Bottlenecks: A Primer for Discussion

Background

Conservative projections, based on current information about population growth rates, pollution, salinization, waterlogging and groundwater overdraft, all indicate a high increase in the number of countries that will experience significant water stress and scarcity in the near future. The United Nations system presented a Comprehensive Assessment of the Freshwater Resources of the World to the nineteenth Special Session of the United Nations General Assembly in 1997. This assessment made it clear that a "business-as-usual" approach to water allocation and management is not sustainable. The 2002 World Summit on Sustainable Development in Johannesburg agreed on specific and time-bound goals for the alleviation of poverty, hunger and health; these goals necessitate effective water management policies and strategies.

The situation for a majority of the world's population has not improved since the Comprehensive Assessment of the Freshwater Resources of the World was presented to the United Nations in 1997. Still, over a billion people lack access to safe drinking water and almost 3 billion lack proper sanitation. Millions of people die each year from water related diseases and there are no clear indications that these trends will improve in the near future. The increased use of pollutants associated with the technological development of countries with evolving market economies, life-style changes all over the world and the increased need to develop sustainable water resources and infrastructure for growing populations all contribute to the urgency associated with advancing hydrological sciences and water management strategies. Increased competition among and within sectors calls for strategies that will help to balance water use for the multitude of purposes required by humans, while protecting the integrity of the ecosystems. Some of the statistics are staggering. By 2020, water use is expected to increase by 40 percent, and 17 percent more water will be required for food production to meet the needs of the world's growing population.

Over the last decade it has become increasingly clear that if we are to face the water challenges of the future we must view the Earth as a single, though highly complex, integrated system. The atmosphere, the hydrosphere and the biosphere extend throughout the globe. They are very dynamic and highly interactive. Changes that occur in one location can influence the environment somewhere else in ways that are not always expected and are frequently poorly understood. The complicated interactions between the physical and human systems are equally critical. The scientific and technical community has a very important role to play in this regard. This role is not only related to scientific monitoring, analysis and interpretation, but also to guiding future policies and action programs. Effective water management is not purely a political problem, a scientific problem, a technological problem, nor a managerial problem; it is a complex problem that demands interaction between all of these areas. It is clear that to assuage the impending water crisis, cooperation between the scientific disciplines, as well as the scientific and water policy arenas, must dramatically improve. A directed effort must be taken now to improve the recognition of the impending water crisis by all stakeholders and to improve the understanding of the components involved with the natural system and allocation of its resrouces.

The Hydrology 2020 group was assembled by IAHS to assess how the discipline of hydrology should evolve to meet the world water challenges that are expected to prevail by 2020. The hydrology 2020 group has identified what it feels are the most critical "bottlenecks", or barriers to the advancement of hydrological science, as well as some solutions necessary to overcome the obstacles. These bottlenecks, which are described below, have categorized into three areas:

- Organizational,
- Scientific and
- Technical.

At this juncture, the Hydrology 2020 group is soliciting input from the scientific and water policy arenas to assist in further developing the discussion of "key bottlenecks" and in finding innovative solutions to the identified problems.

1. Organizational Capacity

Water issues are complex, as water acts as a link between various water uses, land use and ecosystems. Calls are often made for integrated water resources management strategies, such as basin-wide hydrosolaridarity, which focuses on water allocation principles based on equity and efficiency. However, such concepts are still poorly defined and even more poorly understood. It is clear that effective policies are needed to strike compromises among competing water uses, to develop sustainable water resource plans, to alleviate and mitigate pollution, and to allay water-related disasters. *These policies must be driven by scientific knowledge and scientifically based recommendations, which stem from appropriately directed hydrological research and adequate funding.*

Although water quality and resource management cut across political and national boundaries, no strong and well-funded intergovernmental global hydrological organization exists that can coordinate and fund research and operational efforts within the broad range of hydrological sciences. A global hydrological intergovernmental organization is needed to serve as the authoritative scientific voice of hydrology and also to organize research efforts toward world water problems. It could have a role in facilitating integrated approaches to water development and management and offer a capacity to provide advisory services and implement and strengthen technical cooperation and investment projects targeting critical areas of water resource management. Scientific results must be translated into action-oriented recommendations so that they can be used in national and international policy evaluation, formulation, and planning. These recommendations should be formulated in terms that are clear, specific and realistic. With substantial funds and commitment, this organization could be developed anew, or the hydrology and water management sections of WMO/UNSECO and other UN agencies could be combined and expanded to meet the organizational needs of the hydrological sciences. The primary responsibilities of this global organization would include:

- Water policy. The organization would both coordinate and contribute to water policy activities, serving as the central spokes-organization for global hydrology and water management;

- Coordinated Research Management. A central focus of the organization would be to develop, fund and coordinate long-term research programs. Included in this task is the coordination of research programs that are developed by individual countries and organizations in order to most effectively tackle the existing scientific challenges.
- Testing Centers. The organization would be responsible for establishing linked testing centers/areas that scientists can use to test models and approaches, to share data/instrumentation and to train students or representatives from developing countries. The centers should work together to establish acceptable data standards, formats and calibration approaches and to coordinate long-term data acquisition, archiving, and dissemination. These centers are currently critically needed, yet are too costly to develop by individual researchers or small groups of researchers.
- Education/Outreach. The organization should establish standards and advocate public education in hydrological sciences. The organization should oversee outreach efforts to engage young and bright scientists into the discipline, and to make formal connections between the many sub-disciplines that interact with hydrology.
- Public Awareness. An important component of the organization will be to raise public awareness about the impending water crisis in a manner similar to how awareness was raised about climate change and ozone depletion issues. Greater awareness translates into more political support and more funding geared toward hydrological sciences.
- Technology Transfer and Capacity Building. The global hydrological organization would strive to strike a balance between supporting fundamental research and devoting resources toward capacity building and toward finding practical solutions to hydrological and water management problems in developing countries. In many locations, there is a current disconnect between the state-of-the-art in hydrology (represented by complex research advances) and the state-of-the-practice (the tendency to implement the developed approaches in the field). While many hydrologists in developed nations focus on issues such as resolution, uncertainty, and accuracy of advanced prediction/estimation approaches, those in less developed nations are enthusiastic about, for example, the development and dissemination of inexpensive treadle pumps that can deliver irrigation water to their crops using human (cycling) power. Thus, in addition to support of fundamental research (which will be described below), there also needs to be support and guidance for well-trained hydrologists and water managers who can focus on solving practical solutions, often in the face of incomplete fundamental theory, using currently available approaches and instrumentation.

There have been unsuccessful attempts to develop such a global organization in the past. The attempts met with resistance, not only because of protectionism among existing organizations, but because of the lack of willingness to support additional intergovernmental organizations among national funding agencies. Water issues are far too often considered to be part of national security with a strong unwillingness to open up for international cooperation. However, the current situation, typified by a lack of coordination and the duplication of efforts, is not an effective way to handle the challenges that we face. Water quality and quantity trends are not auspicious, and no clear solutions are on the horizon. We urge the hydrological sciences and water policy communities to reconsider the issue of developing a global hydrological intergovernmental organization that would serve as the authoritative scientific voice of hydrology and to organize research efforts toward world water problems.

2. Scientific Challenges

The Hydrology 2020 group has recognized many fundamental bottlenecks within hydrological sciences that must be reconciled in order for hydrology to meet the water scarcity and pollution challenges of the next few decades. These scientific bottlenecks include persistent obstacles that cut across many disciplines, such as data integration, scaling, and numerical representation of complex processes. However, some of these bottlenecks are associated with the lack of understanding of fundamental processes, systems, or cycles that are most germane to hydrologists, such as the water cycle and the vadose zone. For some problems, the theory and approaches within individual subdisciplines are quite advanced, but the links to neighboring disciplines are often not well established. The individual scientific bottlenecks are described below.

- Incomplete Understanding of Hydrological Processes

  Deficiencies in our understanding of many of the hydrological processes and systems greatly handicaps our efforts to guide water resource planning, to predict hydrologic extremes, and to predict contaminant migration. For example, as crucial as the water cycle is to human and ecosystem existence, there are still many gaps in the understanding of the individual components that comprise the water cycle, as well as the interactions between these components. Additionally, the vadose zone, which supports our agriculture, serves as the repository for most of our municipal, industrial and government wastes and contaminants, and supports our infrastructure, plays a crucial role in both the water cycle and in contaminant hydrology. In spite of its importance, the understanding and prediction of flow and transport of water and contaminants through the vadose zone and across the upper (soil-air) and lower (groundwater) boundaries are inadequate.

  Improved understanding of the hydrological processes and system components can be obtained through nested and coupled experiments replete with field measurements using several techniques, remote sensing measurements, process investigation, and modeling. Improved observations of water vapor, clouds, precipitation, evaporation, surface and subsurface runoff, groundwater, soil moisture, snow and ice using new technologies and networks collected over various spatial and temporal scales are needed to improve our understanding of the water cycle. These measurements must have enhanced resolution, increased accuracy, and be maintained for long time periods relative to the currently available data acquisition schemes. These measurements must be coupled with process studies of the individual components as well as the linkages between components over various spatiotemporal scales. The measurements and process studies must be incorporated into improved models (see below). Establishing coordinated and linked field observations with remote sensing data and modeling efforts over a variety of spatial and temporal scales is necessary for an improved understanding and prediction of water cycle, hydrological extremes, and contaminant infiltration.

Successful implementation of the nested and coupled field experiments will require advances in our approaches to modeling, data integration, and scaling. These topics are also current scientific bottlenecks, as described below.

- Modeling. Many numerical models are based on hydrological principles; these models range from flow and transport in the groundwater to global circulation models. In most cases, a combination of both incomplete theory and data exist. Because of these inadequacies, many different modeling approaches have been developed, ranging from deterministic to stochastic and from data-driven to physics-based. Modeling should continue to be a research topic, with more emphasis on uncertainty assessment, improved parameterization and data assimilation approaches, standardized validation procedures, improved frameworks for incorporating indirect data (tracers, geophysics, remote sensing, etc.) and improved numerical representation of coupled processes (such as hydrogeological-biogeochemical) and systems (such as land and atmosphere).

- Data Integration/Calibration. Various data sets, such as tracers, ground-based geophysics, and remote sensing are becoming increasingly available for use in hydrological studies. More research is needed to fully develop the potential that these tools have for assisting with hydrological problems. Many current obstacles are associated with improving the accuracy and resolution of the geophysical and remote sensing measurements. With both data types, a better understanding of data integration approaches are needed to enable routine calibration (often using data sets that are collected at different spatial scales) or to facilitate a comprehensive interpretation. With both ground-based geophysics and remote sensing data sets, we should strive to move beyond site-specific inference based on spatial patterns toward an improved understanding of the physics so that the data can be used to more generally and quantitatively estimate hydrological-climatological parameters of interest.

- Scale problems - Issues related to scale are persistent across all aspects of hydrological sciences as well as in many other disciplines. Among other topics requiring additional research include investigation of dominant processes and interactions between processes that occur at different spatial scales, and reconciling the different spatial scales associated with measurements, physical processes and numerical models.

3. Practical/Technological Issues

There are several issues where funding or commitment is the major impediment to progress rather than development of new theory. These practical/technological bottlenecks are briefly described below.

- Inexpensive access to data. Many of these obstacles have to do with acquisition of and access to data. In order to better assess and manage the world's water supplies and prevent hydrological catastrophes, free access to current hydrological data is needed, concomitant with long-term commitment to establishing and maintaining monitoring networks.
- New Sensors. New sensors are needed to obtain improved data sets. Although microsensors that are cheap, small, automated, smart, injectable and innocuous are currently being developed in engineering and biomedical fields, development of such sensors for hydrological sciences has been sluggish. On the other end of the spatial scale, satellite sensors, which have hydrological applications as the *primary* goal, should be developed. These sensors should be improved to offer higher spatial resolution over more specific spectral bands, and should have faster return periods.

- Water Database development and management. Another practical bottleneck within the hydrological community is lack of a worldwide water resources database. Water resources cannot be managed unless we know where they are, in what quantity and quality, and how variable they are likely to be in the future. Development and maintenance of a database using high quality data is crucial for assessing global water resources and proper planning for their conservation. The Global Runoff Data Center is currently establishing a data base that compiles freshwater fluxes and long term mean monthly discharges from selected monitoring stations. Databases such as this should be expanded to include complete information of all significant world aquifers that includes information about capacity, water balances, purpose, and type of runoff control and associated GIS coordinates.
- Technologies for Developing Countries. Development of small-scale technologies and approaches for dealing with (often nation-specific) water supply and sanitation issues could dramatically improve conditions in many developing countries. Although development and deployment of such technologies could be performed with minimal funds, a global commitment is needed to both identify the needs and to organize the effort.

4. Summary

The bottlenecks described above focus on organizational, scientific, and technological obstacles. We are at a point in the evolution of hydrology where many of the complex problems that exist can often only be solved with improved political and organizational support, with more funds committed over the long term to technological development, research and monitoring, and with and emphasis on coupled, cross-disciplinary, and integrated scientific approaches. The fusion of different types of information and specialists (including scientists and water policy specialists) to solve hydrological problems is perhaps a central theme of how hydrology should evolve scientifically to meet the world water challenges. Although the list of bottlenecks is extensive and the approaches towards solutions would be costly to implement, the repercussions of not attacking these obstacles now may be much more costly to future generations. *The hydrology 2020 group solicits input from the scientific and water policy communities to assist in further development of the bottlenecks discussion, and in finding innovative solutions to the identified problems.*