VII.4

Managing the Global Water System

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OUTLINE

An important new insight is that water in its various forms operates as a system on scales much larger than a single lake, river basin, aquifer, or municipality. Although the global cycling of water through the earth's physical system (ocean, atmosphere, terrestrial freshwater bodies) has long been recognized, researchers are only now uncovering a much wider net of connectivities that binds together the flow of water on a global scale. The connectivities are physical (e.g., upstream storages of water cause large-scale changes in the residence time of surface water), economic (e.g., water is embedded in food and other products and traded internationally), and even institutional (e.g., decisions about trade of water technology have a global impact). This new awareness of connectivities has spawned the concept of the "global water system." Recent research has also made it clear that the global water system is undergoing large-scale, unparalleled, and poorly understood changes that pose major risks to ecosystems and society. The policy community needs to respond immediately to these risks, and this response should take place at all levels, from local to global. At the global level, there are three main tasks to take on. First, we need to expand our knowledge base about the global water system by extending the scope of earth observations, by conducting new large-scale field experiments, and by developing new tools for the simulation of the global water system. Second, we should expand global governance of the water system through various means (as a complement to governance at the local and other levels). Options include invoking an international convention on environmental flows, instituting water labeling of products at the international level, and enforcing water efficiency standards of internationally traded products. Finally, we should challenge current assumptions about water use in the world by stimulating a public debate on the definition of "essential water needs" and by broadening the viewpoint of water professionals to include the global perspective.

GLOSSARY

teleconnection. A cause-and-effect chain that operates through several intermediate steps and leads to a linkage between two parts of a system that (to researchers at least) is unexpected or surprising.

virtual water. The volume of water that circulates in an economic system as an embedded ingredient of food and other traded products. This concept originated from the idea that arid countries compensate for water deficits by importing water-intensive commodities rather than domestically producing these commodities.

1. UNCOVERING THE WORLDWIDE CONNECTIVITY OF WATER

Although the Earth is known as the "water planet," most water researchers and managers focus on scales much smaller than the planetary. Indeed, most freshwater studies concentrate on lakes, streams, or perhaps watershed-scale hydrologic processes, and nearly all water managers concern themselves with planning the water supply in their community or perhaps river basin. Water science and management were basically local activities until "watershed thinking" revolutionized these endeavors in the 1960s and 1970s. Afterward, it became more common for water researchers and engineers to incorporate watershed-wide relationships among climate, runoff, and water use into their work.

Now we are again called on to broaden the perspectives of water science and management. The motivation comes from recent research showing that water is interconnected on a planetary level more tightly and in more ways than previously appreciated.

Table 1. Agents of change in the global water system and their impacts

Agents of change	*Environmental changes*	*Global issues* A	B	C	D	E	F	G
1. Climate change	Change in flow regime (runoff volume and timing)		•	•		•		•
	Indirect effects caused by vegetation change		•	•		•		•
	Development of nonperennial rivers		•	•	•	•	•	•
	Segmentation of river networks					•	•	
	Alteration of extreme flow events		•			•	•	•
	Changes in wetland distribution	•	•	•	•		•	•
	Changes in chemical weathering				•			•
	Changes in erosion and sedimentation				•	•		
	Saltwater intrusion in coastal groundwater	•						
	Accelerated salinization through evaporation	•	•				•	
2. Water management (including dams, diversions, and channelization)	Nutrient and carbon retention				•			•
	Retention of particulates				•	•		•
	Change in flow regime (runoff volume and timing)		•	•		•		•
	Streamflow variability and extremes		•					
	Loss of longitudinal and lateral connectivity						•	
	Creation of new wetlands	•		•	•		•	
3. Land use change	Wetland filling or draining		•	•	•		•	
	Change in sediment transport				•	•		•
	Change in vegetation cover		•					
	Alteration of first-order streams					•	•	
	Nitrate and phosphate increase	•		•	•			•
	Pesticide increase	•		•				•
4. Irrigation and water transfer	Change in flow regime (runoff volume and timing)		•	•		•		•
	Salinization through evaporation		•	•				
5. Release of industrial and mining wastes	Heavy-metal increase	•		•				
	Acidification of surface waters			•			•	
	Salinization	•		•			•	
6. Release of urban and domestic wastes	Eutrophication	•		•	•		•	•
	Development of water-borne diseases	•						
	Organic pollution	•		•			•	
	Persistent organic pollutants	•		•				•

Source: Global Water System Project: Science framework and implementation activities. 2005. http://www.gwsp.org.
A: human health, B: water cycle, C: water quality, D: carbon balance, E: fluvial morphology, F: aquatic biodiversity, G: coastal zone impacts. Only the major links between issues and impacts are listed here.

Although the existence of a global hydrologic cycle has been recognized for decades, science is now uncovering a vastly wider web of biological, biogeochemical, and even socioeconomic connectivities that bind water globally. Furthermore, we are only beginning to understand the nature of these interconnections and their implications for society and the rest of nature.

This new awareness of connectivities has spawned the concept of "global water system" (Framing Committee of the Global Water System Project, 2005). Water is considered to be a global *system* in the conventional sense of being an entity made up of components linked together and working as a unit. What are its functions? Although researchers are a long way from uncovering these and other attributes of the global water system, a first hypothesis might be that it redistributes moisture in the most thermodynamically efficient way, transports energy and materials around the world through climatologic and geologic processes, makes moisture available where it is needed by organisms, and, overall, contributes to the sustenance of life on earth. Humans are part of the system and also have their own particular goals in appropriating water

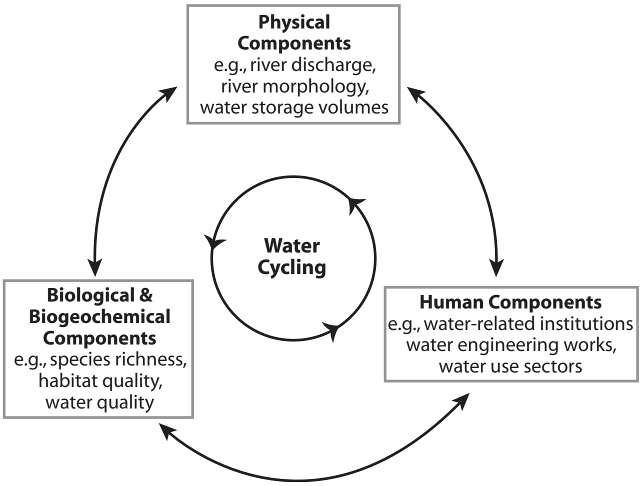

Figure 1. Components of the global water system. (From Global Water System Project of the Earth System Science Partnership. Framing Committee of the Global Water System Project. 2005. The Global Water System Project: Science Framework and Implementation Activities, Earth System Science Partnership, Global Water System Project Office, Bonn, Germany. Downloadable from http://www.gwsp.org)

from the system. It is also clear that in pursuing their goals, humans have caused a drastic transformation of the system, as described in table 1.

In this chapter, we elaborate the concept of the global water system, especially its freshwater part, and describe the components of the system as well as some key connectivities that bind it together. We then discuss the widespread transformations taking place in the system and the many uncertainties that remain about these changes. Finally, we discuss threats to water security as a type of failure of fulfilling the functions of the system and discuss the kinds of interventions that may help us to cope with these threats.

Components and Connectivities

The global water system can be understood as a structure made up of three types of components—physical, biological/biogeochemical, and human—that are linked internally and with each other through a network of connectivities or teleconnections with spatial scales of hundreds to thousands of kilometers (Framing Committee of the Global Water System Project, 2005) (figure 1). What are the major features of these components and their connectivities?

Physical Components

Decades of research in climatology and hydrology have firmly established the physical connectivities of water in a worldwide system of stocks and flows. The cycling of water in a physical sense is the most obvious part of the global water system. By far the largest stocks are the world's oceans, storing about 1.35 million km^3 of water and providing around 86% of the total continuous source of water for the atmosphere (Framing Committee of the Global Water System Project, 2005). Ice caps take a distant second place as a repository of moisture. Each year evaporation from the world's oceans combined with evaporation/transpiration from the land provide a flow of nearly 500,000 km^3 of water to the atmosphere. This volume is returned to the earth's surface as precipitation. The cycle is closed in that about 40,000 km^3 of this precipitation finds its way back to the ocean each year through rivers and subsurface watercourses.

Other physical connectivities arise from the interplay of land, atmosphere, and hydrology, which affects energy and moisture fluxes and can influence precipitation patterns over large areas. As an example, scientists hypothesize that moisture feedbacks among vegetation, soil, and the atmosphere play a key role in the persistence of both dry and wet conditions over the Sahel in Africa (Nicholson, 2000). Another well-known example is the link between deforestation of the Loess Plateau of China and changes in sediment and flow characteristics of the Yellow River for hundreds of kilometers downstream of the plateau. Uncovered soils wash off to the river, and this substantially increases the river's sediment load. Sediment settles out in the delta of the Yellow River, raises the riverbed, and thus contributes to more frequent downstream flooding.

Scientists have documented many other examples worldwide of engineering works and land use changes that have caused major changes in sedimentation and flow characteristics of rivers for very long distances downstream.

Biological and Biogeochemical Components

Water is essential for maintaining the integrity and biodiversity of both terrestrial and aquatic ecosystems. Hence, the living parts of the world's freshwater ecosystems, both aquatic and riparian organisms, are part of the global water system. Biogeochemical processes are also covered here as well as the sum of processes determining water quality in freshwater systems. Various biogeochemical connectivities occur in the global water system because water is an important medium for transporting carbon, nitrogen, phosphorus, and other elements through the earth system and serves as an important repository for these elements (Cole et al., 2007). Hence, the global biogeochemical cycles are intertwined with the global water system. Through its linkages with the carbon and other biogeochemical cycles, water helps regulate the release and sequestration of CO_2 and other radiatively important trace gases. On a global basis, the hydrologic cycle is one of the principal vehicles controlling the mobilization and transport of chemicals and other constituents from the continents to the oceans.

Human Components

The many manifestations of society's manipulation of water resources make up an essential part of the global water system. These include water engineering structures (reservoirs, canals), water-related organizations (financers of water infrastructure, water planning agencies, water companies), and water use sectors (municipal water utilities, thermal power plants). Society is not only a component of the global water system but also a major agent of change within the system (table 1).

We are only now beginning to realize the extensive connectivities that bind the socioeconomic part of the global water system together. Some linkages are formed by economic relationships, as in the case of the international flow of "virtual water" embodied in cross-boundary food trade. The basic idea of virtual water is that arid countries compensate for their water deficits by importing "virtual water" in the form of food products rather than using their own scarce water resources for growing food themselves. Because large volumes of water are needed to grow crops (e.g., cultivating 1 kg of grain requires approximately 1000 to 1500 liters, depending on location and type), it follows that the enormous international trade in foodstuffs involves a similarly huge trade in virtual water. The annual global volume of virtual water imported in food is around 1250 km^3 (Oki and Kanae, 2004), a substantial volume as compared with the global total of 2400 km^3 of water withdrawn for irrigation (Alcamo et al., 2007). On one hand, the virtual water concept can be thought of as a new variation on the old principle of competitive advantage. On the other hand, it provides new insight into how humanity mobilizes and controls a significant part of the hydrologic cycle.

Another form of socioeconomic connectivity arises between centralized organizations and worldwide development of water infrastructure. Only now are researchers beginning to uncover the sweeping influence of centralized development agencies, banks, private water companies, and other organizations on the worldwide water system. Decisions taken in a few world capitals about the structure of water pricing or the sale of water engineering are having wide-scale impacts on water use and supply (Pahl-Wostl, 2002). As the world economic system becomes ever more integrated, it should be expected that more water-related connectivities will emerge.

The System Transformed

Far from being static, the global water system is undergoing changes that are widespread, worldwide, and concurrent. In the following paragraphs, we review some of these important changes.

The *physical characteristics* of freshwater systems are undergoing a major transformation, which includes persistent changes in precipitation and hydrologic patterns, changes in runoff and the retention time of fresh water on the continents, modification of the sedimentation characteristics of rivers, and alteration of the moisture fluxes between the atmosphere and terrestrial environment (Vörösmarty et al., 2003; Meybeck, 2003). One sign of widespread changes is that the flow and storage characteristics of 172 of 292 of the largest river systems in the world have been significantly altered by impoundments (Nilsson et al., 2005).

Climate change will have an increasingly noticeable impact on freshwater systems throughout the world over the coming decades. Some semiarid and arid regions (e.g., northeastern Brazil, the western United States, southern Africa) are expected to have significantly declining average river discharge and groundwater recharge (Kundzewicz et al., 2007). As recently reported by the Intergovernmental Panel on Climate Change, more than one-sixth of humanity lives in river basins fed by snow and glacier melt, and it is expected that winter flows will temporarily increase here (relative to annual river discharge) because of warmer temperatures (Kundzewicz et al., 2007).

Although the local mechanisms of physical changes are fairly well understood, many questions remain about the global manifestation of these changes as well as their intensity. For example, what will be the combined impact of climate change as compared with continued flow diversions and impoundments on freshwater inflow to the world's estuaries?

The *biological and chemical characteristics* of freshwater systems are undergoing widespread modifications, including major alterations in dissolved oxygen levels and other important water quality parameters (Meybeck, 2003) as well as long-term changes in the flux of sediments and nutrients delivered by freshwater systems to oceans. Chemical and physical modifications of freshwater systems have constricted the habitat of aquatic organisms and severely impacted aquatic ecosystems (Naiman et al., 1995; Polunin, 2005). An example of this is the Rhine River, which has experienced more than a century of channelization and riparian development, leaving it isolated from 90% of its original floodplain. Some rivers, such as the Colorado and the Yellow rivers, often do not reach the ocean. More than 20% of freshwater fish species have become threatened, endangered, or extinct within the past few decades (Dudgeon et al., 2005).

The continent of Africa could endure particularly wide-ranging transformations of its water chemistry and biology. In the absence of specific action, recent scenarios point to a four- to eightfold increase in wastewater loadings over most of Africa within the next four decades, suggesting a likely worsening of freshwater quality (Alcamo et al., 2005). What will be the implications of these increased loadings on water chemistry and biology? What will be the spinoff effects on aquatic ecosystems and the freshwater fishery, which is an important protein source for inland African countries?

Widespread changes are also occurring in the anthropogenic use of water, with declining trends in water withdrawals in some industrialized countries and rapid increases over most river basins in the developing world (Alcamo et al., 2003, 2007). The structure of the water economy is also rapidly changing in the developing world as water use in the domestic and manufacturing sectors claims a larger and larger fraction of total water withdrawals (Alcamo et al., 2007). Furthermore, only now have scientists begun to study the underlying causes of global changes in water use, and an open question is which factor—demographic change, economic growth, technological change, consumption patterns, or other—will be most important and where (Alcamo et al., 2003, 2007). Because water abstraction is rapidly expanding, we should expect sharper competition among households, irrigated farmers, electrical utilities, and other water users. What impact will this competition have on achieving the Millennium Development goal of halving the world's population without access to sustainable water supply by 2015?

Although changes are taking place throughout the global water system, not all parts of the world will be affected to the same degree. Key questions are, where will the most important changes occur, and how much

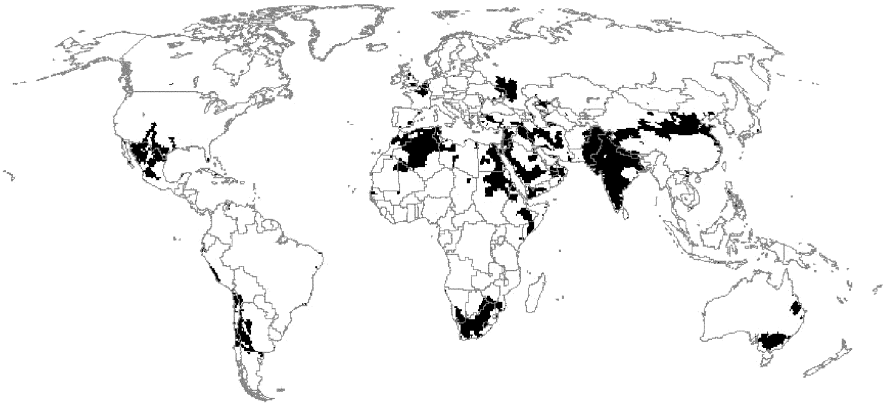

Figure 2. An example scenario of "hot spots" of increasing water stress. This map depicts (in black) the river basins where the ratio of water withdrawals increases between 1995 and 2030 because of a combination of increasing water withdrawals and decreasing water availability related to climate change. Watersheds depicted in black were already in the "severe water stress" category in 1995. This simulation is driven by the climate and socioeconomic assumptions of the "Market First" scenario of the Third Global Environmental Outlook of UNEP. (From Alcamo, J., and T. Henrichs. 2002. Critical regions: A model-based estimation of world water resources sensitive to global changes. Aquatic Sciences 64: 352–362)

of the world will be affected? According to one estimate, future "hot spot" areas with increasing abstraction and/or decreasing availability related to climate change will cover 7–13% of the world's river basin areas (Alcamo and Henrichs, 2002; figure 2).

2. INTERVENING IN THE GLOBAL WATER SYSTEM

Why Intervene at the Global Level?

We have seen that the global water system is undergoing important changes in its physical composition, its chemical and biological characteristics, and in its human dimensions. What implications do these have for water security? From the viewpoint of the global water system, water security can be seen as a long-term but temporary balance between water users and water availability or services. On one hand, water availability and quality are determined by the spatial and temporal patterns of precipitation and other meteorological phenomena, the structure of watercourses, the characteristics of the Earth's surface, and wastewater loadings. On the other hand, human water users (households, municipalities, industries, water sports enthusiasts) or nonhuman water users (aquatic and riparian organisms and their ecosystems) adjust over time to the spatial and temporal pattern of water availability or services. The system is shaken out of this temporary balance by rapid or abrupt changes in the global water system, some of which are described above. It is also made unstable by continuing pressure on the water system from water users aspiring to a higher level of water use to support a higher standard of living.

From the systems viewpoint, a breakdown in water security represents a *systems failure* in that the global water system cannot fulfill the goals of water users. The failure is most often manifested as too little water or, more precisely, a gap in many parts of the world between the water available to water users and their current aspirations or requirements. Depending on local and regional circumstances, this gap can disrupt aquatic ecosystems, cause temporary or persistent water shortages, displace current water users with those having a competitive advantage, and cause a decline in living standards or hinder their improvement.

Too much water, as in severe flooding, is also a systems failure in that a temporary but extreme state of the system poses a threat to one of its own components, namely people. (Although droughts and floods may pose a security threat to humans, they may be beneficial in some ways to aquatic ecosystems. For example, studies of river hydroecology are beginning to show that very low and very high river discharges sometimes play a key role in the life cycle of aquatic organisms.)

How can we as human agents in the global water system cope with global threats to water security? How should we intervene to address failures of the system? In reality, society acts every day through conventional water management to ensure or enhance water security at the local and river basin level. The wide palette of response options is shown in table 2.

But when is it appropriate to intervene at the global level as compared to the local or watershed level? We suppose that global action would be worthwhile in a few different cases: (1) when the driving forces of change are global in scale, as in the case of climate change impacts on water resources; (2) when changes are driven by worldwide institutions such as multinational water companies or international funding agencies; (3) when connectivities are global or large-scale in nature, as in the case of the strong feedbacks among land, atmosphere, and hydrology in the Sahel region or the large volume of virtual water that links nations together through international food trade; (4) when a threat arises to a globally important part of the system, such as an impending extinction of an aquatic or riparian species or the deterioration of vital ecosystem services; and (5) when an important change occurs concurrently throughout much of the world, as in the case of rapidly increasing water withdrawals and wastewater discharges in developing countries. Given these justifications for intervening globally, what form should these interventions take? The following paragraphs describe three clusters of action.

Intervention 1: Extending Our Knowledge Base of the System

A prerequisite for selecting the right way to intervene in the global water system is to have enough knowledge at hand to act wisely. But the reality is that the knowledge base is quite weak, and special effort should be expended in improving this base. Below, we consider three approaches: global monitoring, large field experiments, and new modeling and assessment tools. These activities should all work toward enhancing our understanding of the intensity, location, and causes of change in the water system. A particularly important task is to identify "hot spot" areas of the world of rapid change or particular sensitivity to change (see figure 2 for an example of hot spot analysis).

Expand the Scope of Remote Earth Observations of the Global Water System

The past decades have seen enormous progress in the use of satellites and aircraft in collecting data about the global environment. One effort particularly relevant to

Table 2. Response options for fresh water and related services from inland water ecosystems

Legal and *regulatory* interventions include:

- Ownership and use rights at different administrative levels
- Regulation of pollution
- Regulation of environmental flows and artificial flood releases
- Legal agreements for river basin management
- Regulations related to ecosystem and species conservation and preservation

Economic interventions include:

- Markets and trading systems for flow restoration and water quality improvements
- Payments for ecosystem rehabilitation
- Point source pollution standards and fines/fees, taxes, incentives
- Demand management through water pricing
- Payments for watershed services

Governance interventions include:

- Participatory mechanisms (e.g., watershed/catchment councils and farmer-based irrigation management systems)
- River basin organizations (international or regional scale)
- Integrated water resource management and basin planning
- Private sector participation
- Institutional capacity building (e.g., for regulatory agencies)

Technological interventions include:

- Water infrastructure projects (such as dams, dikes, water treatment and sanitation plants, desalinization)
- Soil and water conservation technologies (such as physical and vegetative measures for soil and water conservation)
- End-use and transmission efficiency options (such as drip irrigation and canal lining/ piping)
- Demand management/technologies for higher end-use efficiency (such as low-flow showerheads, energy conservation programs/ incentives)
- Research into water-saving technologies and breeding crops for drought tolerance

Social, cultural, and *educational* interventions include:

- Environmental education and awareness
- Making explicit the value of nonprovisioning water ecosystem services
- Research into land–water interactions in a watershed context

Source: Aylward, B., J. Bandyopadhyay, and J.-C. Belausteguigotia. 2005. Ecosystems and Human Well-Being: Volume 3. Policy Responses. Washington, DC: Millennium Ecosystem Assessment, Island Press, 213–255.

the global water system is the Soil Moisture and Ocean Salinity (SMOS) Mission of the European Space Agency. Beginning in 2008, SMOS will collect planetwide data on soil moisture, a key parameter of the earth's water cycle (Berger et al., 2002). Although they are very useful, the SMOS and other space-based missions tend to concentrate on the physical side of the global water system despite the urgent need for planetwide data on ecological, biogeochemical, and anthropogenic variables (e.g., spatial variation of water quality, state of aquatic ecosystems, and locations of human appropriation of water resources). Collecting these types of data will certainly pose technical challenges, but the scientific community has already shown that satellite sensors can meet the challenge. For example, satellite sensors have been used to measure changes in the spectral signature of radiance of freshwater systems, and these measurements have been used to derive various water quality parameters including temperature, turbidity, salinity, and chlorophyll concentrations (IGOS, 2004).

Conduct New Large-Scale Field Experiments and Surveys

Although remote earth observations are ideal for providing a global picture of changes in the water system, intensive field experiments are useful for providing better understanding about the details of processes and feedbacks in the system. Programs such as the "African Monsoon Multidisciplinary Analyses" (AMMA) collect vast amounts of hydrologic and climatological data by concentrating the capacity of scientists in an efficient way over a short period of time. From the perspective of global water research, AMMA-type experiments bring us further along in understanding large-scale teleconnections among land use, climate, and the hydrologic cycle. Another useful type of field campaign consists of flow manipulation experiments (as conducted on the Colorado, Snowy, and other rivers) in which experimental flows are released from dams in order to study their downstream ecological effects (Arthington et al., 2003). Data from these campaigns provide valuable new insight into the flow requirements of aquatic and riparian ecosystems. But field campaigns are needed not only by natural scientists but also by the social scientists. It is urgent to conduct planetary-scale social science surveys covering a wide range of social groups and countries. Data from these surveys are needed to improve our knowledge about human vulnerability to changes in the water system, in particular about its spatial variability and variety. This knowledge will allow researchers to better identify locations of both rapid change and vulnerable populations.

Develop and Use New Tools for Simulating the Global Water System

Collecting new data is important, but these data must also be analyzed by new types of analytical tools. A new generation of global- and continental-scale water models is required for comprehending and anticipating future changes in the global water system. To be useful for addressing policy-relevant questions, these models must be able to integrate a very wide range of global-scale information about the socioeconomic system, land use, climate, hydrology, and aquatic ecosystems. Model builders will have to team up with groups collecting data to identify the current and future "hot spots" of changes in the global water system. Because of the importance of simulating the global water system, the new generation of water models must be hooked into worldwide Internet-based "user support systems" that store key model outputs and make them widely available to researchers, policy analysts, and interest groups. New integrated assessment procedures are needed for systematically tracking the state of the global water system and computing scenarios of future changes and policy responses and especially for communicating this information to society. Perhaps the water community can gain from the experience of the Intergovernmental Panel on Climate Change, which periodically assesses and interprets the state of understanding of climate change issues in a way relevant for policymakers and other stakeholders.

Intervention 2: Expanding Governance of the System

As compared to global monitoring, field experiments, and the like, a more direct intervention would be to expand the global governance of water. "Water governance" is defined by the United Nations Development Programme as "the political, economic and social processes and institutions by which governments, civil society and the private sector make decisions about how best to use, develop and manage water resources" (UNDP, 2004). The first steps to govern water globally were already taken in 1921 with the adoption of the "Convention and Statute on the Regime of Navigable Waterways of International Concern," which prohibits states from impeding the navigation of important international waterways passing through their territory. Two years later, a convention concerning "Hydraulic Power" established guidelines for states to negotiate about hydropower projects affecting international waters. The much more recent "Convention on the Law of the Non-Navigational Uses of International Watercourses" (1997) also intervenes in international waters by urging the prevention, reduction, and control of pollution; by hindering the further introduction of alien species; and by fostering cooperation between and among states in the management of water resources.

The aim of the preceding three conventions was to influence the development and management of international watercourses. But what about the rest of the global water system? The Ramsar Convention (1971) ("Convention on Wetlands of International Importance Especially as Waterfowl Habitat") established the principle that the international community can intervene even if a particular issue does not involve international waters. Ramsar promulgated international guidelines for protecting wetlands *within the borders of countries* because these wetlands are internationally significant to "ecology, botany, zoology, limnology or hydrology." As an example of "international significance," the Convention argues that wetlands are vital to migrating waterfowl whose habitat can include many other countries outside of the wetlands locations.

As noted in the above definition, water governance can also be carried out by nonpolitical or quasipolitical institutions. Examples at the global level include the Global Water Partnership, the World Water Council, the World Water Forums, the World Conservation Union, and the World Bank. These institutions, and especially the political conventions noted above, have established the basic legitimacy of governing water on a global basis. How should we now build on this experience? Some ideas are described in the following paragraphs.

International Convention on Environmental Flows

A timely follow-up to the Ramsar Convention would be an international convention establishing universal compliance with environmental flows. Such a convention would set up international guidelines for the natural flow regimes needed for protecting or restoring aquatic ecosystems and would require that these flows be protected in undeveloped river basins and reestablished where possible in developed basins. These guidelines would have to be quite general and flexible because of the large differences between flow requirements of different ecosystems. The convention would cover both international and noninternational rivers following the precedent established by the Ramsar Convention. Rivers within country borders would be covered by the agreement because of their "international importance" in providing vital ecosystem services such as regulation of the global nutrient cycle and provision of food. Of course, such a convention could not provide full protection for aquatic biota because it would not address the physical modification of aquatic and riparian habitats or the degradation of water quality or other factors endangering ecosystems. Nevertheless, universally protecting natural flow regimes where they still exist, and restoring some semblance of these patterns where they do not, would be important steps in protecting the biological side of the global water system.

International Water Labeling

Product labeling falls somewhere between consumer protection and public education; it is used to inform consumers about the performance of a product with the aim of reducing the use of dangerous or environmentally harmful products. A prominent example regarding water is Australia's national water labeling program in which notices are placed on dishwashers and other appliances. These notices indicate the water use intensity of the appliance and whether it conforms to minimum water efficiency standards. The promoters of labeling programs believe that well-informed consumers will voluntarily seek out water-saving products. Hence, Hoekstra and others have proposed that water labeling be tried on an international basis to stimulate global water conservation (Hoekstra, 2006). Although water labeling does not exist internationally, the forest industry has established a valuable precedent that could be built on. Internationally traded wood products carry a certification label of the Forest Stewardship Council if they comply with "responsible forest management" criteria. The water community could adopt a similar approach and carry out its own "certification" of the water performance of internationally traded appliances. Alternatively, labeling could be introduced by governments through a convention of the type described above. Either way, a labeling program would require information on water use efficiency to be placed on all internationally traded products that use significant amounts of water, and this could ultimately become a powerful tool to stimulate worldwide water conservation.

International Regulation of Water Use Standards

The international community could go beyond labeling and pass a law setting a maximum permitted water use on internationally traded products. Agreement would be needed on reasonable water consumptions for different technologies, and the law would have to be updated periodically to keep pace with technological improvements in water use efficiency. Such a statute could require that major technology exports such as power plant turbines be water efficient, and this would encourage not only industrialized countries but also developing countries to use the most up-to-date water-saving equipment. Because these technologies may be costlier than their less water-efficient counterparts, measures have to be taken to avoid burdening developing countries with unfairly high compliance costs.

The Human Right to Water

Many groups and organizations are advocating an explicit international declaration of the human right to adequate water supply and sanitation. With around 1.1 billion people lacking access to safe water and 2.4 billion to basic sanitation (UNDP, 2004), it is thought that such a declaration would pressure governments to comply with Millennium Development Goal 7: "To halve, by 2015, the proportion of people without sustainable access to safe drinking water." But the international acceptance of this human right is unclear. To date, the strongest official statement is "General Comment No. 15" published in 2002 by the Committee on Economic, Social and Cultural Rights of the United Nations. This statement decrees that "the human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water, for personal and domestic uses" and makes important statements about the obligations of governments to deliver clean water and adequate sanitation to their citizens (see Committee on Economic, Social and Cultural Rights: http://www.unhchr.ch/html/menu2/6/cescr.html). Although it represents "decisive progress" on this question, General Comment No. 15 is a recommendation rather than a legal document. An unfinished task of the international community is to make an unequivocal legally binding statement about the human right to water. It is also time to think about how such a right will be enforced. A first step could be for UNESCO and UNICEF to expand their current surveys of compliance with international goals for water and sanitation to include a broader examination of government compliance with basic rights to water (WHO and UNICEF, 2004).

Intervention 3: Challenging the Goals of the System

The educator and systems theorist Donella Meadows conjectured that systems have particular "leverage points" where humans can intervene most effectively to change the system's behavior (Meadows, 1999). Furthermore, she claimed that the most sensitive of these points was challenging the goals of the system and their underlying assumptions. How does this idea apply to the global water system? What would it mean to challenge its goals? From the human standpoint, these goals are to provide humanity with adequate water for its perceived aspirations or requirements. To challenge these goals would be to ask: Do we really need the volume of water we now use and aspire to use? In the following paragraphs, we review two ways to address this basic question.

Stimulate a Public and Institutional Debate on Water Needs

Just as the many impacts of conventional energy use have stimulated a worldwide debate about how much energy we really need, so too the consequences of human abstraction of water justify a serious public and institutional debate about the volume of water sufficient for the needs of humanity and nature. The bottom line is our physical requirement for water. The United Nations High Commission on Refugees recommends a minimum allocation of 15 liters per day for each person in a refugee camp, but regards 7 liters per day as the "minimum survival allocation." Going beyond survival, the United Nations estimates 20 liters per day as a guideline for "reasonable access to water." In the "World Water Vision Scenarios," the Secretariat of the World Water Commission assumed that 40 liters per day per person was the minimum needed for basic personal and household use (Rijsberman, 2001). Another widely quoted figure is 100 liters per day per person, which Falkenmark and Lindh (1993) call a "fair level of domestic supply." Hence, the range of minimum personal needs outside of crisis situations is estimated to be around 20–100 liters per day per person. In the actual situation, the average daily water use of a sub-Saharan African is about 25 liters, which is not much above minimum personal needs. (These and other estimates of water use following in this paragraph are taken from World Resources Institute, Freshwater Resources for 2000: http://earthtrends.wri.org/pdf_library/data_tables/wat2_2005.pdf. These are water withdrawal data and are therefore somewhat larger than water requirements. To convert water withdrawals to water requirements it is necessary to subtract losses between the point of withdrawal and the point of use.) At the other extreme, the current European lifestyle requires 233 liters per person per day, and North Americans use 638 liters per person per day, a considerably higher figure than estimates of minimum personal requirements. In the face of these data, we need to seriously examine the questions, "What is an equitable level of water use, and how can this be universally achieved and complied with?" In the same way, the assumptions behind the water needs of industry and agriculture also have to be critically examined.

Reform the Education and Training of Water Researchers, Engineers, and Managers

If our aim is to make a lasting change in society's attitudes about water, we will eventually have to train a new generation of researchers, engineers, and managers to think in a new way about water. The reality is that conventional education and training tend to reinforce current assumptions about water resource development. Students learn how to design water infrastructure and to develop water management plans but much less about competition between water sectors or the global factors discussed in this chapter. An exception to this rule, called "integrated water resources management," is slowly finding its way into university curricula. This is a management approach that "integrates" many different aspects of river basin development by promoting a long-term perspective to planning, by encouraging the participation of diverse interest groups in the planning process, by reconciling the water needs of many different human users together with needs of aquatic ecosystems, and by advocating a strengthening of water use efficiency as an alternative to expansion of water supply.

Adopting integrated water resources management in the routine training of water researchers and professionals would be a major step in encouraging new thinking about water. But a further step is needed. It is just as urgent to expand university curricula in ecology, economics, hydrology, water and wastewater management, and other water-related disciplines to encompass the global perspective. The new generation of water researchers and professionals must understand that water can no longer be considered just a local or river basin issue. On the contrary, research has uncovered widespread and large-scale connectivities showing that water is also a global system. Moreover, pervasive changes going on in this system pose risks to humanity and the rest of nature that require global attention. In summation, a major task for the new generation of water specialists is to enlarge the scope of water research and management from the local, watershed, and regional levels to include the global scale.

FURTHER READING

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