Towards a Framework for Community Modeling in Hydrologic Science

Report from the
2nd Workshop on a Community Hydrologic Modeling Platform (CHyMP):
Blueprint for a Community Hydrologic Modeling Platform
University of Memphis, Memphis, TN
March 31-April 1, 2009

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June 16, 2010

Executive Summary

The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) is continuing to encourage the development of a Community Hydrologic Modeling Platform (CHyMP). A first, scoping workshop was held in March, 2008 [*Famiglietti et al.*, 2008], and identified the need for a substantive, university-led community modeling activity in hydrologic science. A second workshop, *Blueprint for a Community Hydrologic Modeling Platform (CHyMP) Workshop,* was held on March 31-April 1, 2009 at the University of Memphis (U of M). Sponsored by the National Science Foundation (NSF), CUAHSI and the U of M, the goal of this second workshop was to engage the broader community to identify the scope, form and requirements of the modeling activities. Planned outcomes from this second workshop include the identification of further constraints on the needs and specifications of CHyMP, coordination with several ongoing community modeling activities in related disciplines, as well as in the operational community, and to identify the key science goals that will drive the development of the platform components.

Findings and Recommendations

Over 65 participants attended the second workshop (see Participant List), which was held at the University of Memphis' FedEx Institute of Technology. Attendees from the U.S. and abroad represented universities, government labs and federal agencies. Key findings and recommendations from the workshop are noted briefly here, and described in more detail in the body of the report. Importantly, there was unanimous support for continued planning and development of community hydrologic models and associated infrastructure. A PI-led grassroots effort was envisioned, much like the Hydrologic Information System, in which CUAHSI plays a supporting role by helping to organize the community and enable linkages to other CUAHSI and associated activities as appropriate. The key outcomes of the workshop were:

1) The CHyMP effort[1] will first focus on evaluating existing platforms or integration software, which are already being developed in support of other modeling activities such as the Earth System Modeling Framework (ESMF), the Community Surface Dynamics Modeling System (CSDMS), the NASA Land Information System (LIS), NOAA's Integrated Water Resources Science and Services (IWRSS), its Community Hydrologic Prediction System (CHPS), etc. Compatibility between the CHyMP and these parallel efforts will be maximized by adopting, to the degree possible, a common software platform. This will

[1] The 'CHyMP effort' refers to a group of future investigators, which at present is represented by the report authors and selected workshop participants who currently comprise the CHyMP working group or leadership.

enable future CHyMP research and development efforts to benefit from existing capabilities. Ultimately, CHyMP will adapt current capabilities, and develop new algorithms and methodologies needed to create and sustain the next generation of simulation tools.

2) The need to establish a Hydrologic Modeling Community of Practice was identified. CUAHSI, and the CHyMP effort in particular, can play a leadership role in developing standards, metrics, benchmarks, and in identifying 'best modeling practices' for model development, coupling, testing and application.

3) As in the case of the Scoping Workshop [*Famiglietti et al.,* 2008], participants expressed strong support and enthusiasm for a National Water Model as one key focal point of the CHyMP effort and an important application of platform software. The structure of a National Water Model, based on existing and new components, datasets and software, was discussed at length. Participants encouraged its implementation as an important first step for CHyMP.

Next Steps

Next major steps for the CHyMP effort will be a third community workshop on implementation of these recommendations in late 2010, and coordination with existing, related community modeling efforts such as the NSF-sponsored CSDMS and those funded by other agencies such as NOAA, NASA, the USGS and the EPA. In particular, the workshop will consider the following issues:

- Refining the concept of a hydrologic modeling platform, including key differences in the capabilities of existing platform software, as discussed in this report.
- Refining the concept of a National Water Model by developing a set of common objectives, performance metrics, and identifying model components.
- Establishing a set of Process Teams and Working Groups to focus on a range of issues in model development, software engineering, model integration and benchmarking
- Refining the elements of a Community of Practice, including CUAHSI's role in its establishment and support.

With input from CUAHSI, the NSF and other sponsors, the CHyMP leadership will continue to refine its strategy to move towards the implementation phase by identifying a candidate platform, by articulating the form of the National Water Model, and by establishing Process Teams and Working Groups, and by proposing a set of strawman metrics in order to initiate a Community of Practice.

Introduction

Our nation faces a number of critical, water-related issues that require near- and long-term solutions. Will there be enough fresh water to supply our growing population in the face of climate change, a dwindling snowpack and over-stressed groundwater supplies? How will changes in the water cycle impact energy production in the United States, including hydropower and biofuel production? Will increasing intensity of hydrologic extremes of flooding and drought impact the safety and security of our population? The public and policy and decision makers need answers to these questions, as well as adaptation strategies to accommodate the realities of the changing water landscape of the future.

The hydrologic community plays a pivotal role in addressing these challenges. Comprehensive, long-term planning must be informed by the latest research and best available technologies. However, the development of integrated hydrologic simulation models, which are essential tools in the effort to predict and understand the complexities of water cycle change and its impacts, has lagged far behind the urgent need to provide answers to today's environmental issues. All too often, hydrologic models are developed by individuals or small groups, for a specific, narrowly-focused task. The result is that model development remains disjointed, with little coordination and model integration across subdisciplines. To date, this approach remains a significant impediment to the holistic representation of the water cycle in hydrologic models, as well as to sharing model software. As such, an accelerated pathway towards significant advances in hydrologic modeling capabilities and accessibility must be undertaken now.

With the support of the Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. (CUAHSI), a focused effort called the Community Hydrologic Modeling Platform (CHyMP) [*Famiglietti et al.*, 2008, 2009] has been initiated in order to enable this accelerated development path. The CHyMP effort will provide infrastructure for community-driven platform and integrated model development, as well as the framework for distribution, high performance computing access and technical support. A key benefit of community software is that it eliminates duplication of effort, allowing researchers to spend more time on exploration rather than on 'recreating the wheel.' While the goal of the CHyMP effort is to support the university water research community, coordination with similar, ongoing efforts by government agencies and in related disciplines is essential to maximize its utility and impact.

A first, scoping workshop was held in Washington, DC, in March 2008. The results of that workshop are summarized in *Famiglietti et al.* [2008, 2009]. In brief, workshop participants expressed unanimous support for moving forward with the CHyMP effort, along with recommendations to pursue emerging computational methods, and the development of an integrated, national-scale water model.

This document reports on the second CHyMP workshop, held on March 31-April 1, 2009, at the University of Memphis. The goal of the second workshop was to engage the broader community to identify the scope, form and requirements of the community modeling activity, and to identify the key science goals that will drive the development of the platform components. Over 65 participants attended, from the U.S. and abroad, and represented universities, government labs and federal agencies. A participant list is appended to this report.

Summary of Major Findings

Overall, participants were fully supportive of a significant, community modeling effort. The three major recommendations that emerged from the second workshop were as follows.

1) Build upon existing platform software. CHyMP components, data, and models can be linked together using existing platforms, or integration software. Several efforts, for example, the Community Surface Dynamics Modeling System (CSDMS), the NASA Land Information System (LIS), and others, have already invested heavily in the development of platform software. The CHyMP effort can leverage these developments, allowing more time for research on model components, rather than the software required to link components together. Moreover, a common software platform will readily accommodate linkages to models from other disciplines that use the same platform. For example, adopting the CSDMS or the LIS platforms will ease potential future modeling coupling and research linkages to these groups and to others that adopt their standards.

2) Establish a Community of Practice. Another important recommendation of the workshop was for the CHyMP effort to take a leadership role in establishing a Hydrologic Modeling Community of Practice (CoP). The CoP would establish a set of 'best modeling practices' for a range of issues regarding coding, input, output formatting and standards; the establishment of a comprehensive set of benchmarks and metrics to quantify model performance; and to evaluate CHyMP and other model performance and model improvements based on these metrics. Workshop participants agreed that a standardized set of benchmarks and metrics to help define model performance would be a welcome contribution that would likely raise the bar in the hydrologic modeling community by holding it to an agreed upon set of standards.

3) The concept of a National Water Model continues to be embraced by CHyMP workshop participants. Such a model is essential in order to address several of the high-priority issues mentioned above and described in more detail below. A

National Water Model will provide a framework for simulating all the major features of the natural (i.e. snow and ice, permafrost, frozen ground, lakes, wetlands, rivers, floodplains, soil moisture, groundwater, evaporation, transpiration, infiltration, percolation, runoff generation, streamflow) and human (reservoir storage, surface water conveyance, irrigation, surface and groundwater withdrawals, etc.) components of the water cycle, in an integrated manner and at high spatial-temporal resolution. The framework will readily accommodate data from CUAHSI Water Data Services for model calibration and validation; and as well as relevant remotely-sensed data, e.g. for precipitation, surface water, vegetation, surface temperature, snow, soil moisture and groundwater. The multiple potential model uses and stakeholders, as well as space-time scales of application (including upscaling, downscaling and telescoping resolution) were clearly recognized, and viewed as a significant, but tractable research challenge. An important goal of the National Water Model will be to provide the best available assessment of the stocks, fluxes and flowpaths of the terrestrial water cycle, from the regional scales that are critical for environmental decision makers, to the national scale, where issues of national security, policy and climate take precedence.

The National Water Model will also serve as a focal point for the CHyMP community. Workshop participants were quite enthusiastic about building a benchmark model from existing and emerging components, and to work as a community to continuously improve the model with time. Note that this type of focus activity is analogous to the Community Climate System Model (CCSM) effort hosted at the National Center for Atmospheric Research (NCAR). The NCAR community activities are among the most successful in the Earth and atmospheric sciences, and provide an important example for CHyMP development.

What is CHyMP?

CHyMP is a grassroots effort with a goal of developing, providing and supporting advanced simulation tools to the academic community within a community-based 'development-user-feedback' framework. The CHyMP effort proposes to significantly accelerate the development of advanced hydrological modeling capabilities in order to address complex water issues of the highest priority at national and international levels.

The major elements of CHyMP are:

- A platform of modular components that can be linked together to form integrated water cycle models across of range of space-time scales
- A community-driven research agenda on all aspects of platform and model development, including broad community engagement and input through Process Teams, Working Groups and annual meetings

- The development of a National Water Model that includes all major components of the natural and managed hydrologic cycle
- Close integration with other parallel activities, in particular CUAHSI Water Data Services, and other community efforts including CSDMS, NCAR CCSM/CLM, NOAA CHPS/IWRSS, NASA LIS, USGS, etc.
- The ability to link to models from other disciplines, including climate, ecology, biogeochemistry, etc.; and to ground- and remotely-sensed data of varying spatial and temporal resolution
- HPC compatible/scalable and access to high performance computing
- The development of benchmarks and standards for model performance, component model development and platform tools
- Mechanisms for model support and distribution

In short, the CHyMP effort will fill a critical gap by developing integrated models of the terrestrial water cycle, and by catalyzing academic researchers towards the development of community models and their application to high-priority science issues. An implicit goal of CHyMP is to spur the development of next-generation models that can readily exploit recent advances in computing power and structure, the internet, and access to very high-resolution data. At present, significant impediments exist to acquiring advanced observations and using them appropriately in hydrologic models. For example, the use of satellite altimetry data for heights and slopes of inland water bodies cannot yet be readily accommodated by current models. Similarly, the use of satellite time–variable gravity data in models poses its own set of challenges. Moreover, access to high performance computing to run these advanced models remains limited in hydrology. An important component of the CHyMP effort will be to address these challenges in terms of both model development and community services for data and model users.

Finally, the CHyMP effort can play an important role as a bridge between research and operations via a coordinated model development strategy; between science and policy by providing high-quality hydrologic predictions for decision makers, as well as a forum for researcher-stakeholder interactions; and between federal agencies and the academic hydrology community, effectively broadening their participant base beyond a small set of funded researchers.

What is the National Water Model?

The vision for the National Water Model is a simulation tool that provides the best current prediction of the fluxes and stores of terrestrial water and related processes in the United States. It consists of a series of hydrological process components, integrated with each other and linked to a database, using a modeling platform. The National Water Model will require the best capabilities for representing a wide range of processes over broad space and time scales, i.e., it will require the CHyMP. For example, all major components of the natural and human components of the water cycle (as described in the *Summary of Major Findings*) must be incorporated in an integrated manner, with the ability to adaptively simulate specified regions at very high spatial and temporal resolutions. The database will contain the hydrologic parameters and forcing required to enable accurate predictions, and could easily be accommodated by the CUAHSI Data Services activity. While there are examples of such models and databases in the government, operational and hydrometeorology communities (e.g. Rodell et al., 2004), they are typically driven by an agency (e.g. NASA, NOAA, NCEP or the USGS) or small group of investigators with a narrowly focused goal.

In contrast, we envision a community-wide effort to develop a model with integrated process representations (e.g. coupled human and natural systems; fully-coupled surface, unsaturated zone and groundwater flow), advanced simulation capabilities (e.g. watershed-based framework, telescoping resolution, capabilities to link to models of other disciplines) and data access (e.g. primarily through tight coupling to CUAHSI Data Services) that extends well beyond previous small-group efforts, to significantly accelerate predictive understanding of the water cycle from hillslope to continental scales. To the degree possible, it will be highly desirable to partner with and leverage against complementary, mission-driven efforts. While the National Water Model will be an important application for CHyMP and a research model for the community, we also expect that the simulation capabilities outlined for CHyMP will have research applications far beyond the National Water Model.

What science issues will it enable?

Over the past few decades, the hydrologic community has made great scientific progress across the full spectrum of hydrologic research. This work has employed our essential tools, observations, models and analyses, and enabled great strides in predictive understanding of all components of the water cycle, and across a wide range of space-time scales.

However, the world and our place in it is changing rapidly. Climate is changing while population is growing. The importance of water to society, including its availability, its quantity, and the impact of extremes such as flooding and drought, will likely grow significantly in the coming decades. While our current generation of models have and will continue to serve many of our research needs well, new models that integrate the natural and human components of the water cycle, and that readily link to models in other disciplines (e.g. of climate, biogeochemistry and ecology, water management and human behavior) are required to address the pressing issues that we face today. Several of these issues are highlighted in recent NSF calls such as the Water Sustainability and

Climate (WSC) solicitation (e.g., *How can we protect ecosystems and better manage and predict water availability for future generations given alterations to the water cycle caused by climate variability and change and human activities?);* while an important aspect of and the NSF Decadal and Regional Climate Prediction Using Earth System Models (EaSM) is the development of models to help ensure adequate water supply in the future. Likewise, the NRC report on Integrating Multiscale Observations of U. S. Waters (*NRC*, 2008) contains several recommendations for advancing hydrologic model development by PIs and by agencies in order to address these societal needs of the decades to come.

How much fresh water is stored on the land surface? How will this change over time? Will there be enough fresh water to supply our growing population?

These questions can only be addressed with a fully-integrated water cycle model (i.e. that includes all major natural and managed components of the water cycle) that can predict how snow, surface water, soil moisture and groundwater are distributed across the continents. Moreover, the resolution of such a model must be great enough to inform water managers at the local-to-regional scales at which water management decisions are made. While many research groups are running existing models at high space-time resolutions, few if any models represent the fully-integrated water cycle and the major human components (e.g. rates of groundwater extraction irrigation, reservoir storage, surface water redistribution). In short, an important long-term vision for the CHyMP effort is to enable seamless prediction across spatial and temporal scales of the quantity and quality of water at every point on and in the land surface, including human modifications of the water cycle.

Do hydrologic tipping points exist? Can human activity cause irreversible change to the water cycle?

At the global scale, unless carbon dioxide emissions are strictly curtailed, most scientists agree that the water cycle will fundamentally change. Changes will include melting ice and decreasing snowpack, more severe storms and drought, and changes in the space-time patterns of where rain falls (e.g. less in mid-latitudes, more at high latitudes), among others. While recent observations are documenting that these suspected changes are occurring at the global scale, the regional to local-scale impacts of an accelerating or intensifying water cycle are poorly known. A greatly enhanced ability to downscale climate change information to regional scales, and conversely, to upscale land-use change and human activity information to the global scale, is essential in order to enable environmental decision making in the face of a changing water cycle. Significantly improved regional climate models, regional-scale hydrologic prediction, and a framework for coupling regional climate models to comprehensive, integrated hydrological models, are imperative to address these issues in a substantive manner.

Global issues notwithstanding, the question of how much land use change a watershed can sustain (or alternatively, how to balance land use change with changes to hydrology, climate, ecology, and biogeochemistry) is one that simply cannot be answered at present. Simply put, the required level of model integration, both within hydrologic models, and the ability to readily link to models of other disciplines, does not exist in any convenient form. Issues related to the representation of water stores, flowpaths, residence times, at regional scales that are important for decision makers, have long been central research themes in hydrology, and ones that the CHyMP effort will ultimately enable.

Water management for national security: the water-energy-food nexus. Is there enough water and land to support large-scale biofuel production and food production in the United States?

Among the most challenging future water management decisions will be those related to energy production. Few people recognize that nearly 25% of our nation's energy budget is used to treat, transport and heat water; and that the major use of water in the U. S. is for power generation (though much of this is 'once-through' use returned to streams or to the ocean). Clearly then, decisions about water use have major implications for energy use, and likewise, decisions regarding energy production significantly impact water use.

Agriculture follows energy production as the second largest use of water in the United States. Much of this water is groundwater drawn from the Ogallala aquifer beneath the High Plains, and the Central Valley aquifer in California. Yet groundwater in these two aquifers is being mined (used more quickly than it can be replenished), posing very real threats to the food security of our country. Simultaneously, discussions regarding large-scale biofuel production continue. Although new, clean, renewable sources of energy are essential for the economic stability of the U. S., large-scale fuel-stock production would displace large-scale food-stock production. Moreover, the water and acreage requirements for biofuel production will be daunting.

These are pressing issues that will only be exacerbated by population growth. In all cases, national-scale, integrated hydrological models are required to explore a range of potential trade-offs between environmental protection and national security. The hydrologic models must also have the capacity to readily couple with climate, agricultural, energy, and economic models in a comprehensive, human-natural system simulation framework, so that the full impacts and feedbacks of possible solution scenarios can be carefully explored.

What about other community modeling efforts?

There are several ongoing community modeling efforts with which the CHyMP effort can coordinate. Although the planned mission, vision and stakeholders for CHyMP differ significantly from the efforts described here, coordination is desirable for many reasons. These include leveraging existing platform software, enabling opportunities for coupling to models of different disciplines, and learning from the experiences of these other groups. In addition to encouraging CHyMP development efforts, CUAHSI can play an important role in enabling broader participation in other community modeling efforts by the academic hydrologic research community. This could be accomplished by CUAHSI-led workshops, as well as by continued participation in federal, interagency modeling working groups

Here we describe several ongoing efforts with which the CHyMP effort will coordinate. These are not an exclusive set of collaborators. The CHyMP effort will remain as open as is feasible towards coordination with any ongoing community modeling activities in hydrology and related disciplines.

Community Hydrologic Prediction System (CHPS). NOAA's Community Hydrologic Prediction System provides software infrastructure, built in support of NOAA's hydrometeorology operational prediction mission. CHPS has a goal of sharing its modeling tools with the broader hydrologic community. CHPS represents a modernization of NOAA software tools, and is being built using standard software packages and protocols. It will ultimately enable integration with software and data in use by other federal agencies, academia, and the private sector. CHPS is essentially a customized application of the Flood Early Warning System (FEWS). While the CHPS framework is being developed primarily in support of NOAA's operational flood forecasting mission (in contrast to CHyMP, which will be developed by the academic research community in support of its broad research agenda), close coordination between CHyMP and CHPS will enable maximum interoperability and compatibility between the efforts. CHPS has not been fully deployed by the NWS yet, so that a detailed approach for integrating CHPS and CHyMP cannot yet be defined.

Community Land Model (CLM). The Community Land Model is the land surface component of the National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM). The CLM is broadly representative of the class of land models that are coupled to atmospheric general circulation models, or to fully-coupled land-ocean-atmosphere models like the CCSM. This class of models is optimized to calculate vertical water, energy and biogeochemical exchanges between the land and the atmosphere, but is less so with respect to terrestrial hydrology. For example, the representation of glaciers, rivers, lakes, reservoirs, wetlands, and groundwater are primitive with respect to the current need for climate adaptation and mitigation solutions. As such, the land components of climate models still require significant development before they can realistically represent all facets of terrestrial hydrology and their interactions with climate. The hydrometeorology community has been intimately engaged in advancing the hydrology in land surface mode, although this represents only a small portion of the community and its interests. However, hydrologists' participation in CLM development represents a grassroots forum for addressing the challenges of representing subgrid-scale hydrologic detail in larger-scale land surface models. We expect that such scale issues will form a central component of CHyMP research, and that the CHyMP will provide an advanced numerical laboratory for such studies.

Climate modeling efforts at NCAR have a rich history of community input, development and use. Component models like the CLM have been developed via a long-standing working group structure (e.g. in the case of the CLM, the Land Working Group), in which membership is open. Working groups vet proposed model changes, and prioritize development and simulation activities. The CHyMP effort will maintain strong ties to the CLM and the Land Working Group in order to learn from their experiences, to coordinate climate aspects of CHyMP model development, and to help integrate a broader swath of the hydrologic community into hydrology-climate research at both NCAR and through CHyMP.

Community Surface Dynamics Modeling System (CSDMS). The CSDMS is an NSF-funded effort to develop models of Earth surface processes, in particular, those that affect landform evolution, such as erosion, sediment transport and geomorphology. The movement of water over and through the land surface clearly plays a central role in these processes, and as such, the CSDMS group has devoted significant effort to developing the software required to couple hydrologic model components (e.g. infiltration and runoff) to surface dynamics components (e.g. erosion). For example, CSDMS scientists and engineers have archived a number of commonly used hydrologic research models, disaggregated them into process component modules, and embedded the components in software that allows them to be easily coupled to other components from other models. The CSDMS group is also identifying standards for model developers and for model coupling to enhance access to the CSDMS by developers and users. While the platform and coupling software that the CSDMS is developing may form a strategic starting point for CHyMP activities, it is important to appreciate the difference between the efforts. A fundamental goal of the CHyMP effort is to research and develop hydrological process model components and integrated models themselves. In contrast, the CSDMS uses existing hydrological model components to help develop and drive models of surface processes. In short, they are distinct but highly complementary efforts.

The CSDMS has also built a structure for community input and involvement through its main Working Groups and Focus Research Groups. This structure could also provide an important model for the CHyMP effort. CUAHSI has already engaged with the CSDMS through their joint sponsorship of the Hydrology Focus Research Group [http://csdms.colorado.edu/wiki/HMC]. The mission of this Focus Research Group is to advise the CSDMS Executive Committee on models and model components that are appropriate for achieving CSDMS science goals.

Land Information System (LIS). The Land Information System (LIS) is a flexible land surface modeling and data assimilation framework developed with the goal of integrating satellite- and ground-based observational data products and advanced land surface modeling techniques to produce optimal fields of land surface states and fluxes. The LIS infrastructure provides the modeling tools to integrate these observations with the model forecasts to generate improved estimates of land surface conditions such as soil moisture, evaporation, snow pack, and runoff, at 1 km and finer spatial resolutions and at one-hour and finer temporal resolutions. The fine scale spatial modeling capability of LIS allows it take advantage of NASA's Earth Observing System (EOS)-era observations, including those that are critical to understanding water cycle dynamics. LIS features a high performance and flexible design, provides infrastructure for data integration and assimilation, and operates on an ensemble of land surface models. LIS is designed using advanced software engineering principles to enable the reuse and community sharing of modeling tools, data resources, and assimilation algorithms [http://lis.gsfc.nasa.gov].

To date, the LIS sponsoring-agency missions (enhanced prediction through assimilation of remotely-sensed atmospheric and hydrologic data) do not allow for significant community input to model development or for substantial technical support for distributed code. However, model code and output are freely available. As a result, they are examples of models where source code can be accessed by the community, although the opportunity for input from the community is limited. As with the above community efforts, while the planned CHyMP mission and stakeholders differ greatly from that of LIS, the potential for leveraging software platforms and model components, and for CHyMP to serve as a critical bridge between NASA researchers and the broader hydrologic community, underscores the need for close coordination between CHyMP and LIS as the CHyMP effort enters the implementation phase.

Where do we go from here?

Next steps for the CHyMP effort include a third workshop for the development of an implementation plan (late 2010), preliminary investigation and intercomparison of platform software, exploration of the process modules that will comprise the National Water Model, and continued engagement with several of the community modeling activities described above. Following the third workshop and the delivery of the CHyMP Implementation Plan, we will coordinate with NSF and other funding agencies regarding plans for funding our community to establish CHyMP research and development activities.

Key near-term goals for the CHyMP effort and for the third workshop are to:

- Refine the concept of the modeling platform as the core data and computational engine of CHyMP. Identify key differences in the capabilities of existing software for hydrologic science and applications. Develop a strategy for selecting or modifying platform and related software tools to serve as the foundation for CHyMP.
- Refine the concept of a National Water Model by articulating a set of common objectives, performance metrics, and potential model components. Identify a strategy for testing and integrating existing and new process components using platform software. Explore partnerships with complementary efforts as appropriate
- Explore the establishment of Process Teams (e.g. for developing and testing hydrologic components) and Working Groups (e.g. for Software Engineering, Benchmarking, Model Integration, etc.) as key mechanisms for advancing the CHyMP effort.
- Refine the elements of a Community of Practice, including CUAHSI's role in establishing and its maintenance. Develop a strategy for initiating this activity.

In the meantime, the authors of this report continue to engage with several agencies to keep them abreast of CHyMP plans, progress, and efforts to interact with other major community modeling activities. We submit proposals for CHyMP planning and prototype efforts as appropriate. Your participation in these efforts is encouraged.

It is important to note that as the hydrologic community embraces the major challenge of seamless prediction of the stocks and fluxes of the water cycle across the spectrum of space-time scales, a comprehensive, integrated hydrologic modeling framework lies at the core of such an ambitious endeavor. Understanding and predicting the quantity, and ultimately the quality of water at all points on land and beneath its surface, can surely only be accomplished by a coordinated, community, national-scale effort, in collaboration with a network of global partners. It is our hope that the CHyMP effort will represent a major first step towards addressing this challenge for our nation.

References

Famiglietti, J., L. Murdoch, V. Lakshmi and R. Hooper, 2008, Community Modeling in Hydrologic Science, EOS, Transactions, American Geophysical Union, 89(32), pp. 292

Famiglietti, J., L. Murdoch, V. Lakshmi and R. Hooper, 2009, A Community Modeling Platform for the Hydrologic Sciences: Rationale and Strategy. A Report from the Hydrologic Community to the National Science Foundation. CUAHSI Technical Report doi:10.4211/techrpts.200911.tr8.

NRC, 2008, Integrating Multiscale Observations of U. S. Waters, The National Academies Press, Washington, D.C., 198 pp.

Rodell, M., et al., 2004, The Global Land Data Assimilation System, Bull. Am. Meteor. Soc., doi:10.1175/BAMS-85-3-381, 381-394.

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