

Strategic Instrumentation to Advance Water Science

An executive summary of the HMF Blue-ribbon committees on Opportunities for Advancement on Hydrologic Instrumentation.

Agenda

Hydrologic science is based on theory, mathematical description, and experimental verification. The complexity and variability of the hydrosphere demands that experimental data provide ever more precise approximations of reality to which the theory and math asymptotically converge. The Hydrologic Measurement Facility (HMF) is dedicated to advancing accurate and rapid monitoring of hydrological truths from nature. Three Blue-Ribbon committees were established to envision a strategy to achieve the HMF mission. The HMF organized its strategic planning efforts around three topic areas: Water Cycle (WC) sciences, Geophysics, and Biogeochemistry. Three committees were convened to identify opportunities for the HMF to contribute to the advancement of hydrologic science within the topic areas. These committees of 8-10 scientific leaders drew from their own experience as well as the 2005 HMF survey of the community. The committee findings are synthesized here.

Context: The Sensor Revolution

Electronic technology has transformed modern life following a timeline culminating in a nexus of opportunity for environmental sensing. Bulk electrical power transformed lighting and labor just over 100 years ago; telephone and radio just over 80 years ago; television and computation 50 years ago; integrated circuits 40 years ago; CMOS no-current circuitry 30 years ago; and cellular telephony 20 years. In the last decade, system-on-a-chip Ultra-Large-Scale Integration (ULSI) and microelectronic machines (MEMS) have stepped into daily life from inkjet printers to wristwatch radios, and lab-on-a-chip sensors. Environmental sensing, which forms the core of field hydrology, requires continuous (i.e., low-power CMOS), distributed (i.e., telemetry) measurements (typically based on ULSI MEMS) of diverse parameters. Only in this decade has the electromechanical technology matured to the point to afford observation across the scales and processes that address the complexity of the physical, chemical and biological functions of the hydrosphere. A central task of the HMF is to bring to fruition the opportunities of the revolution in sensing technology for application by the scientific community.

Community Survey Findings

A survey receiving more than 360 responses to an extensive list of prescribed and open-ended questions (see the full report at www.CUAHSI.org). Respondents were asked to prioritize 23 opportunities to advance hydrologic sciences; with possible scores ranging from -100 (not needed) to 100 (critically needed). There was overwhelming support (>75%) for four major initiatives:

1. Improving the integration between measurement and modeling methods (80.6%)

Assisting scientists making critical experimental discoveries in the hydrologic sciences

2. Improving spatial resolution of measurements (79.7%)
3. The ability to make more/better measurements through distributed sensor networks (77.3%)
4. Improving our ability to measure and quantify the subsurface (76.4%).

There was strong support for providing access to expensive equipment with recognition that accompanying technical support for both deployment and data interpretation was critical. Respondents identified high-priority field deployable equipment that could augment ongoing studies: atmospheric profilers (RASS, LIDAR, SODAR-RASS); ground penetrating radar (GPR) and electromagnetic induction (EMI) sensors, weather radar, and atmospheric flux towers. The call for a fundamental change in access to instruments was dramatic, fitting well with the sentiments that gave rise to the HMF concept.

Committee Findings

Many of the most important problems that society faces, climate change, habitat value for biodiversity, urbanization, flooding, agricultural impacts, waste assimilation, and toxin dispersion, require a detailed and integrated understanding of **geophysical**, **hydrological**, and **biogeochemical** dynamics. Change underlies these challenges and marks a fundamental shift in the demands on hydrologic science from documenting outcomes (e.g., stream flow time series) to understanding processes that will advance prediction in a changed world. This is the grand challenge facing hydrologic science.

Biogeochemistry and hydrology must be considered as an integrated whole to understand how complex watersheds process key perturbations such as land use and climate change. To the hydrologist, **biogeochemistry** provides an ensemble of tracers to reveal the history of the sampled water. To the Biogeochemist, hydrology defines the reactor and mixing for the complex chemistry experiment taking place in nature. Integration will require innovative new techniques and technologies to more accurately, efficiently, and reliably measure sources, stores, movement, and transformations of biogeochemical constituents over large areas and long time intervals. Many of the major environmental issues are manifested at large spatial scales (e.g., eutrophication of lakes, estuaries, and coastal waters; role of freshwaters in greenhouse gas emissions). In order to develop a predictive understanding of biogeochemical processes at these larger scales, it is necessary to make simultaneous measurements within many smaller basins as well as along longitudinal gradients. Key technologies identified to advance these studies included field mass spectrometers, electromagnetic geophysics, and fiber-optic distributed temperature sensing.

The three broad **Water Cycle** research focus areas are 1) Water Supply/Droughts/Flood Forecasting, 2) Hydrology and Climate/Agricultural and Ecosystem Productivity, and 3) Opportunistic Measurements - Extreme Events (Prediction and transformation). The HMF must support access to timely, emerging suites of technologies that are well suited to close the water cycle by monitoring across water cycle subdisciplines. Improved measurement resolution in space and time are high

priorities. We envision that the most significant advances will require the parallel deployment of multiple instruments in a campaign style across multiple watersheds. This concept assumes that instrumentation selection is explicitly informed by priority science questions and defined challenges in our ability to measure water resources. A suite of current and emerging technologies were prioritized for HMF delivery.

Characterization of the subsurface structure, in relation to water storage and flow, is a fundamental obstacle to understanding the hydrosphere. The **Geophysics** committee concluded that electromagnetic methods offer the greatest current opportunities in developing 3D reconstructions of the subsurface to determine structure and identify flow paths. These technologies span instruments that are commercially available to those which have only recently shown their potential. Delivery of these complex systems to practicing hydrologic scientists is as much a matter of building collaborative teams between geophysicists and hydrologists as it is one of particular tools and technologies. A key logistical obstacle to development of a shared pool is exposure of fragile, costly instrumentation to damage, and the concern over the qualification of random users to collect high quality data. The HMF has responded to this particular need immediately by working to secure insurance coverage to be granted to projects between hydrologists and geophysicists that make use of cutting-edge technologies.

The HMF Center and Node Model

The HMF tactical model provides a focal point for hydrologic instrumentation and supports community-based access to key technologies. The proposed HMF model is a small Center with a number of nodes. The **HMF Center** is envisioned to be a competitively selected location where logistics, community strategic planning, and a small cadre of support staff are co-located. The Center will also house community instruments which are based on **mature technologies**. The **HMF-nodes** are medium-term focal points, which develop and support a specific **emerging technology** or provide a **specialist service**. Nodes are to be competitively funded by the NSF (or other sources) based on the expertise and potential of a particular facility through proposals written independently of the HMF that carry the HMF letters of endorsement and reflect their desire to abide by the principles the HMF defines regarding community access. Nodes would be expected to have a 3-6 year lifecycle to marshal the maturation and dissemination of key technologies within the facilities where these methods have been demonstrated. Examples of node-based technologies might include x-Band precipitation radar; back-scatter LIDAR; wireless sensor networks; and electromagnetic hydrogeophysics. Maintaining these technologies in laboratories rather than trying to assimilate them into a central HMF center ensures that the scientists continue to be exposed to the cutting edge of research, whilst ensuring that the HMF plays a supportive rather than competitive research role. The HMF Center would coordinate with the nodes to assure that development is timely and community access is open and fair. The technologies developed at nodes would ultimately be disseminated either through commercial channels or from the HMF Center. The Center-Node model will provide an efficient, adaptable center that can respond quickly to new challenges. It will allow new

technologies to be rapidly embraced whilst efforts with aging technology can be wound down with no impact to the central HMF facility infrastructure. It builds a stable structure dedicated to delivery to the entire research community and foster the dynamic development of key systems based on community expertise.

The HMF Service to Current and Emerging Missions

While the HMF is being shepherded by CUAHSI, our mission is the advancement of science wherever hydrologic processes might be of interest. The HMF will be a critical resource to a broad range of existing and emerging major scientific missions. CUAHSI itself is developing long-term observatories which will depend upon the HMF for technical support, but this is but one of an array of large-scale environmental research efforts planned and underway to which the HMF will contribute.

Within the programs of the NSF, the many Long-Term Ecological Research (LTER) sites run for over 30 years by the Division of Environmental Biology could benefit immensely from access to a service which facilitated better characterization of fluxes of water and its solutes. Beyond the NSF there are federal agencies with research missions that will be strong partners to the HMF. The HMF already has a formal relationship to the USGS through the Hydrological Instrumentation Facility (HIF) and exploring opportunities with the USGS in Geophysics. Collaboration with the USDA Experimental Watersheds program has begun. The National Ecological Observatory Network (NEON) plans to establish a continental-scale environmental monitoring network (www.neoning.org). Within the sphere of hydrologic parameters the HMF is in a position to provide both guidance and material support. The Environmental Engineering community's "Collaborative Large-scale Engineering Assessment Network for Environmental Research" (CLEANER) is focused broadly on water. CLEANER-CUAHSI's planned WATER and Engineering Research System (WATERS) Network will benefit directly from the HMF capabilities. The HMF capabilities will be in very high demand in the coming decade during the implementation of these large existing and emerging initiatives, as well as the hundreds of individual PIs who have expressed their strong desire to use HMF facilities. The HMF services are needed by the community of scientists as well as the planned and ongoing national campaigns. Through landmark investment of effort by the community we have a logical, efficient, and dynamic strategy to address these needs.