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Saving Earth's Rivers

The preservation of ecosystem health must become an explicit goal of water development and management.

The odds do not look good for the future of the planet's rivers. As populations and economies grow against a finite supply of water, many previously untapped rivers are being targeted for new dams and diversions, and already-developed rivers are coming under increased pressure. A number of major rivers, including the Colorado, the Indus, and the Yellow, are already so overtapped that they dry up before reaching the sea. Meanwhile, India is proposing to link all 37 of its major rivers in a massive water supply scheme, Spain plans to build 120 dams in the Ebro River basin, and China intends to transfer water from the Yangtze River north to the overstressed Yellow River basin. In the United States, a project has been proposed in Colorado in which a pipeline would capture Colorado River water at the state's western boundary and move it eastward across the Continental Divide to the growing metropolitan areas of the Colorado Front Range.

These proposed projects will almost certainly add to the ledger of ecological damage already wrought on the planet's rivers. Dams and diversions now alter the timing and volume of river flows on a wide geographic scale. According to Carmen Revenga and colleagues at the World Resources Institute, dams, diversions, or other infrastructure have fragmented 60 percent of the 227 largest rivers. Most of the rivers of Europe, Japan, the United States, and other industrialized regions are now controlled more by humans than by nature. Rather than flowing to the rhythms of the hydrologic cycle, they are turned on and off like elaborate plumbing works.

During recent decades, scientists have amassed considerable evidence that a river's natural flow regime—its variable pattern of high and low flows throughout the year as well as across many years—exerts great influence on river health. Each aspect of a river's flow pattern performs valuable work for the system as a whole (see table). For example, flood flows cue fish to spawn and trigger certain insects to begin a new phase of their life cycle; very low flows may be critical to the recruitment of riverside or riparian vegetation. When humans alter these natural patterns to supply growing cities and farms with water, generate electricity, facilitate river-based navigation, and protect expanding settlements from

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floods, the vitality and productivity of river ecosystems can become seriously degraded.

Societies have reaped substantial economic rewards from these modifications to rivers. However, because inadequate attention has been paid to the ecological side effects of this development, society has lost a great deal as well. In their natural state, healthy rivers perform myriad ecosystem services, such as purifying water, moderating floods and droughts, and maintaining habitat for fisheries, birds, and wildlife. They connect the continental interiors with the coasts, bringing sediment to deltas and coastal beaches, delivering nutrients to fish habitats, and maintaining salinity balances that sustain productive estuaries. From source to sea and from channel to floodplain, river ecosystems gather, store, and move snowmelt and rainwater in synchrony with nature's cycles. The diversity and abundance of life in running waters reflect millions of years of evolution and adaptation to these natural rhythms.

In little more than a century, human societies have so altered rivers that they are no longer adequately performing many of their evolutionary roles or delivering many of the ecological services on which human economies have come to depend. Just as each river has a unique flow signature, each will have a different response to human disruptions of its flow regime. But in nearly every case the result will be a loss of ecological integrity and a decline in river health. In addition to harming the ecosystems themselves, these transformations also destroy many of the valuable goods and services on which people and economies rely.

The construction of Egypt's High Dam at Aswan during the 1960s, for example, greatly altered the habitat and diversity of life in the northern extent of the Nile River. Of the 47 commercial fish species in the Nile before the dam's construction, only 17 were still harvested a decade after the dam's completion. Similarly, fisheries declined dramatically after completion in 1994 of the Pak Mun Dam on Thailand's Mun River, a large tributary of the Mekong. Globally, the World Conservation Union estimates that 20 percent of the world's 10,000 freshwater fish species are at risk of extinction or are already extinct. According to Bruce Stein and colleagues at NatureServe (a biodiversity information organization), 37 percent of freshwater fish species in the United States are to some degree at risk of extinction, as are 69 percent of freshwater mussel species.

For too long, government officials and water planners have allowed water development to proceed until the river flows and the life they support are severely compromised. The historical view of water development that has dominated up to the present time considers freshwater ecosystems to be resources that should be exploited for the growth of the human economy. Because the health of ecosystems themselves and the natural services they provide is not an explicit goal in this mindset, nature's water needs go unrecognized and unspecified. For a period of time, this approach appears to work: Economies reap the rewards of additional irrigation, hydropower, and other human water uses, while the residual is still sufficient to sustain natural ecosystem functions to a reasonable degree. Over time, however, as human pressures on water systems increase, the share of water devoted to ecosystem functions declines to damaging levels. In much of the world, nature's residual slice of the water pie becomes insufficient to keep ecosystems functioning and to sustain freshwater life.

It's time for a shift to a new mindset, one that makes the preservation of ecosystem health an explicit goal of water development and management. It would recognize that the human water economy is a subset of the one provided by nature and that human societies depend on and receive valuable benefits from healthy ecosystems. To preserve these benefits, society needs to make what we call an "ecosystem service allocation": a designation of the quantity, quality, and timing of flows needed to safeguard the health and functioning of river systems. This allocation implies a limit on the degree to which society can wisely alter natural river flows. Rather than freshwater ecosystems receiving whatever water happens to be left over after human demands are met—an ever-shrinking residual piece of the pie—they receive what they need to remain healthy. Modification of river flows for economic purposes could expand over time, but only up to the sustainability boundary defined by the flows allocated for ecosystem support.

Contrary to initial appearances, this limit on river alterations would not be a barrier to economic advancement but rather a necessary ingredient for sustainable development. Once human water extractions and flow modifications have reached the limit in any river basin or watershed, new water demands would be met not by further river manipulation but by raising water productivity—deriving more benefit out of the water already appropriated for human purposes—and by sharing water more equitably. In this way, establishing an ecosystem service allocation would unleash the potential for conservation, recycling, and efficiency to help society garner maximum value from rivers, including in-stream and extractive benefits.

Translating an ecological mindset for river management into tangible policies and practices will not be easy.

In the Murray-Darling river basin in Australia, for example, water officials have capped withdrawals in an attempt to arrest the severe decline in the river's ecological health. This cap on future water extractions provided a much-sought degree of certainty that existing rights to water use would be protected from future impingement and helped ensure that existing rights holders would enjoy their full allotment more of the time. Further, the cap is expected to create a strong incentive to improve water use efficiency and to raise water productivity (the value derived per cubic meter of water extracted). In fact, one study by the Australian Academy of Technological Sciences and Engineering and the Institution of Engineers in Australia projects a doubling of the size of the Murray-Darling basin economy over 25 years with the cap and water reforms in place.

Developing tangible policies.

Translating this ecological mindset for river management into tangible policies and management practices will not be easy. The challenge of managing rivers for ecological sustainability will require concerted action on two fronts. First, many more scientists must be enlisted in the task of defining the quantity, quality, and timing of water flows needed to protect river health, so that a sound foundation for decisionmaking is developed. Second, appropriate water policy tools and governance structures must be instituted to manage human demands for water within the scientifically defined sustainability boundaries.

The scientific knowledge and tools for determining river flow conditions necessary to protect ecosystem health have advanced rapidly in recent years. Although such analyses once focused only on protecting minimum flow levels intended to keep rivers from going completely dry, scientists now understand the need to prescribe a full spectrum of flow conditions to sustain ecosystem health, ranging from normal low-flow levels to frequently recurring high-flow pulses and even occasional floods. Once dominated by fish biologists, assessments of river flow needs have become highly interdisciplinary, involving specialists in riparian and estuarine ecology, water quality, hydrology, and fluvial geomorphology, as well as fish biology.

The ecological knowledge and scientific methods used in assessing water management activities will likely continue to mature swiftly as societal demand for river protection or restoration grows, creating opportunities for river scientists to practice their trade in a growing number of places. A number of regulatory mandates or policy decisions are forcing changes in water management activities that will require scientific input. For example, at least 177 hydropower dams in the United States are scheduled for relicensing by the Federal Energy Regulatory Commission by 2010, providing opportunity to negotiate new license conditions that improve ecological conditions in the affected rivers.

The formulation and adoption of scientific recommendations remain problematic in many instances, however, as is made clear by the heated debates about scientific uncertainty in the Klamath River basin in Oregon. In recent years, a number of scientific analyses of the water needed to protect endangered salmon runs and other aquatic species in the Klamath basin have been debated by scientists, conservationists, governmental water agencies, and farming interests.

A number of daunting challenges commonly arise in the process of developing flow recommendations for rivers, including (1) the difficulty of translating ecological knowledge into a clear quantitative flow recommendation that can be implemented by water managers; (2) the tendency for uncertainties and data gaps to paralyze scientific deliberations; (3) a bias toward allocating water to activities with well-defined economic benefits, which causes many ecosystem services to be ignored or discounted in decisionmaking; (4) inadequate time frames or funding available for conducting assessments; (5) the lack of a clear process or timeline for implementing flow recommendations, which can dissuade many scientists from contributing the necessary time and effort to the process; and (6) an aversion on the part of scientists to offering quantitative recommendations if opportunities for improving them in the future are ill-defined.

Flow restoration efforts are planned, underway, or have been completed on more than 350 rivers globally.

Fortunately, these obstacles are being surmounted with increasing frequency. Despite highly publicized conflicts such as that over the Klamath, many reform projects are quietly moving forward. A Flow Restoration Database compiled by the Nature Conservancy lists more than 350 rivers globally for which flow restoration efforts are planned, under way, or completed.

One such place is the Savannah River, which forms the border between South Carolina and Georgia. Flow alterations from upstream dams have affected fish populations and severely limited the reproduction of bottomland hardwood trees in the river's floodplain. More than 40 scientists from 20 state and federal agencies, academic institutions, and conservation organizations have been working collaboratively to develop flow recommendations to restore the river and floodplain ecosystem and estuary. Sponsored by the U.S. Army Corps of Engineers and natural resource agencies in the two states, the scientists in 2003 prepared a set of quantified flow recommendations that will form the basis of an adaptive flow-restoration program. The Corps is currently examining the feasibility of implementing the recommendations while meeting as many other demands for the river's water as possible, and hopes to begin pilot-testing some of the recommendations as early as spring 2004. The inclusive and collaborative nature of the scientific process being employed on the Savannah River has garnered broad stakeholder support and enabled the Corps to address the water needs of the ecosystems along with other human demands as part of a comprehensive river basin planning process for the river. By identifying key aspects of the flow recommendations that can be implemented without contention from existing water users, flow restoration can begin and scientists can start to document the recovery of the ecosystem.

Another example from the Green River in Kentucky has demonstrated that significant movement toward ecological sustainability can sometimes be attained in just a few years. The Corps is working with conservationists and scientists to modify its dam operations on the Green River for ecological benefit. The Green River Dam, built in 1969, has been managed for two primary purposes: flood control and reservoir-based recreation. During the summer, the Corps maintained a high lake level behind the dam to maximize recreational benefits. Then, at the end of the summer season, the Corps would rapidly lower the lake level to provide storage capacity for controlling winter floods. As the lake level was being lowered, the rapid release of water from the dam would wreak havoc on the downstream river environment. River creatures adapted to the river's naturally low and slow water levels in the fall season would get hit with an artificial flood. Discussions of these ecological problems began in 2000, and the Corps has already begun implementing a new operational plan for the dam that continues to support its original operating purposes while returning the river's flow to a close semblance of its natural variability. Under a new Sustainable Rivers Project with the Nature Conservancy, the Corps' leadership is now promoting similar flow restoration efforts at many other places in its portfolio of more than 630 dams.

Sweeping changes needed

Although these two examples demonstrate that important progress can be made through cooperative alliances between water managers, conservationists, and scientists, sweeping changes in existing water policies are needed to foster such activity on the thousands of other rivers needing such restoration or protection. Specifically, such policies need to allocate

Ecological Functions Performed by Different River Flow Levels

Flow Component	Ecological Roles
Low (base) flows	**Normal level:** • Provide adequate habitat space for aquatic organisms • Maintain suitable water temperatures, dissolved oxygen, and water chemistry • Maintain water table levels in the floodplain and soil moisture for plants • Provide drinking water for terrestrial animals • Keep fish and amphibian eggs suspended • Enable fish to move to feeding and spawning areas • Support hyporheic organisms (those living in saturated sediments) **Drought level:** • Enable recruitment of certain floodplain plants • Purge invasive introduced species from aquatic and riparian communities • Concentrate prey into limited areas to benefit predators
High pulse flows	• Shape physical character of river channel, including pools and riffles • Determine size of stream bed substrates (sand, gravel, and cobble) • Prevent riparian vegetation from encroaching into channel • Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants • Aerate eggs in spawning gravels and prevent siltation • Maintain suitable salinity conditions in estuaries
Large floods	• Provide migration and spawning cues for fish • Trigger new phase in life cycle (e.g., in insects) • Enable fish to spawn on floodplain, provide nursery area for juvenile fish • Provide new feeding opportunities for fish and waterfowl • Recharge floodplain water table • Maintain diversity in floodplain forest types through prolonged inundation (different plant species have different tolerances) • Control distribution and abundance of plants on floodplain • Deposit nutrients on floodplain • Maintain balance of species in aquatic and riparian communities • Create sites for recruitment of colonizing plants • Shape physical habitats of floodplain • Deposit gravel and cobbles in spawning areas • Flush organic materials (food) and woody debris (habitat structures) into channel • Purge invasive introduced species from aquatic and riparian communities • Disburse seeds and fruits of riparian plants • Drive lateral movement of river channel, forming new habitats (secondary channels and oxbow lakes) • Provide plant seedlings with prolonged access to soil moisture

Source: Sandra Postel and Brian Richter, *Rivers for Life: Managing Water for People and Nature* (Island Press, 2003).

to river ecosystems an adequate supply of water to sustain their long-term health and productivity. We can cite two examples of progressive water policy—one at the state and one at the national level—that set appropriate limits on human alterations of river flows and that foster scientific assessment of sustainability boundaries.

South Africa's 1998 National Water Act is a landmark in international water policy. It integrates public trust principles, recognition of ecosystem service values, and scientific understanding of ecosystem water needs in a way that could revolutionize that society's relationship with rivers. Specifically, the law establishes a two-part water allocation system known as the Reserve. The first part is a nonnegotiable allocation to meet the basic water needs of all South Africans for drinking, cooking, sanitation, and other essential purposes. The second part is an allocation of water to ecosystems to sustain their health and functioning in order to conserve biodiversity and to secure the valuable ecosystem services they provide to society. Specifically, the act says, "the quantity, quality, and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that the human use of water does not individually or cumulatively compromise the long-term sustainability of aquatic and associated ecosystems."

The water determined to constitute this two-part Reserve has priority over all other uses, and only this water is guaranteed as a right. The use of water for purposes outside the reserve, including, for instance, irrigation and industrial uses, has lower priority and is subject to authorization. One year after the law's enactment, the government issued guidelines describing in detail how the Reserve should be determined. Many of the river scientists in South Africa are now engaged in quantifying the flow allocations that will constitute the ecological component of the Reserve in each major watershed.

In the United States, most states have the ability to grant, deny, and set conditions on permissions to extract water from state water bodies, giving them substantial potential to protect river flows. To be used effectively, however, state permitting programs must be directly keyed to the maintenance of ecological flow regimes, so that that the sum of all flow modifications in a river does not exceed the threshold defined for that place and time. The Florida Water Act, passed in 1972, provides for such protection through its mandate to set "minimum flows and levels" to protect ecological health in each river basin in the state. A "percent-of-flow-approach," adopted by one of the state's five water management districts, illustrates a mechanism for setting and protecting a sustainability boundary. In 1989, the Southwest Florida Water Management District began limiting direct withdrawals from undammed rivers to a percentage of the natural streamflow at the time of withdrawal. For example, cumulative withdrawals from the Peace and Alafia Rivers are limited to 10 percent of the daily flow; during periods of very low flow, withdrawals are prohibited completely. The district is now using percentage withdrawal limits that vary with seasons and flow ranges in order to better protect the ecological health of rivers under its jurisdiction.

Importantly, this mechanism preserves the natural flow regime of rivers by linking water withdrawals to a percentage of flow, specifically by ensuring that a major percentage of the natural flow is protected every day. If a new permit application would cause total withdrawals to exceed the threshold, denial of the permit is recommended unless the applicant can demonstrate that the additional withdrawals will not cause adverse ecological effects. This provision allows for flexibility but places the burden of proof on potential water users to show that their withdrawals would not harm the ecosystem.

Can we save Earth's rivers? These examples of applied river science and progressive policy demonstrate that it is possible. But it will still require many countries to make a dramatic departure from the destructive path they are on.