage capacity of surface reservoirs in a basin; in some environments those reservoirs wax and wane over time, whereas in others (such as the high plains aquifer) we are mining groundwater that is thousands of years old. This setting, where drought is a direct reflection of the rate of resource consumption in an environment that would be relatively dry in the absence of deep wells, is represented in the pseudo-network only in the GSL HO. Karst systems are yet another type of hydrogeologic setting. Some karst areas are represented in the network, though not necessarily all major varieties. Another issue of concern is whether the HOs allow us to assess the feedback effects of droughts on climate; the spatial scale of the HOs probably is still too small for this purpose.

c. General: We may need to think beyond the boundaries of the HOs to allow for rapid deployment of resources to respond to extreme events in areas that are not already part of an HO. Should HO resources be use for this purpose? Should HO-based expertise in designing response plans be used to inform such plans for other areas? The spatial extent of a severe drought covers an area considerably larger than an HO. HO design needs to consider how measurements and characterization within the HO would inform less spatially well recorded information that is of considerable interest to large-scale modelers and to society.

Although there are various measures for assessing magnitude or intensity of a drought or flood, their impacts are a function both of natural factors and of the ways that human societies have adapted to these phenomena. Therefore, to the extent that we are concerned with their societal significance, we need to incorporate understanding of the strategies different communities have developed (or not developed) to cope with these events when they occur.

2. Does CUAHSI have to develop a set of cross-observatory hypotheses in order to design an effective network? If so, how should such hypotheses be selected and by whom?

Group A participants generally agreed that we do need a set of cross-observatory hypotheses in place to ensure that individual network proposals view their own field areas within the broader context. Each proposal should be able to characterize the range of conditions represented by its particular study area and to assess that range of conditions in relation to the broader range that might characterize the network as a whole. For example, we must make sure that the human impact and the role of urbanization are included in the scope of investigation, but this does not mean that every HO in a larger network would need to incorporate an urban area. The *network* of HOs must cover the range of important problems they are designed to address, but not every HO needs to address every problem. Instead, we must make sure that each HO rigorously address the problems that the selection process identifies for it. The cross-observatory hypotheses should give some guidance about the function of individual HOs within the network, but should still allow flexibility on the part of individual design teams to respond to their own specific circumstances.

An example was discussed as a way of looking at how a cross-observatory hypothesis might help to set the research agenda for individual observatories: Regionalization of flood peaks has a long history in hydrology. Rainfall-runoff modeling also has a long history, and at least some rainfall-runoff modeling is process-based. Flood-peak regionalization is frequency based. How are these related? This has not been answered. How might HOs help us answer this question? Both the dominant processes and the frequency distributions will be different from one HO to another, and only by comparing across the network might it be possible to detect larger-scale relationships.

With a limited temporal scope of measurements, we may find it easier to answer process-based questions than to collect enough years' worth of data to resolve frequency questions, hence the desirability to locate HOs in areas with some long-term data available. Furthermore, the application of statistical models may require that certain assumptions about the data series be satisfied, whereas process-based measurements do not require the same assumptions. On the other hand, a network may allow us to substitute space for time through the greater variety of hydrologic settings and the different frequency distributions observed for extreme events. We might be able to improve on existing regionalization approaches, whereas under present circumstances we often do not have enough gauged watersheds to be able to generate regional curves. We might need to invest in finding proxy paleoclimate data to augment instrumental records. Finally, the investigation of process will help us to account for changing landscape response to hydrometeorological drivers, thus improving statistical models.

Other network-level hypotheses might address the uncertainty of existing stage-discharge relationships for assessing flood peaks. Because of the difficulty of measuring flood flows, the upper ends of most rating curves are based either on indirect discharge measurements or on simple extension of the relationship derived for much lower flows. USGS is already engaged in attempts to assess accuracy of extreme flood peaks derived from indirect estimates. A cross-observatory initiative might focus on developing improved protocols for assessing flood peaks and temporal and spatial pattern of inundation. These in turn could contribute to improved approaches for assessment of flood hazards—including frequency analysis and innovative mapping procedures—at national and regional levels.

Should CUAHSI, NSF, or some other body decide on what should be the cross-observatory hypotheses? Group A participants suggested that for practical reasons, it would be desirable to take a first cut at this in time to provide some guidance for the first round of proposals to be completed in spring 2005. The suggestion was that example questions might be developed by network design teams and posted to the CUAHSI web site for general consideration. It was also suggested that CUAHSI might want to provide NSF reviewers some general guidelines about the range of conditions and processes that ought to be represented in the network.

3. Do you agree that effective integration can occur at level of mass, flux, flowpath, and residence time?

It was generally agreed in group A that these four characteristics are the appropriate ones to consider, but that the three cross-cutting themes—scale, feedback and coupling, and prediction and limits to prediction—ought to be explicitly incorporated in the discussion. An example was the question of how many direct precipitation measurement stations are needed to calibrate weather radars, and the extent to which the density needed varies across physiographic boundaries. Experimental design might itself be an object of research, for example, by deploying a network of portable radars and a dense network of rain gages to gather enough data to develop an effective network for a more permanent installation. We often lack adequate data on the spatial gradients and range of variability that we are trying to monitor. Thus, we may need different networks for characterization of patterns as compared with networks for estimation of the properties of those patterns. Not every HO team will have the same level of expertise on every such technical question and, therefore, we may need to have portable equipment and expertise to allow training and transfer of expertise in areas that may not originally have been recognized as important.

A key aspect of the discussion also focused on the need for adaptive monitoring—altering the spatial and temporal monitoring design to account for changing circumstances and to take advantage of opportunities as they arise. Partnerships with the atmospheric modeling community might also help to improve the sampling design, for example, of precipitation measurement stations. In more general terms, it was agreed that there is a need to develop strong integration of measurement and modeling. Only adequate data can be used to test models, but in many cases models are essential to fill in gaps at locations or times where data are not available. Furthermore the improvements in science need to be shared with the monitoring agencies for improvement of agency-based monitoring networks.

Another point recognized by group A was the need to identify appropriate scales for measurement in different landscapes and to determine how to scale up from point-based observations to spatially valid representations. For example, it was suggested that the resolution of soil-moisture datasets needs to be on the order of a 1-km^2 grid; yet we know that soil moisture content and saturated hydraulic conductivity may vary tremendously within distances of only a few meters. There is also a need to move from the notion of characterizing frequency distributions at isolated points or nodes in a network vs. characterizing the spatially extensive patterns throughout a network—such as looking at the frequency distributions or temporal patterns of stage or discharge at a single location during a flood, as compared with the spatial heterogeneity and temporally dynamic pattern of flood inundation and its influence on changing discharge in the longitudinal direction as well as the time dimension. One comment suggested that we need to use data to change the science rather than simply to make marginal improvements in existing models.

Remote sensing is recognized as a natural tool for bridging scales, for example in assessing soil moisture or snow cover. For soil moisture, however, the promise has not yet been realized, and the natural variability and patchiness of soil moisture are very difficult to characterize in the lateral direction; three-dimensional profile characteristics are even more difficult to characterize. If we can find ways to bridge these scales, can they be applied at more than one observatory?

ECOLOGY AND HYDROLOGY

1. Is the selected pseudo-network of five Hydrologic Observatories effective to address the issue of hydrologic extremes? If not, are there other combinations you would recommend?

In general, the selected pseudo-network can be effective at addressing the interactions between hydrology and ecologic health. The group did not choose a different set of five sites, but rather recommended that there should be diversity within sites and across the network. Thus, it is important to have urban areas and undeveloped areas; a variety of land uses; a variety of ecosystems; a variety of climates; and controlled and uncontrolled rivers. In addition, researchers should be able to make recommendations for areas where no HO exists. Research from the HOs should assist in making recommendations that can address societal problems across the nation.

It was noted that the pseudo-network does not include Sonoran, Chihuahuan, or Mojave deserts; Arctic systems; or short-grass prairies. It was also noted that the network does not include a presence of large reservoirs. The pseudo-network includes large urban areas located in upper and lower parts of the watersheds. A wide variety of land uses and climates are represented; although the lower latitudes of the United States are not captured.

The group agreed that the most important consideration to initiate the network is the ability of the first two HOs to succeed, so that the network will expand and continue. Furthermore, once two HOs are selected it is imperative that all immediately move from a spirit of competition to one of cooperation.

2. Does CUAHSI have to develop a set of cross-observatory hypotheses in order to design an effective network? If so, how should such hypotheses be selected and by whom?

This discussion was the most opinionated with one researcher immediately objecting to the idea of a certain set of hypotheses driving network design. The key word, may be "level" in that some general, high-level hypotheses could be appropriate for most proposed networks while more-specific (lower-level) hypotheses could be addressed only by individual observatories. Most agreed that an NSF-run competition or a CUAHSI committee would not be necessary to develop a set of hypotheses. Instead, the HO proposals will include hypotheses, some of which will be cross-observatory hypotheses. Hypotheses should deal with climate change, scaling issues, urban development, conservation practices, water development, water protection, and land management. The type of general, high-level question that would be appropriate for driving network design is, "How is the partitioning of water in different stores related to ecological health?"

Several participants discussed that the hydrologic community has an obligation to help change policy. One person noted that eastern U.S. water law is changing dramatically. Another noted that HOs could be used to help set appropriate Total Maximum Daily Loads (TMDLs) for agencies. The work done at one HO should have impact on policy at a national level. Some examples of these considerations are wetlands and endangered species. Protection of wetlands has become a national issue. Threatened and endangered species databases should be included in the HIS component of the HO. There is so much diversity in landscape that it is hard to generalize but we want to be able to apply what we learn from one place to another.

Collecting similar data across a network of HOs will facilitate the testing of hypotheses that could not be tested otherwise. One person noted that Eagleson could not test his hypotheses, but that his hypotheses could be tested with an HO network. Another participant noted that the network can provide a uniform way to test things like the 'minimum disturbance' hypothesis. Tree ring and spring data are two specific examples of useful data facilitation or collection by HOs. It would be useful if the HOs made tree-ring data available, and HOs could install instruments at springs, as this is relatively inexpensive.

3. Do you agree that effective integration can occur at level of mass, flux, flowpath, and residence time?

There was general agreement that data can be integrated at the level of the four fundamental characteristics of the basin (mass, flux, flowpath, and residence time of water, sediment, nutrients, and contaminants). Several participants noted that energy and carbon should be explicitly included. Several commented that the Nuese prototype does not address ecology or biology at all and most believed the conceptual model needs to include some reference to ecology. The focus of the observatories on hydrology will naturally lend themselves to expanded ecology research, because all ecology shares the dependence on water. We should encourage ecologists to work at the HOs, and thus include them in some of the planning, but hydrology should still be the main driver.

There was some discussion about the benefits of LTER sites in the basin. Some were concerned that LTERs do not share data/information, but several others pointed out that NSF recently mandated that LTERs share data and be open to outside researchers. Assuming coordination with LTERs, an HO with an LTER would certainly be advantageous for researching questions dealing with the interactions of hydrology and ecology. In addition, some upfront coordination with NEON would be extremely useful.

In general, the research of hydrologic and ecologic interactions requires detailed characterization of shallow groundwater, biotic mapping, and water quality data. In addition, the hydrologic (both surface water and ground water) regime needs to be well defined at multiple scales and its relationship to land use/land cover/land alteration.

Similar to some of the discussions for the individual HOs, there was discussion of strategically placing instruments to understand "hot spots." The group was asked to give some examples of research questions that could be answered by having an HO network.

The example questions are as follows:
- What are the interactions of surface and groundwater in karst systems and how does that impact the fauna that rely on nutrients via the transport of water?
- What is the hydrologic response to different activities in the basin? What is the impact on stream health?
- Do wetlands and floodplains really help improve stream water quality? What is the connectivity between wetlands and rivers and how does it vary for different flow rates?
- Can you restore the riparian areas?
- What is the resilience of a watershed after disturbance?
- Can conservation design protect ecosystems?
- What are nutrient requirements? State agencies have to come up with nutrient requirements. Agencies need standards (i.e., what is normal versus what is elevated).

FATE AND TRANSPORT OF CONTAMINANTS

Given this major driving issue, the goal of a hydrologic observatory network (with respect to contaminant fate and transport) is to:
- Examine water-quality issues across land use contrasts (differing extents of particular land use types), and land use change contrasts (differing rates of change between land use types).
- Examine water-quality and flow-path issues across geologic contrasts, which control the time scales of groundwater and surface water transport, sediment loads, and solid-phase reactivity.
- Examine water quality issues across climatic contrasts, which control precipitation and recharge rates and, hence, also transport times and storages.

The core data collection activities would/could include:
- Characterization of the hydrologic system via geophysical, geologic, hydrologic techniques (of course).
- Characterization of groundwater ages and transport times via environmental tracers (e.g., tritium, He, CFCs).

- Monitoring of atmospheric influx of major contaminants (e.g., PAHs, Hg, nitrogen, chemistry of precipitation)
- Monitoring of major surface water and ground water discharge points of system (e.g., major municipal or other wells) since these locations act as integrators (e.g., basin mass discharge, groundwater age, quality).
- Monitoring of land and water use via on-ground methods in concert with remote sensing methods.
- Identification of critical hydrologic zones (e.g., recharge areas, biogeochemically important areas) a prerequisite to evaluating effect of development on water quantity and quality.
- Target water quality monitoring strategically, for example, transect extending up-, across-, and down-gradient of an urban system.
- Target instrumentation across gradients in land use (to capture spatial and temporal changes).

Important emerging issues and opportunities in contaminant fate and transport that could be addressed within the framework of a hydrologic observatory include:

- Comprehensive monitoring of known contaminants (e.g., de-icing salts, nitrate) to elucidate flow paths in the system (opportunity tracers).
- Salinization of groundwater due to irrigation and over drafting.
- Widespread occurrence of pharmaceuticals, health care products, and other compounds with uncertain biological significance.
- Lack of monitoring of water quality in infiltration basins in urban areas, lack of knowledge of flow paths to receiving water bodies down-gradient of urban areas.
- Effects of dam removal on downstream water quality.
- Fracture, karst, and other preferential flow pathways.
- Catchment-to-basin transport of contaminants. Scaling transport processes between defined units within the basin.
- Comprehensive stormwater urban runoff monitoring over long term. Characterize first flush mass discharge and compare to baseline mass loads.
- Groundwater quality monitoring below urban, urbanizing, or suburbanizing areas. Characterize transitions in water quality.

REPORTS OF FOCUS GROUPS

Four focus groups were formed to identify and discuss outstanding procedural or operational issues that were not addressed in the scientific focused portion of the workshop.

The first focus group was on observatory proposal evaluation criteria. The group identified key components of a proposal and gave relative rankings to them.

EVALUATION CRITERIA

Purpose of HO: To provide the scientific community with a field facility that is well characterized by core data and provides the necessary services to enable its utilization by researchers across the country and around the world.

A. Core Data (40%)

1. **Conceptual basis for design.** The conceptual basis for the design should have the following characteristics:
   a. **Hydrologic Cycle.** Embraces the entire hydrologic cycle and enables research at the boundaries between traditional subdisciplines
   b. **Breadth.** Provides a characterization useful to a range of disciplines including physical hydrology, biogeochemistry, geomorphology and ecology.
   c. **Scalable.** Provides a strategy for testing hypotheses across a range of scales, up to and including the entire proposed HO.
2. **Hypotheses posed.** The core data should be justified on the basis of a set of hypotheses that will enable resource allocation decisions to be justified among the competing demands. Discussion should include an objective basis for delineating core data from investigator data.
   a. **Breadth.** As a set, the hypotheses should address at least three of the five priority science topics identified by CUAHSI.
   b. **Specificity.** The hypotheses should be sufficiently specific to enable design decisions to be made, such as the location of sampling points, precision and resolution of data to be collected. Fundamentally, the hypotheses establish the scientific value of the data. Have quantitative models been proposed to allow for evaluation of the relative utility of different data series?
   c. **Scientific creativity and importance.** Hypotheses will be evaluated based upon how fundamental they are and how innovative they are.
   d. **Testability.** Can the hypotheses posed by rejected by the proposed data? Are alternate hypotheses stated? How objective are the proposed tests?
3. **Utility.** Will the proposed core data be useful to the community at large? Has a sufficient context been developed to allow "outsiders" to understand what the data represent?
4. **Leveraging of Existing Data.**
   a. **New data collection.** Has an analytical approach been specified that uses existing data to justify new data collection?
   b. **Value added.** What is the relative value of the existing data that will be used for characterization of the proposed HO and the new data to be collected? In general, new data collection should enable larger bodies of data to be used for scientific purposes.
5. **Evaluation of Core Data.** Have sufficient resources been requested to evaluate whether the data collected meet their intended uses? At what time intervals will such evaluations been accomplished?

B. Data (20%)

Although the HIS effort will provide a search tool ("HydroViewer"), specify the structure of data files, and provide metadata standards, it is the responsibility of the HO to assure data quality, to track samples that are collected for laboratory analysis, and to assemble data series meeting the specified structure, and to host one node of the Federated Digital Library of HOs.

1. **Quality Assurance Plan**. Although detailed QAP's do not have to be specified in the proposal, does the proposing team have experience in developing such QAP's and/or demonstrate knowledge of the content and structure of these plans.
2. **Data Management System.** Are sufficient labor and computing resources requested to deliver authoritative core data in a timely manner? Have targets been set for release of reviewed data?
3. **"Real-time" Data.** Has a mechanism been proposed for streaming sensor-collected data directly to the web?
4. **Derived data products.** Have derived products (such as material fluxes) that will be provided by the HO been identified? What is the proposed delay between delivery of these products and the release of the data? Are there sufficient resources to deliver these products as promised?
5. **Site Description.** For HOs to be successful, potential users must be able to understand the site. Extensive descriptions of the site, including both text (e.g., land use history, settlement patterns, etc.), maps (e.g., geological setting, geomorphological development) and multimedia products (e.g., actual or virtual fly-overs of the basin, 3-D renderings of the basin, and interactive tools for exploring the basin) are critical. What are the plans for developing such a library of products? How will a new user get oriented and understand the HO?
6. **Data Archiving and Back-up**. Have mechanisms been specified to maintain the integrity of the data base?

C. Management Plan (20%)

CUAHSI will provide a management plan to provide community input into the annual work plan collecting core data and coordination of HOs. Proposing teams may accept CUAHSI management at this level or propose an alternative mechanism if they do not wish to have CUAHSI manage the HO network. All proposals, however, must specify internal management of the HO.

In this discussion, the following terms will be used:

- **Science PI:** The principal investigator of the NSF proposal who has led the design effort
- **Site Director:** The person who oversees the day-to-day operation of the HO
- **HO Executive Committee:** The group of co-PI's and other senior personnel who are receiving salary from the grant
- **User Committees:** Committees of various user groups, potentially chaired by a member of the HO Executive Committee, whose time is uncompensated.

The generic model for HO management consists of the Science PI who is responsible for meeting the terms of the grant. The Site Director reports to the Science PI; the professional staff, in turn, report to the Site Director. A major concern under this model is that there is sufficient oversight by CUAHSI that the Science PI does not co-opt the HO to meet his or her own research agenda. Proposals should indicate what checks exist on the power of the Science PI and how community input will be received and acted on.

1. **Duties and Lines of Authority**. Have the duties for each of the constituent parts of the HO team (Science PI, Site Director, HO Executive Committee and User Committees) been specified and their authorities delineated?
2. **Evolution of and Changes to Core Data**. Have processes been specified to change the core data? Who makes that decision and at what intervals can changes to the core data be considered?
3. **Project Management System**. Has a management system been specified that will collect the data necessary to evaluate whether the HO is delivering its products on-time and on budget? [Note: CUAHSI plans to offer project management services to HOs, but will require the cooperation of HO teams to collect the necessary data.]

Services (10%)

HOs must be able to accommodate non-local scientists to achieve the goal of making them a community resource.

1. **Access Permits**. Has the proposing team made provisions for acquiring permits to access private lands and to place

instruments in public lands? Is there a mechanism for enforcing permit restrictions on users of the HO, such as the development of a User's Handbook or orientation session for users?

2. **Facilities**. What laboratory, office, library, and computing facilities will be available for use by visiting scientists and students? What vehicles (cars, trucks, boats) will be available for visitors? Will insurance be provided for visitors? Will students be able to access university resources, such as auditing or taking classes?
3. **Housing.** What assistance will be provided for short-, medium-, and long-term visitors to find housing?
4. **Environmental Health and Safety.** Are orientation classes available to users of the HO, whether for field work (e.g., wilderness survival, firearms training, first aid) or for laboratory work? Have liability concerns been thought through for users of the facility (e.g., what insurance should users provide, what is the host university liable for).

Education and Outreach (10%)

To assess the broader impacts of a project, NSF requires a statement of the educational opportunities afforded by each proposed project. Clearly, HOs offer many possibilities. All areas of education (K-12, 13-16, Graduate, and Informal) should be considered. CUAHSI will request a full-time E&O Coordinator as part of its management budget to assist the HO network to achieve a strong E&O component. Past experience has shown that both a bottom-up and top-down approach must be pursued simultaneously for an effective E&O program.

HO MANAGEMENT

- Need dialog between PIs and focus groups so recommendations for management plan are not developed in a vacuum.
- Need to provide two levels of information: (1) guidelines on management principles (objectives) and (2) guidelines on structure.
- Need to define the relationship among the following (Figure 2):
    - PI (scientific leadership, tenure track faculty member)
    - ODT (co-PIs from host institutions)
    - OPS (site director, Ph.D. scientist non-tenure track
    - Non-local PIs (cooperating investigators)
    - Science Advisory Board (locally focused)
    - HO standing Committee (works for CUAHSI)
    - CUAHSI E&O standing committee
    - CUAHSI HIS standing committee
    - NSF
    - CUAHSI Headquarters staff
- Need flexibility so that can adapt to change (i.e., when funding comes through CUAHSI rather than NSF).
- Need a mechanism to add outside collaborators to ODT.
- Need a mechanism to track observatory use by others.

METRICS OF SUCCESS

Three-year metrics

- Progress in installation of core data, accessibility of data, prompt archival of data
- Physical facilities to support mission are in place
- Integration with HMF/HIS activities has been achieved
- Survey hydrologic science community on value of HO, including level of interest in HO; also establish structure for regular survety/feedback
- Reporting requirements for HO – success in implementing objectives, marketing efforts, business plan implementation, new courses and curriculum development
- Site visit by CUAHSI/NSF team at three years
- Administrative efficacy – Is staffing complete? Evaluation of personnel performance?
- Linkages to static info, other auxilliary data, other agency data
- Quality of data, QA/QC protocol development
- Improvements in conceptual model of hydro. system, integration with modeling efforts

What should be achieved in five-year cycle?

- Strong evidence if having engaged community (hydrologic and broader societal, other scientific disciplines, demonstrate increasing trend of interest level, geographic diversity of users)

- Generation of core data, what fraction of sensor network has been installed and is functioning (100%)
- First publications should be coming out
- Publications of data, studies that use the data
- High level of integration with HIS/HMF
- Strong evidence of impacts on education (grad student research through outreach partners—college /K-12)
- Strong evidence of integration/coordination with network of HOs
- Clearly distinguish contribution of HO infrastructure (new/scientific accomplishments) that would not have been possible without the HO)
- Well-defined plan for second cycle of funding and long-term plan
- five-year synthesis report
- Strong evidence of having addressed all CUAHSI science themes

Long-term metrics

Quantitative measures

- Hits on website
- Data downloaded; how to track data downloads
- Publications
- Use by outside PIs/outreach
- Use of data in papers
- Track service to outside researchers (hours? number of projects
- Non-NSF resources acquired
- Number of visiting scientists, sabbaticals, graduate students from the outside

Long-term

- Enhancement of HOs by partnership with other agencies, other communities

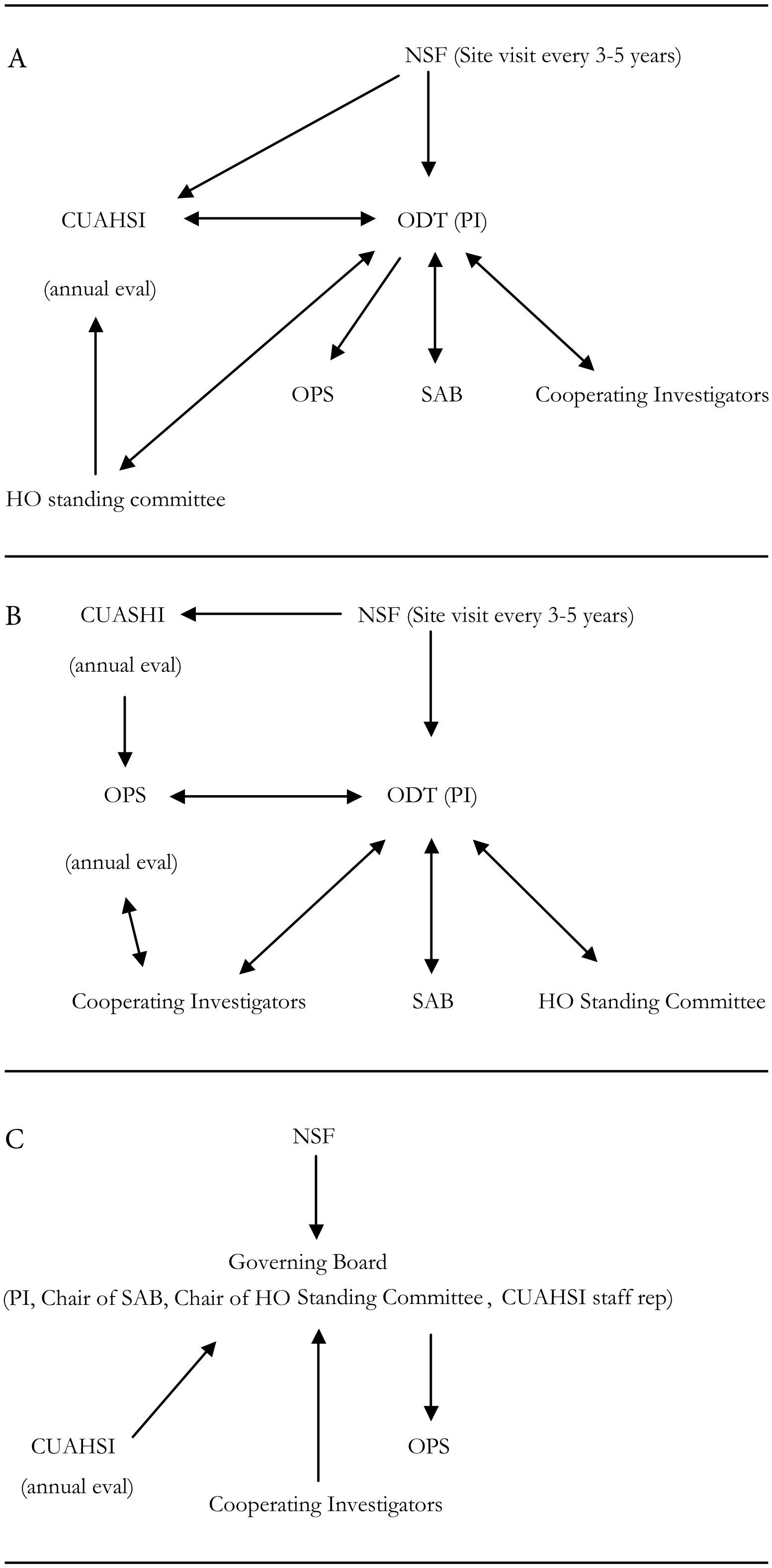

Figure 2. Possible HO management models.

- Evaluation of societal impacts
- Adaptation of HO model at other levels (local scale)
- Contribution to advancing science, improving forecasts of hydrologic quantities
- Attracting young people/researchers to go into the field of hydrology
- Integration/real establishment of networks

DATA COLLECTION PROTOCOLS

Observatories are envisioned to have many scientists and research teams working at multiple sites. Therefore, to be broadly useful, the data from these observatories should be collected by employing citable methods. Having standards and protocols to ensure data comparability is essential for observatories to function properly. There is a long current list of citable methods to use for the myriad of environmental data that will be compiled. Where possible, it would be better to use a predefined set of methods and protocols than to have CUAHSI define new ones. However, if there are competing standards, it would be necessary for the Hydrologic Measurement Facility team to provide a mechanism to decide on one.

A list of current citable methods include:
- USGS
- Nexrad
- ASTM standards
- EWRI
- EPA Water Quality Methods
- LIDAR
- Ameriflux
- Other NSF Observing initiatives

There are some data that do not have guidelines and therefore need more urgent attention. For example, derived indices that could be part of the core data, like surface roughness.

One possible way to overcome these differences is to have testbeds with cross-validation of the same sensors in different environments and with different probes using the same calibration techniques. It would be essential for observatory teams running these testbeds to share information and interact with the HMF. Core data would have more stringent requirements. The investigator specific data would be less stringent.

Other issues to be dealt with by the Observatory Standing Committee include standardizing the reporting units used (e.g., nitrogen-nitrate). Each observatory team would have to commit to one procedure for core data so that the broader community could reliably use that data. Quality assurance and control are obviously big services the observatory staff would have to perform, but deciding on what methods to ensure data quality would also have to be decided. A protocol establishing communication guidelines for sensors would also be important if a researcher wanted to use a sensor in multiple observatories. The HMF will take the lead in determining these standards and training all cognizant people at each site.

CONCLUSIONS

The workshop was instrumental in coalescing hydrologic science researchers around a truly community oriented platform to transform the science. In addition to elaborating on the incentives of a platform (versus a specific research tool such as standard instrument packages), it also pointed out the insufficiency of current plans to operate such a large-scale network effectively in the immediate future. There are many issues to be resolved at many levels.

To this end, a small number of testbeds (n equal to or greater than 2) could, for a relatively small investment, resolve a great number of standards, sensors, and management issues.

Additional findings:

1. Providing high spatial and high temporal resolution data collected at frequent intervals (wall to wall data) would be more beneficial and less costly to researcher than more dynamic types of data.
2. Having a community organization such as CUAHSI is essential for managing the open and equitable research platform that observatories will be.
3. Despite pointing out the many issues to be resolved, the workshop was a smashing success because it laid a more solid foundation for hydrologic science researchers to build, manage, and deliver a successful community resource.

APPENDIX 1. WORKSHOP AGENDA

DESIGNING HYDROLOGIC OBSERVATORIES AS A COMMUNITY RESOURCE

CUAHSI National Workshop, Logan, Utah, August 24-25, 2004

Tuesday August 24

7:30 – 8:30	Registration. Continental breakfast provided.

Plenary Session. Room ENGR103. Webcast overflow in ENGR101.

8:30	Kermit Hall (USU president): Welcome
8:45	John Wilson: Opening remarks
9:00	Rick Hooper: Charge to Workshop
9:30	Jay Famiglietti: Neuse River Prototype Observatory
10:00	Break
10:30	John Selker: CUAHSI HMF and HOs
11:00	David Maidment: CUAHSI Data Model and HOs
11:30	Doug James: What Makes a Good Proposal?
12:00	Lunch: Taggart Student Center
1:30	Poster Session: Poster Area. ENGR building 3rd floor
4:30	Election closes

Plenary Session ENGR 103

4:30	Peggy LeMone (NCAR). GLOBE and HOs
5:00	John Wilson. After the Neuse: Opportunities to get involved with CUAHSI Discussion of volunteer opportunities in various CUAHSI committees, including 1. HIS Standing Committee 2. HIS Users Committee 3. VP Editorial Board 4. HO Focus Groups a. Proposal Evaluation Criteria b. HO Management Structure c. Metrics of Success d. Concepts for Data Collection Protocols, Lab Methods, and Data Standards
5:30	Announcement of Election Results
6:00	Shuttle buses depart for Conference Dinner at the Copper Mill Restaurant.

Wednesday August 25

7:30 Continental Breakfast

Plenary Session. Room ENGR103.

8:00 Rick Hooper: Charge to Break-out Groups

Breakout Sessions in rooms ENGR 104, 106, 201, 202, 203, 204, 205, 206, 238, 328

8:15 Breakout Sessions by HO: Core data to attract non-local scientists

10:15 Break

10.30 Break-out sessions by science topic: What hypotheses can be answered with a Network of HOs?

- Linking Hydrologic and Biogeochemical Cycles
- Sustainability of Water Resources
- Hydrologic and Ecosystem Interactions
- Understanding of Hydrologic Extremes
- Fate and Transport of Contaminants

12:30 Working Lunch

- Leaders/Recorders of 10 HO break-out groups summarize/synthesize results
- Leaders/Recorders of 10 science topic break-out groups summarize/synthesize results
- For all others who are interested in writing advisory white papers there will be an initial meeting of 4 focus groups.
    - Proposal Evaluation Criteria
    - HO Management Structure
    - Metrics of Success for HOs
    - Concepts for Data Collection Protocols, Lab Methods, and Data Standards

Closing Session ENGR 103

2:00 Summary of HO break-out

2:15 Discussion

2:45 Summary of Topical break-out

3:00 Discussion

3:30 Doug James: Workshop Observations

4:00 John Wilson: Summary and Next Steps

4:30 Adjourn

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