Freshwater Ecosystems and Their Management: A National Initiative

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Fresh water is a strategic resource that structures the nation's natural and cultural landscapes and is a major determinant of regional economies and demographic patterns. Water consumption in the United States has more than doubled since 1940 and is likely to double again within the next 20 years (*1–3*). Critical water-related challenges now face the nation regarding availability, human health and safety, and environmental integrity. These challenges persist despite numerous federal laws (such as the Clean Water Act, Safe Drinking Water Act, Endangered Species Act, Forest Practices Act, and National Environmental Policy Act) and state provisions regarding surface water, ground water, and water rights.

Collectively, these laws and their implementing regulations have created a legislative and judicial pastiche that does not allow the integration necessary to resolve issues related to fresh water. The Clean Water Act, for example, has been the foundation for water quality programs nationwide since 1972. In many ways it has been successful: Sewage treatment and drinking water supplies have improved, and severely polluted systems such as the Cuyahoga River and Lake Erie show signs of renewed vitality. But the Clean Water Act's focus on point-source pollution shifted emphasis away from other equally harmful and pervasive forms of environmental degradation, such as altered hydrological regimes, habitat destruction, invasions by exotic species, and nonpoint-source pollution (*4, 5*). In addition, the Clean Water Act failed to provide a framework for identifying research priorities, making decisions, or directing broader statutory attention. Similar problems exist with other legislation; each law does some good but also shifts attention away from competing or broader issues. No one law provides a comprehensive approach.

These concerns are exemplified in current discussions about reauthorization of the Clean Water Act and the Endangered Species Act. The nation would benefit if these discussions were centered on how to improve protection and restoration of water resources and aquatic species, and how to integrate human needs with protection and rehabilitation. Instead, the discussions are more ideological than factual. The Clean Water Act Amendments of 1995 (H.R. 961) reverse many of the advances made since 1972 by providing pollution waivers to industries, decreasing wetland protection and sewage treatment, loosening rules against contaminated runoff, and compensating landowners not to harm public resources. If we are to develop a workable plan for fresh waters, decisions must be based on an understanding of freshwater ecosystems and on more effective and comprehensive laws and policies.

Scientists, managers, and politicians are routinely called on to address competing demands on freshwater supplies and ecosystems, but they are increasingly unable to respond at scales commensurate with the issues. Why? Policy development and management activities are frequently undertaken without an adequate empirical foundation; inappropriately short-term, single-focus approaches are accepted with little question; human-caused change is often difficult to distinguish from natural variation; and even when relevant data are available to guide decision making, the legal and regulatory framework is inadequate (*6, 7*). Consequently, the criteria for effective management and policy decisions are ambiguous at a time when degradation of water supplies and aquatic resources is accelerating.

Meeting human needs for the goods and services provided by freshwater systems can be accomplished only if the people of the United States improve the local, state, and federal institutions charged with understanding, protecting, and managing fresh waters. Collectively, the institutions must be able to predict the consequences of human actions on the aquatic resources, provide an integrated socioenvironmental perspective, and respond to present and emerging issues through education and research.

Research Priorities

Given the complexity of the challenge and the inherent institutional constraints, scientists and managers recently identified six freshwater priorities on the basis of scientific significance, sociopolitical relevance, and the needs of decision makers (*8*).

Ecological restoration and rehabilitation. To recognize human-induced degradation and to guide effective restoration and rehabilitation, we must understand how natural systems—from molecular to watershed scales—operate. Even though many rehabilitation activities are under way, in most cases the approaches do not allow for learning by adaptive management (*9*). Restoration and rehabilitation are a high priority because, whatever the advances generated by the Clean Water Act and related legislation have been, water quality does not meet current standards in one-third of the nation's freshwater ecosystems. The actual proportion is closer to two-thirds if more comprehensive biological criteria are used. The reported proportions of substandard water quality also vary among freshwater environments assessed: one-third for rivers, >50% for lakes, 98% for Great Lakes shorelines, and 44% for estuaries (*5, 10*). In addition, commercial fish harvests have declined drastically, fish consumption advisories occur in at least 45 states each year, and many aquatic species are threatened with extinction (*4–6, 8*). Most of the nation's freshwater systems are best characterized as ecologically impoverished (*5, 10*).

Maintaining biodiversity. The goal of maintaining biodiversity includes not only individual species but also the diversity of ecological processes and the integrity of ecological systems. Understanding relations between species and ecological processes as well as the consequences of exotic invasions (for example, the zebra mussel and the stocking of game fish) is fundamental. The nation's capacity to address this area is rapidly declining: Fewer systematists are being trained, and opportunities for applying molecular techniques to species identification remain limited. In the United States, the proportion of freshwater biota classed as rare or in danger of extinction ranges from 34% for fish to 65% for crayfishes and 75% for unionid mussels. Of 214 stocks of Pacific salmon, 74% face a high or moderate risk of extinction. Despite massive expenditures to improve water quality, none of the 251 fishes listed as rare in 1979 was removed from the list in 1989 because of successful recovery efforts (*11*). Less conspicuous species languish in obscurity; for example, only about 30% of commonly collected immature forms of aquatic insects are readily identifiable (*8*).

Modified hydrological flow patterns. With the exception of Alaska, the hydrological regime in virtually every body of fresh water in the United States has been modified to some extent by dams, diversions, and with-

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drawals (*2*, *12*). Hydrological changes have greatly modified conditions for riparian and aquatic organisms in major ways: Habitats for organisms adapted to natural discharge and water level patterns are reduced, rivers are much less able to serve as migratory and material transport corridors, and riparian zones no longer serve as filters between upland and aquatic systems (*2*, *12*).

Ecosystem goods and services. Modifications have severely altered the resources provided by freshwater ecosystems: water quantity and quality, biological productivity and other living functions, and aesthetics and recreation. Improved understanding of the environmental factors responsible for these benefits and their values—including the costs associated with their loss—is necessary for responsible management.

Predictive management. Three types of uncertainty—"noise," unknown but potentially knowable states of nature, and surprises (*13*)—frustrate ecologists and managers because they perpetuate resource management failures. Data are needed on disturbance regimes and their physical and biological legacies if we are to predict the consequences of cumulative and synergistic impacts.

Solving future problems. Many pressing issues associated with fresh waters are unsolvable at present, yet they promise to become increasingly complex, contentious, and strategic for the United States as demographic patterns, resource consumption, environmental quality, social and institutional organization, and technologies change. Large interdisciplinary programs as well as single investigator–initiated basic research have proven their worth as investments in detecting and solving unforeseen problems (*6*, *8*). We must ensure that basic science and education can provide the framework for meeting emerging water-related challenges.

Achieving Coordination

Research priorities can only be useful if they are effectively coupled to management and policy. How can that complex link be forged? An effective national water policy requires the coordination of the individuals and institutions that plan research and management programs; this could be accomplished through either a strengthened National Biological Service or a central science office. Coordination on a national scale, however, should be integrated with regional needs. The regional level is the primary level for effective management and policy decisions because diverse institutional and political cooperation requires spatial scales that are both ecologically realistic and relevant to human communities.

We estimate that such an approach would cost about $200 million per year, less than 1% of what the United States spends annually on procurement, regulation, and remedial protection of fresh waters. Monies far in excess of what is needed for a comprehensive freshwater program are already being spent on ineffective and contradictory programs (*8*, *14*). For example, according to the Northwest Power Planning Council (Portland, Oregon), more than $150 million is spent annually on the recovery of the degraded salmon and steelhead runs in the Columbia River, yet a monitoring program that would enable the measurement of the major sources of mortality at key points in the river and ocean ecosystem does not exist. With little or no formal peer review, this spending constitutes well over twice the annual budget of the Environmental Biology Program at the National Science Foundation (NSF), which is the primary source of competitive funding for basic research in freshwater ecology in the United States. We do not mean to be critical of any particular program without a full analysis of the situation. Our point is that freshwater research in this nation should be prioritized in relation to documented problems, and that cost effectiveness should be emphasized through scientifically based monitoring and evaluation of all water-related research and management programs.

We envision two broad implementation categories, one focusing on institutions and the other on knowledge (*8*). The first category includes (i) efforts to strengthen existing agencies to promote understanding, protection, and regulation of freshwater ecosystems and resources; (ii) enhancement of existing agency programs to support innovative research and technology development and transfer; (iii) establishment of regional institutions designed to integrate human and natural sciences and to bring together managers and scientists from government, academia, and the private sector; and (iv) a new, integrated NSF program to promote effective interdisciplinary freshwater research on a scale commensurate with contemporary issues.

The second category addresses professional and public literacy about freshwater ecosystems and their management. It includes (i) a national center to provide data on freshwater biodiversity, develop sensitive biotic indices of environmental change and ecological integrity, and enhance the accuracy and precision of monitoring programs; (ii) an array of long-term natural and human-altered research sites with a specific focus on fresh waters (*15*); and (iii) the strengthening of education and communication to provide truly innovative training for students and professionals in freshwater disciplines, including continuing education for midcareer scientists and managers.

Science and policy based on factual information must form the basis for the regulation and rehabilitation of the nation's fresh waters. The nation cannot otherwise protect its long-term cultural, economic, and environmental interests that are intimately tied to fresh water. As we enter the 21st century, demands on water resources will intensify and the need for sound information, an ecologically literate population, and comprehensive legislation will become even more obvious. To protect our freshwater ecosystems, we need knowledge, wise leadership, and real cooperation to find the correct mix of laws, incentives, and regulations as well as the political will to enact them.

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14. Examples of expenditures that consume fiscal resources but do not effectively protect water resources include a nearly exclusive reliance on chemical criteria to meet the goals of the Clean Water Act, the use of hatcheries to maintain fish populations, bounty programs to maintain dwindling fish stocks affected by water resource development, and massive engineering projects that fail to account for the natural dynamics of the freshwater ecosystem.
15. The United States boasts an array of biological field stations, but they generally receive substandard support and are seldom organized to foster long-term integrative research. Likewise, of the NSF's 18 Long-Term Ecological Research sites, only two have a primary freshwater focus.

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