VISIONARY REFLECTIONS FROM A CRYSTAL CLEAR POOL OF WATER SCIENTISTS

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Our goal is to keep the planet blue
    For that we need some green
To justify our requests we need not dream
    A surfeit of quandaries around us gleam
Pondering growing bread
    can make some of us see red.
The phosphorescence of sheets white and bright
    may impede our amity with creatures of the bight.
A lot of what we put in the air
    accumulates in receptors beyond repair.
Inscribing the chain of cause and effect in blood
    could lead to a flood
Keeping our clients mellow
    with trustworthy numbers can turn us yellow
    Even as on issues wet and profligate
    we readily pontificate
Integrating the disciples of many creeds is the cry
    to keep the well from running dry.

INTRODUCTION

Water, an essential resource, seems to be headed for unprecedented prominence in the public eye and as a field of scientific inquiry. Given its many spheres of influence and interaction (Fig. 1), this is hardly surprising, as we ponder scarcity induced by growing population, intensification of use, changing climate, and by the modification of the natural setting. The sustainable development and use of water and the environment are recognized as the key to reducing poverty, and societal vulnerability to the vagaries of nature. Many, many initiatives for water research and its application in a societal context are being advanced in the United States and worldwide by various groups of scientists and research agencies. While there is broad consensus on the importance of water research and the major areas of inquiry at least in the United States, consensus on a strategy for funding and managing water research appears to be emerging rather slowly, despite direct and significant efforts by the National Science Foundation and leading scientists. Funding levels for coordinated basic and applied research consequently continue to languish well below what one would expect for a scientific field of this size and importance. The diversity of needs represented by the field presents a massive opportunity, but may also inhibit the ability to clearly identify and prioritize a non-controversial research program on a limited budget. An interpretation of this socio-cultural dilemma is presented here in the context of the developments behind the formation of the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI), an organization dedicated to improving the state of research associated with the hydrologic and associated material cycles.

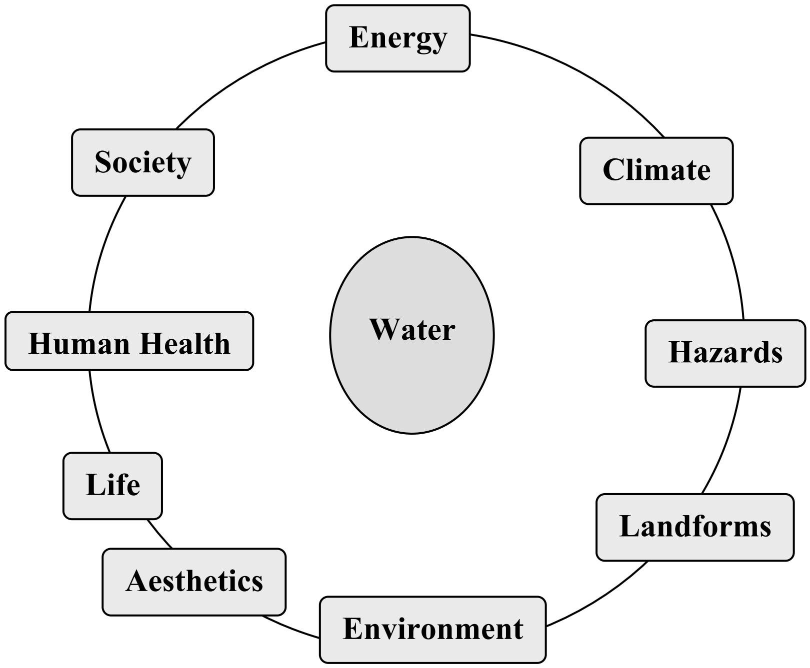

Figure 1: The "Hydrosphere." Some of the areas that contribute to and derive benefits from research on water and related material cycles. Water scientists include hydrologists, hydraulic and water resource engineers, chemists, ecologists, social scientists, biologists, geomorphologists, and many other species. Hydrology has long been the largest section of the American Geophysical Union, and water related fields are well represented in other professional societies.

BACKGROUND

The 20th Century witnessed intensive global development of surface and ground water resources, success in harnessing the power of flowing water, in mitigating the effects of floods and droughts, in the provision of clean water, and in sanitation and wastewater treatment. Extensive engineering projects and physical and social infrastructures emerged around such developments. The academic research agenda was closely tied to these developments and engineers, economists, chemists and other specialized applied professions dominated the field. In the latter third of the century, environmentalism emerged as a major force and the ecological and social effects of large physical modifications to natural systems came to be better appreciated. Some of these effects are largely irreversible, some were unanticipated, and almost all indicate modifications that have spatial and temporal scales much greater than those of the alterations to the landscape. Anthropogenic climate change may fall in this category. Thus, changing values and changing physical conditions have jointly conspired to change our perceptions of the relative importance of different elements of water practice and research. The conflict between the aspirations of the rich and the poor, between countries at different stages of development and between different market and scientific philosophies also colors such perspectives. We can be sure that 50 years hence all these factors will have yet another tint.

The transitional 1980s also saw the resurgence of conflict in the water research community. Some decried the "engineering" bent of hydrologic research and sought to develop it as an earth science. The deliberations of some of these scientists, led to the production of the widely read and cited volume "Opportunities in Hydrologic Science", published by the National Research Council (NRC), in 1991. In a subsequent science planning document, that arguably led to the emergence of CUAHSI, Gupta et al (2000), state that the 1991 report marks the emergence of "Hydrologic Science" as a distinct, interdisciplinary Geoscience. Interestingly, while the NRC (1991) report, the Gupta et al (2000) report, and the plethora of recent science planning documents (e.g., Hornberger, et al, 2001, Entekhabi et al, 1999; NRC, 1998, 1999) stress the development of new methodologies for the development of data and analytical techniques to support research towards a fundamental understanding of hydrological, earth and biological processes, they motivate these research efforts through the identification of significant challenges faced in predicting and managing variations in water quantity and quality and the associated social and ecological vulnerability and adaptability. The link between proposed research directions and the solution of the society-driven challenges identified can sometimes be tenuous. Clearly, a "hydrologic or water resource engineer" is then puzzled by the writings in these documents, as it becomes difficult to connect the proposed research in some of these documents to tangible operational gains over the methods being used in practice.

The efforts to distance the new science from past research and practice compound the problem. An interesting byproduct of this observation is that while the basic objectives outlined in many of the recent "hydrologic science" research documents are rather similar, the authors often feel that their message and areas of interest are different from and/or superior to those of another report. Shades of difference in the perceived science-engineering continuum of priority selection and problem identification contribute to acrimony aggravated by the perception of a limited pie to be quartered. This is unfortunate, since embedded in these documents are the kernels of major scientific challenges that are core challenges for the natural and earth sciences. For instance, we do not yet have a fundamentally sound approach to the estimation of flow at any operational time scale of interest at an ungaged location, or for the closure of the water balance at a space or time scale of interest, or for understanding the multi-scale nature of hydrologic fluxes and their interactions. Resolving these issues could be a pre-requisite to understanding mass transport and energy exchange, and the relationship of the global water cycle covering the ocean, atmosphere and land to the local, terrestrial water cycle of societal interest. This is a significant departure from the traditional hydrologic science or engineering focus on hillslope or watershed processes, where many of the active variables were considered exogenous to the subsystem modeled and most of the effort seemed to be directed towards the solution of a series of ill-posed inverse problems. Interestingly, these new perspectives significantly change the boundaries, dimension and composition of what one would define as the water resource system. It is perhaps safe to say that while we now realize the importance of studying a much greater set of interactions and scales in order to improve predictability, the ability to successfully do this using either observations or scientific principles is in its infancy.

The excitement of these "hydrologic science" developments and arguments has been largely viewed as peripheral by many of the rank and file hydrologic/water resource engineers in academia and practice. While they seem excited about the prospects of new data and research to solve problems they see every day, they view the oligarchy of "hydrologic science" as elitist, and out of touch with the problems that need solution. The "blue skies" research syndrome is reinforced by many academic researchers who disdain practitioners, and revel in developing solutions to highly idealized settings without necessarily embracing explanation of observations and solution of practical problem as their motivation. Indeed many such academics seem disconnected from management problems or managers and yet speak of multi-disciplinary approaches to study societal decision-making processes, where their role is highlighted as the provision of scientific hydrologic information. Strangely enough, some of them actually belong to the genre of water resource systems analysts, a subfield that originally emerged in the 1960s, and was strongly focused on the collective understanding of the many subproblems facing water resource management and development, and their integration and decomposition in the context of making better decisions. One would expect that the vitality of such a profession would be significantly enhanced in the current setting, where the increase in the dimensions of the water resource problems of concern and of the system boundaries necessitates more clever approaches, and the ability to formulate problems more intelligently than the "kitchen sink" approach a modeler focused on unit processes may use. Unfortunately, the academic components of this profession seem to have become largely focused on specialized methods of mathematical problem solution and idealized uncertainty analyses, rather than on innovative methods of problem formulation, characterization and reduction of complexity, or on integration of scientific principles. As a result, this area has nearly vanished from the academic curriculum and research agenda relative to its heyday. The underlying concepts of systems analysis are now being used by some of the science disciplines (e.g., geography, ecology and the social sciences) related to water. It is my opinion that as stakeholder-driven and market-based processes establish themselves in the emerging multi-disciplinary setting, with a reduced role for traditional institutional managers, a new flavor of water resource or natural resource systems analysis, derived directly from new information and modeling systems, will enjoy a significant resurgence.

The mid-20th Century phase of water resources and irrigation development led to the formation of relatively well-endowed and distributed state water resource research programs that were funded by state and federal appropriations and housed at state Universities with an extension mandate. Collectively, these water research programs had a significant influence on the development of water research and its rapid technology transfer. Unfortunately, federal funds for the water resource institutes program have been vanishing since the 1980s, as the resource development phase gave way to the environmental mandate. Most institutes have struggled since. The more entrepreneurial institutes embraced the environmental mandate and sought supporting funds from diverse sources. Those with significant state funding have clearly fared best in this setting. As the regulatory pendulum has swung back to the issue of non-point source pollution, many land grant college-based water research institutes recognize an opportunity, since they are well placed in their extension role, and through their state and local programs, to effectively contribute technology and solutions. While new funds from NSF generated by the "hydrologic science" community would be welcome, there is skepticism that these would be accessible. The scientific data needs and methodology development and implementation issues are perceived differently, even though the basic science question is often the same – predictability of material cycles (e.g., sediment, water and nutrients) through the watershed. Consequently, this community has sought to coalesce towards a "National Water Initiative." This effort, initiated through NASULGC (National Assn. Of Universities and Land Grant Colleges) in 1998, has sought to engage the major federal agencies involved in water to fund a common, national water research program. The water research needs described by a 2001 report of the Water Technology and Science Board (WTSB) of the National Research Council, headed by Henry Vaux, is considered relevant to the agenda of this constituency. As one may expect, this report differs from the "hydrologic science" research plans in its more direct focus on assuring the safety and reliability of the water resource and the integration of institutional and human factors. One can expect and hope that the complementarity of the two communities will come to the fore as the programs to support these missions emerge. The salient difference between the two communities, and the apparently divergent programs, is that, at least in concept, one hopes that the "basic science" community will focus on the identification and resolution of major hydrologic puzzles, while the "applied science" community will focus on the identification and solution of current and emerging problems. It is easy to see that given the proper "systems" framework each perspective helps the other (Figure 2).

Now that I have possibly insulted every water researcher, I offer my apologies to those who may have been offended and seek to offer a diagnosis of the socio-cultural setting under which the situation described in this section may have evolved, with a view to ultimately offering a recommendation for harmonious development of the mutual perspectives.

PERSPECTIVE

Abraham Maslow, a humanistic psychologist, introduced a theory of personality in 1943 that has influenced many fields. He believed that humans strive to reach the highest levels of their capabilities, but their attainment of such goals is directly influenced by their ability to meet a hierarchy of needs. This theory of needs and information is often presented through a pyramid structure. An embellished form of this diagram is presented in Figure 3. Prior to Maslow, researchers generally focused separately on factors such as biology, achievement, or power to explain what leads to human behavior. Maslow posited a hierarchy of human needs based on two groupings: deficiency needs and growth needs. Within the deficiency needs, each lower need must be met before moving to the next higher level. Once each of these needs has been satisfied, if at some future time a deficiency is detected, the individual will act to remove the deficiency. The first four levels are: Physiological, Safety, Social and Esteem.

Only once the deficiency needs are met is the individual ready to act upon the growth needs. Maslow's initial conceptualization included only one growth need--self-actualization. Self-actualized people are: 1) problem-focused; 2) incorporate an appreciation of life; 3) concerned with personal growth; and 4) have the ability to have peak experiences. Maslow later expanded on self-actualization, adding two growth needs prior to self-actualization and one beyond that level: 5) Cognitive: to know, to understand, and explore; 6) Aesthetic: symmetry, order, and beauty; 7) Self-actualization: to find self-fulfillment and realize one's potential; and 8) Transcendence: to help others find self-fulfillment and realize their potential.

Maslow's basic position is that as one becomes more self-actualized and transcendent, one becomes wiser and automatically knows what to do in a wide variety of situations. He believed that the only reason that people would not move through the needs to self-actualization is because of the hindrances placed in their way by society. For example, education is often a hindrance with imposed ideas of the culture. On the other hand respectful teaching promotes personal growth.

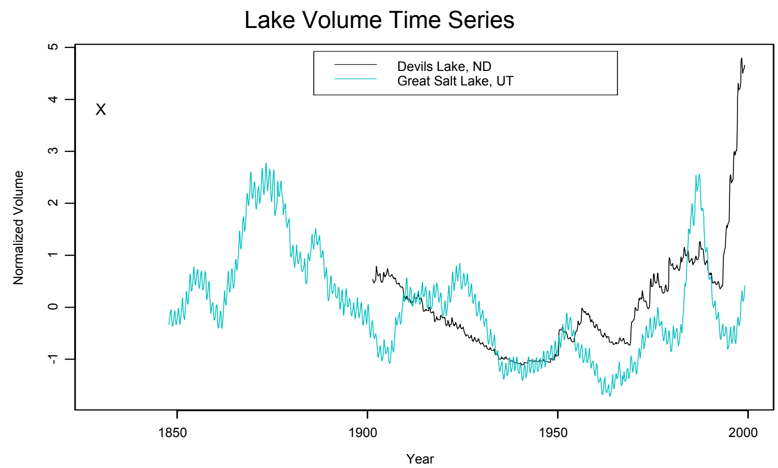

Figure 2. The time series of the Great Salt Lake, UT and the Devil's Lake, N. Dakota. The dramatic rise of the Great Salt Lake from 1983-1987 led to significant flood damages, a declaration by the state legislature making it illegal for the lake to continue rising, and the investment of $60 million in pumps to lower the level of the lake by draining it to the West desert. Soon after the pumps were installed, the climate changed and the lake retreated.

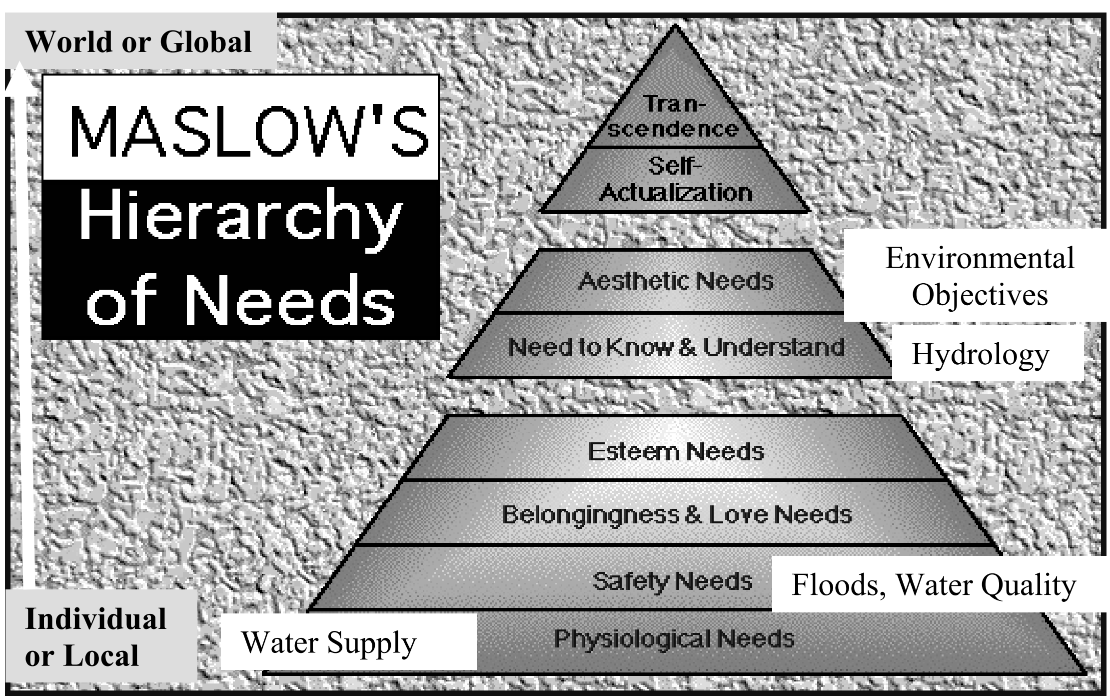

Figure 3. Maslow's Hierarchy of Needs. Physiological needs (e.g., food, water, shelter) need to be satisfied before an individual can address safety needs. Social Needs (e.g., giving and receiving affection and caring for others come next. Once these are satisfied, the individual can develop self-respect or esteem needs. Intellectual needs (understanding and aesthetics) follow. Once these are met, the individual can focus on self-actualization or fulfillment through being problem-focused, appreciative of life, concerned about personal growth and ability to achieve their potential. A parody of hydrological needs and scales is embellished on to this diagram.

Devil's Lake has had a spectacular rise in the 1990s, causing significant dislocation of the local population and services, and leading to speculation about the impacts of anthropogenic climate change. The x in the top left of the graph marks a historical level of Devil's Lake suggesting that this hypothesis may not be the only explanation. Such dramatic changes in the levels of closed basin lakes remain a scientific puzzle that requires an improved understanding of interactions between land surface hydrology and the atmospheric and oceanic branches of the water cycle. Clearly, the solution of this puzzle could also significantly aid flood control and land use planners who struggle with coping during such events and the lack of scientific guidance for design and planning for such changes.

It is easy to relate individual and societal issues to this hierarchy. The stage of development of a country or society defines its position on the hierarchy, as does the situation of an individual. In this context, we can readily see that since water scientists have been apparently starved for research funding, it is difficult to make serious progress as a community without first addressing that issue in a substantial way. Of course, there are large differences across the situation of individuals in the community, and a researcher who has had substantial success in fund raising (relative to his/her needs for such a resource), is tenured, has been well-accepted by the community and feels good about it, may step out of the rat race with the ability and history of developing new ideas and knowledge to the point where they can think of the grand problems facing the community and contribute to the development of a research plan or religion that can in turn benefit the entire community. This is what we assume will happen as our leaders cogitate on such matters. Of course, despite their apparent success, their personal attainment on the hierarchy of needs may vary greatly, and perceived threats to the satisfaction of lower level needs will limit an individual's ability to respond at their expected level of need satisfaction as a community leader and thinker. This recognition could in principle help community leaders facilitate convergence towards common goals. A factor that clearly inhibits such a process is the significant diversity in the water field, which translates into diversity in professional objectives and function of individuals. Thus, given markedly different goals, reconciliation is likely possible only if a large number of the "leaders" are self-actualized and are not likely to perceive esteem, security, or physiological threats.

It is interesting to explore how Maslow's hierarchy may map into functions in the water research community. First, I postulate that the bottom of the pyramid, starting with the efficiency needs, is likely focused on water problems that have a local or immediate focus, while the top of the pyramid, corresponding to transcendence, corresponds to an examination of global problems, or to variations of water over long time scales, either in the past or in the distant future, beyond the immediate concern. Thus, we get an immediate and clear differentiation between the types of professional interests expressed by different members of the community. Second, the development of a water supply is easily seen to correspond to the physiological need at the first tier. This was responsible for the growth of the field in the early 20th Century, and as noted in the WSTB report, and in most UN or other global aid agency documents, the emergency concern over most of the developing world, as water scarcity is expected to become acute in the 21st Century consequent to rapid population growth and the increase in area under irrigation. Given the environmental lessons of the 20th Century, we can hope that new, innovative methods for developing and using these resources are forthcoming. Similarly, once water is available, safety concerns dominate, and professionals or agents who focus on the prevention or mitigation of flood and drought hazards and in assuring water of drinkable quality perform a function. The need to preserve biodiversity and preserve the environment can be perceived partly as a perceived safety need, and partly as an aesthetic need. These are also emerging and critical concerns for the 21st Century, as the intensity of use, alteration of natural landscapes, and global climate change promise to keep us focused on meeting this hierarchy of needs. Only as these are met, through technological means, can we successfully progress to a useful discussion of the social context about how instruments for water allocation and assuring environmental sustenance can be implemented. Societal support of research on hydrologic science or improved understanding clearly comes in settings where the prior needs are being met. This is true in the developed world, where such efforts are well supported, relative to the developing countries. Transcendence of the field can be viewed as the ability of hydrologists to sufficiently understand their field and be comfortable in the knowledge that they can focus on how that knowledge benefits other disciplines. Clearly, fear that the climate scientists, being better organized, are going to take over terrestrial hydrology stem from insecurity or a deficiency in esteem needs, and a higher level of self-actualization in the climate community. Of course, this may work in the other direction as water scientists contribute to other fields. As we move from an individual perspective to a social perspective, we recognize that transcendent individuals or groups within a society will be concerned about the welfare of those whose basic needs are not met at some level, and hence societal progress is greatly determined by the presence and actions of such a group. This is the basic mechanism that drives aid programs from developed to developing countries.

So, we learn that (a) it is important to maintain a strong research program towards meeting each of the needs in the hierarchy, (b) of necessity, activity towards meeting deficiency needs will be greater than that towards meeting growth needs (this is reflected in the existing and historical research allocations), (c) it is vitally important that investments in meeting growth needs be made so that there is general improvement through transcendence, and (d) it is rather counter-productive for water researchers to view the different roles played in the field as contrary or to seek to denigrate one or the other.

These are simple, common sense ideas that did not really require an elaborate motivation from behavioral theory. However, since the community does not seem to be making its way through this rationalization, invoking transcendence from another field may be a useful ploy. Of course, the budgetary constraint, or perceptions thereof, impose a deficiency need that needs to be overcome through education. This has indeed been the most consistent concern in all the public deliberations induced by the NSF-stimulated process to organize the hydrologic sciences.

CONCLUSIONS AND RECOMMENDATIONS

The formation of a hydrologic science program at NSF in 1992 as part of the Geoscience Directorate was a landmark event that restored some research funding for basic water-related research, nearly a decade after the hydrology-related research program was eliminated from the Engineering Directorate. One can view this as a recognition that the research needs associated with meeting physiological water needs were perceived to have been largely satisfied and, once that was recognized, a fledgling effort was started to meet the need for understanding of the hydrologic process independent of a short-term problem focus. We are now at a point where a dramatic increase in this investment is being envisaged. It is clear that such an investment is needed. However, it is also clear that we may be headed into a fresh cycle of deficiency in the basic needs, at least in certain parts of the world, and may need to reassess how to address some critical water-related issues in the United States. A prime example here is non-point source pollution as reflected in the US EPA's Total Maximum Daily Load program that appears to be moving towards implementation of regulations without an adequate understanding of the basic mechanisms that drive the system and its long term change. Thus, support for the WTSB/National Water Initiative recommendations is also critical.

Whereas CUAHSI can provide a framework for moving a hydrologic science agenda forward through support from NSF, complemented by selected agencies, the NWI/NASULGAC interests may be best served by a parallel or different structure where federal agencies such as the US EPA, the US Bureau of Reclamation, the US Geological Survey, the National Park Service, the Bureau of Land Management, and local communities take a more direct role in developing and cooperating with University researchers to solve current community problems. The evolution of the CUAHSI agenda at scales larger than a watershed, and covering long time frames, and of a NIWR agenda focused on solving local and regional problems appears natural and complementary.

At this point, CUAHSI has worked with the Geo Directorate at the National Science Foundation in developing a proposal for "infrastructure in Hydrological Sciences." The NSF has recently issued a call for proposals for a new Global Water Cycle program expected to provide approximately $5 million per year. Thus, efforts towards improved understanding of the natural function of water appear to be bearing fruit. It is very important that these efforts be carried forth to other aspects of water research that demand leadership and understanding. If research on the interaction and feedback between humans and the landscape is left to the domain of mission agencies as hinted in the preceding paragraph, it is likely that our understanding of the actual process of evolution of water, landscape, and society will continue to be weak, and dominated by short-term analyses rather than an ability to constructively project future scenarios. The individuals and groups involved in the water community represent a remarkable diversity of intellectual agendas and expertise. An NSF program in the Engineering and Social and Decision Science Directorates that complements the Geo Directorate effort, and fosters research on the complex evolution and management of the water cycle and its related components, considering both natural and human factors, is critical for planetary sustainability. CUAHSI, NIWR and other groups need to work together to make this possibility a reality.

The responsibility for success lies with each contributor to the field, and their ability to engender mutual respect of perspectives and functions. Given the state of knowledge of the field, we are not even at a point where we can usefully argue about the relative merits of different methodological approaches for the fundamental problems of scale and interaction. Thus, it is not useful to blindly argue for statistical vs. physical or other approaches, when we wallow in ignorance, and lack a scientific epidemiology. Organizations such as CUAHSI need to develop infrastructure around the study or solution of real world puzzles, rather than debating mission vs. science-driven research. Water mixes man and nature. Both are sources of inspiration.

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