HUMAN ALTERATIONS OF EARTH'S FRESH WATER: SCALE, CONSEQUENCES, AND A CALL TO ACTION

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Abstract—One of the biggest challenges society faces in this new century is figuring out how to satisfy the water demands of 8 billion people while at the same time protecting the aquatic ecosystems and ecological services that humans and all species depend upon. Since 1950, water demands worldwide have more than tripled, while the scale of our dams and reservoirs, river diversions, and groundwater exploitation have fundamentally altered hydrological systems and the ecological services they perform. On top of all these stresses, we face the added complexity of global climate change. We are going to need a fundamentally different approach if we are going to have any hope of maintaining some degree of ecological health in the face of these rising demographic and economic pressures. This paper addresses some of the goals and key policy levers necessary for wetland ecosystem restoration and protection. This paper is a transcription of Sandra Postel's plenary talk at the May 2000 Conference.

INTRODUCTION

One of the biggest challenges society faces in this new century is figuring out how to satisfy the water demands of eight billion people while at the same time protecting the aquatic ecosystems and ecological services that humans and all species depend upon. This paper explains why I think this is the case, and explores the critical role of science and scientists in helping meet this challenge.

We have an unsettling degree of uncertainty when it comes to just about all aspects of the world's water—from the natural hydrological cycle itself to the amount of water we have stored in reservoirs, to how much groundwater is stored in aquifers, to how much water humanity currently uses. Most of the numbers discussed below are best estimates rather than precise facts. There's no doubt that we need a much better scientific understanding of many aspects of freshwater. But we know enough to say unequivocally that over the last century, human activities have altered the hydrologic cycle and hydrologic regimes in unprecedented ways and on a global scale—and the costs and consequences of these impacts have just begun to come to light.

Since 1950, water demands worldwide have more than tripled. We now remove from the earth's rivers, streams, lakes, and aquifers about 4,000 cubic kilometers of water per year. Irrigated agriculture has been by far and away the biggest driver behind this rise in water use. Irrigated land worldwide has nearly tripled over the last half century, climbing from 100 million hectares to more than 270 million hectares today. Agriculture now accounts for about 70 percent of world water use, industries for about 20 percent, and cities and towns for about 10 percent.

At first glance, it might seem that at current levels of water use we're still in reasonably good shape. Our current use of 4,000 cubic kilometers represents only about 10 percent of the world's total renewable runoff—the water that annually flows back toward the sea via rivers and aquifers. But if we look more carefully at how much of that river and groundwater flow is actually accessible to us—and therefore can serve as a supply for agriculture, industry, and cities—we find that the situation isn't at all comfortable. Only about 31 percent of global runoff can be tapped where and when we can use it. And of this, we already appropriate about half to meet current human needs—which suggests that global limits are closer than we'd previously realized. The only way to increase the accessible runoff is to capture and store more flood water, which typically means constructing more dams. So we face a kind of Faustian bargain with Nature: In order to meet future human needs, it seems, we need to shift an even larger portion of the world's water from serving Nature's purposes to serving humanity's purposes. And I will come back to this dilemma.

But first, a few reality checks. If we are anywhere close to hitting global limits, we should be seeing physical signs of water stress and unsustainable uses in many freshwater systems and across fairly wide geographic regions. So let's look at what is happening.

Rivers

We have seen the number of large dams (those at least 15 meters high) climb from 5,000 in 1950 to more than 40,000 today. We have a less good count of small dams, but they number somewhere in the 800,000 range. The reservoirs behind these dams are capable of storing nearly 20 percent of total annual global runoff, and as is often the case, this global figure masks great variation and extremes among individual river systems. Lake Nassar, behind Egypt's Aswan Dam, is able to fully store two years worth of the Nile's flow, for example.

Recent surveys suggest that nearly 60 percent of the world's largest 237 rivers are moderately to strongly fragmented by

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dams and diversions. Perhaps more dramatically, we're now seeing that many major rivers are tapped out during the dry season, with virtually no freshwater reaching the sea for months at a time. These include five of Asia's great rivers—the Ganges and Indus Rivers in South Asia, the Amu Darya and Syr Darya Rivers in Central Asia, and the Yellow River in China. The Yellow River first ran dry in 1972. But the situation has worsened greatly over the last 15 years. I remember traveling by train in China in 1988, and awakening early so as not to miss crossing the Yellow River, and being stunned by how little water this great river—the cradle of Chinese civilization-was actually carrying. In 1997 the Yellow ran dry for a record 226 days. Closer to home, the Colorado River doesn't reach the sea at all in an average year, and that's been true more or less since completion of Glen Canyon Dam in the early 1960s.

Groundwater

Groundwater, which forms the base flow of rivers, has come under heavy pressure in the last 50 years as well. Prior to WWII, we just didn't have the technical capabilities of pumping groundwater on a vast scale. But with the advent of powerful pumps and deep drilling technologies, farmers and other water users began to tap groundwater on a historically unprecedented scale. In India, the number of groundwater wells climbed from 4 million in 1951 to 17 million in 1997. In China, the number of irrigation wells has climbed 20-fold over the last three decades. Here in the US, farmers drilled millions of wells into the Ogallala Aquifer—one of the planet's greatest underground water reserves, and which now waters 20 percent of U.S. irrigated land.

The problem is that much of this groundwater use is not sustainable. In just about every area of intensive groundwater-based agriculture, water tables are dropping steadily because pumping exceeds recharge. This is the case in the Punjab of India, the north plain of China, the U.S. Great Plains, California's Central Valley, and much of North Africa and the Middle East. This is a big red flag for future food security, since as much as 5-10 percent of the world's food production may now depend on the overpumping of groundwater. And it's also a great ecological threat as the lowering of water tables dries up springs and wetlands—and, in some cases, turns perennial rivers into seasonal ones by eliminating their base flow.

Together, the scale of our dams and reservoirs, river diversions, and groundwater exploitation have fundamentally altered hydrological systems and the ecological services they perform. It's estimated that half of the world's wetlands have been lost during the 20th century—in part due to direct conversion to agricultural and urban land uses, but also due to the cutting off of rivers from their flood plains and their deltas, and to the overpumping of groundwater.

In many countries, 10-30 percent of freshwater fish are now threatened with extinction. Here in the United States, The Nature Conservancy reports that 38 percent of freshwater fish are at risk, along with 69 percent of freshwater mussels, and 51 percent of crayfish. The U.S. ranks first in the world in the number of known species of freshwater mussels and crayfish and 7th in the number of known freshwater fish species. Freshwater species are proportionately at greater risk than others, and the principal reason for their imperilment is the destruction and degradation of aquatic habitats.

We could, if we had time, run down a long list of aquatic ecosystems on every continent that are in states of rapid decline—from the most dramatic case of the Aral Sea in central Asia, which used to be the world's fourth largest lake, to the Everglades of south Florida, the Danube Delta of Europe, the Ganges and Indus deltas of south Asia, to entire river systems like the Colorado, the Missouri, the Nile, and the Rhine.

On top of all these stresses, we face the added complexity of global climate change. The patterns of river runoff we have measured during the 20th century will almost certainly not be good guides for our planning in the 21st century. Rainfall patterns are expected to shift and droughts and floods to intensify. Many of the world's major rivers are fed by mountain snowpacks, which are fantastic natural reservoirs. They store water through the winter and release it during the spring and summer. As temperatures warm, more of that winter precipitation will fall as rain rather than snow, and the snowpack will melt earlier and faster. In many places, this will mean more intense flooding in the early spring and lower flows during the summer, when water demands are highest.

So we have a large backlog of water problems to confront, even as pressures on water systems continue to increase. Just to supply the food demands of 2025, we could need to find an additional 800 cubic kilometers of irrigation water - a volume nearly equal to the annual flow of ten Nile Rivers.

So I return to our Faustian bargain: We can continue to extract more water from Nature in order to meet rising water demands, but in doing so we place in jeopardy the survival of major pieces of the aquatic world, pieces we depend on for a host of ecological services worth—no one knows how much—but almost certainly in the hundreds of billions if not trillions of dollars annually.

I would submit that there is no winning scenario we can create out of these current trends in water use and management. We are going to need a fundamentally different approach if we are going to have any hope of maintaining some degree of ecological health in the face of these rising demographic and economic pressures.

What are some of the big priorities?

First, I believe we need a multi-disciplinary and cross-professional effort to systematically determine the quantity, quality, and timing of flows needed for freshwater ecosystems to sustain their critical functions. Without an effort such as this, no country or region can answer such basic questions as: how much water is available to meet human needs in a sustainable fashion? Or, how must dams be operated in order to sustain critical ecosystem functions and to protect biodiversity? This initiative would have to be scientifically credible but policy-focussed-that is, produce a strategy that can be implemented. South Africa is the only country I know of that has adopted this kind of goal as a matter of national policy. South Africa's new water policy states that, "The quantity, quality, and reliability of water required to maintain the ecological functions on which humans depend should be reserved so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems.” Many of the aquatic scientists in South Africa are now involved in the effort to determine these “environmental water reserves” in some way. Of course it remains to be seen how effectively this policy will be carried out.

Another bold step has been taken in Australia’s Murray-Darling river basin, where the Commission has placed a Cap on total water extractions from the basin. The rationale here is simply that the river system has already sustained too much ecological harm, and so no additional water diversions should take place. New demands for water in the region are to be met through conservation and water trading rather than by increasing the supply.

Here in the United States, we have had several calls for major initiatives to generate the knowledge-base needed for sound freshwater management and protection of ecosystems. Bob Naiman, Diane McKnight, Jim Karr and others wrote eloquently of the need for a national initiative of this sort in an article in Science in 1995. These and other researchers have written extensively about the geomorphic, hydrologic, and biological parameters that would form the core of this knowledge base for freshwater ecosystem protection and restoration.

I think the time is right to push harder for an initiative such as this, because much has changed in the last five years. When the Edwards Dam on the Kennebec River in Maine was demolished in the summer of 1999, it was a very public symbol and signal—and Secretary Babbitt said this—that dams are not forever. The idea that we’d be having a serious discussion about breaching major dams in the Columbia River basin—four on the lower Snake—would probably have seemed outlandish even 5-10 years ago.

These debates signal a major shift in public attitudes that provides new opportunities. Many more small dams will likely come down over the next few decades, but probably more important is the possibility of rethinking the operation of dams that will remain standing. To what degree can we mimic a river’s natural hydrograph and still meet a portion of the economic uses for which a given dam was built? What will be the ecological benefits of doing this? Marginal tradeoffs like this will be made, and these collectively may be more important than the big-ticket items like a few big dams coming down.

What are the key policy levers for ecosystem restoration and protection that we’re likely to see greater use of?

- FERC relicensing: of private hydro dams (e.g., Edwards Dam)
- Endangered Species Act—which, if invoked in its full force, would dramatically alter water use and river management nationwide.
- Instream flow requirements—On a case by case basis, these are beginning to get clarified. Judges are making decisions about what “impairment” of a river system means in order to determine what uses and extractions of the river are reasonable and acceptable. This is not just happening in the West, but in the East as well. Very interesting case of the Shepaug River in western Connecticut decided in February 2000.
- Public Trust Doctrine—applied in a historically new and much broader way in the case involving Mono Lake in California. It is not yet clear whether this will be a precedent for broader applications.

Unless we have the knowledge base to assist in these legal, regulatory, and management debates, and are able and willing to translate that knowledge base to policymakers and water managers, we will miss big opportunities for conservation and restoration of aquatic ecosystems.

Second, we need an all-out effort in every sector of the economy to raise water productivity. We simply cannot hope to achieve our ecosystem protection and restoration goals if we do not promote more efficient use of water. I believe that with an all-out effort to promote more efficient and equitable use of water worldwide, we could satisfy year-2025 water demands without extracting much more water from the natural environment than we do today. That’s an exciting prospect-but we’re a long way from getting there.

I once heard it said that “Technology is Nature’s experiment with Man.” We need to get smarter about the technologies we employ and how we employ them—whether it’s how we control floods, how we irrigate our crops, or how we operate our dams.

To do this we need to build new research and management partnerships, especially ones that bridge ecology, engineering, and economics. Some of the best attempts I’ve seen to evaluate ecosystem services have been done through interdisciplinary and/or cross-professional collaborations. We need more efforts not just to think out of our box, but to come out of our box. Even applied science is not getting used in making good policy and management decisions because too few scientists are bridging the divide to the policy world.

Finally, I also believe that, as scientists and citizens, we can contribute more to the resolution of our water problems by advocating more forcefully for the adoption of a guiding water ethic in society. The fact that water is the basis of life lends an ethical dimension to every decision that’s made about how to use and manage it. Especially in the face of scientific uncertainty and potentially irreversible change, appealing to an ethic of protection and preservation of freshwater ecosystems can be both justified and compelling.

Eleanor Roosevelt once said, “We should constantly be reminded of what we owe in return for what we have.” I would submit that what we have is more knowledge about the health of our aquatic ecosystems and the threats to them than the vast majority of people on the planet, and that what we owe to society in return is the expression of our best judgement—not perfect judgement, but best judgement—of how to preserve and protect these critical ecological assets.