



SAVING THE LAST GREAT PLACES ON EARTH

Aquatic ecosystem protection and drinking water utilities

DRINKING WATER PROVIDERS WORLDWIDE HAVE BEGUN TO RECOGNIZE THAT SAFEGUARDING AQUATIC ECOSYSTEMS THROUGH WISE WATER MANAGEMENT MAKES SENSE ECONOMICALLY AND ECOLOGICALLY.

As one of the most publicly visible stewards of the earth's water sources, drinking water utilities are uniquely positioned to exert a leadership role in the emerging field of ecologically sustainable water management. In important ways, this field is integrating the traditional goals of water management with those of ecosystem conservation in order to sustain a broader spectrum of the valuable goods and services on which human communities depend.

The water strategies of the twentieth century helped provide much of the human population with drinking water, food, electricity, and flood control. Indeed, it is difficult to imagine today's world of 6.5 billion people and \$55 trillion in economic output without the vast network of water infrastructure now in place—from dams and reservoirs to wells, pumps, and canals. This infrastructure, however, has disrupted the functioning of aquatic ecosystems on a large scale. If future human needs are to be met without costly and irreparable harm to ecological health, new strategies will be needed that incorporate a broader set of ecological goals into water planning and management.

Drinking water utilities will play an increasingly important role in designing and implementing these new strategies. Globally, municipal water use accounts for less than 10% of total water demands. Because municipal demands are concentrated geographically, however, they can disproportionately affect rivers, lakes, aquifers, and related aquatic ecosystems (FitzHugh & Richter,

This article was originally developed as a concept paper by the author at the request of The Nature Conservancy and was modified for publication in JOURNAL AWWA. It is being published with the permission of the The Nature Conservancy.

2004). Moreover, the world has recently crossed an important demographic threshold: more than half the human population now lives in urban areas, and the ratio of urban to rural dwellers is likely to continue to increase for the foreseeable future. This development will heighten tensions over water between farms and cities, a trend already visible in parts of the world (Postel & Vickers, 2004). Much of the world's urban growth will occur near coasts, heightening competition for water in the downstream reaches of many river basins and threatening the health of estuarine and marine ecosystems.

Trends in the United States mirror these global trends to some degree. Now numbering some 300 million, the US population is projected to reach 420 million by 2050 (US Bureau of the Census, 2004). Estimates compiled by the US Geological Survey (USGS) show that withdrawals for municipal water supplies are the fastest-growing category of withdrawals nationwide, rising 8% between 1995 and 2000, compared with a 2% rise for total withdrawals nationwide (Hutson et al, 2005). The prospect of a changing climate that may include an increase in the number and intensity of regional droughts underscores the importance of water managers getting ahead of the game by proactively planning and managing for this emerging new era of water tensions, worsening shortages, and myriad threats to ecological health.

This article details the nature and importance of aquatic ecosystem health and ecological services as well as the ways in which drinking water systems affect and influence aquatic ecosystems, and it offers some methods, tools, and examples that show how more ecologically sustainable water management can be achieved.

PROTECTING AQUATIC ECOSYSTEM HEALTH AND SERVICES IS ESSENTIAL

Aquatic ecosystems provide numerous irreplaceable benefits. Aquatic ecosystems encompass rivers, streams,

New Column Coming to JOURNAL AWWA From The Nature Conservancy

The Nature Conservancy is a global conservation organization whose mission is to preserve the plants, animals, and natural communities that represent the diversity of life on earth by protecting the lands and waters they need to survive. The conservancy works to realize this mission with the best science available, nontraditional partnerships, and respect for all of the communities—human and natural—that we work in.

The Nature Conservancy is a global leader in developing new approaches to managing water for people and nature. By working collaboratively and in a nonconfrontational manner, conservancy scientists and policy specialists are pioneering breakthroughs with cities, utilities, water planners, governments, energy companies, and others by advancing water policies and conservation approaches that continue to meet human needs for water while sustaining freshwater habitats. With careful planning and management, water diversions, well pumping, and reservoirs can be operated in a manner that preserves an adequate volume and timing of water flow—also known as environmental flow—that sustains river ecosystems.

With nearly 3 billion people living in the world's cities today and that number increasing daily, the water needs of cities are putting more and more pressure on river ecosystems. The Nature Conservancy understands the difficulties that water utilities face in trying to meet this growing demand. We also know that by working together, we can provide water for both cities and nature.

We at the Nature Conservancy are honored to have been invited to write a column for *Journal AWWA*. Begin-

ning in April, the conservancy will be writing a column here on a bimonthly basis, exploring environmental topics of significance to AWWA members. Our April column will focus on the conservancy's work with AWWA and other organizations to develop a program that will recognize water utilities that have instituted measures to protect the freshwater ecosystems from which they draw their water supplies. Other columns will include the conservancy's work with cities and municipalities that are protecting water quality, environmental flows, and their source watersheds. Readers will be introduced to the science and methodology behind the conservancy's work in the field of environmental flow protection and see how others are learning to meet human and nature's needs for freshwater. The conservancy is engaged in strategic projects around the world that are designed to develop and test new techniques to support environmentally sustainable water management. These bimonthly columns will bring the lessons that scientists, engineers, and water managers have learned at these demonstration sites to readers of this journal.

We at The Nature Conservancy hope that this column will help foster ongoing dialogue between AWWA members and conservationists that will help us all meet our ultimate goals—providing people and rivers with the water they need, now and for future generations.

To learn more about our approach and our work, please visit www.nature.org/freshwater/.

—The Nature Conservancy

floodplains, lakes, wetlands, underground aquifers, springs, and coastal estuaries (where freshwater meets and mixes with saltwater). All of these ecosystems are part of and are supported by the hydrologic cycle—the sun-powered movement of water between the sea, air, and land that sustains life on earth. To the extent human actions alter this cycling of water, they affect the ecosystems that are sustained by it.

Aquatic ecosystems provide numerous goods and services of significant value to humans (Postel, 2005), including:

- water supplies for irrigation, industries, cities, and homes;
- fish, waterfowl, mussels, and other foods for people and wildlife;
- water purification and filtration of pollutants;
- flood mitigation;
- drought mitigation;
- groundwater recharge;
- water storage;
- wildlife habitat and nursery grounds;
- soil fertility maintenance;
- delivery of nutrients to deltas and estuaries;
- delivery of freshwater flows to maintain estuarine salinity balances;
- recreational opportunities;
- aesthetic, cultural, and spiritual values; and
- conservation of biodiversity, which preserves resilience and options for the future.

The ancient Egyptians thrived for several thousand years on the ecological services provided by the annual flood of the Nile River, which delivered water and nutrients to their fields, carried off harmful salts that had accumulated in the soil, and supported a diversity of fish. Because most ecological services lie outside commercial markets and are not priced in conventional ways, they tend to be undervalued and underappreciated.

In recent years, economists have attempted to place monetary values on some of these ecosystem services, and although these estimates are

imperfect, they do provide society with a ballpark sense of ecosystem worth and importance. The recently completed Millennium Ecosystem Assessment reported that the benefits provided by wetlands—including fishing, hunting, recreation, water supply, flood control, water purification, nursery functions, and biodiversity habitat—totaled on average \$1,325/acre per year (Millennium Ecosystem Assessment, 2005). The estimated value will vary considerably from one site to another; the ecological services provided by wetlands in Massachusetts, for example, have been valued at up to \$6,250/acre per year (Breunig, 2003). Although approximate, such estimates underscore that it is unwise (and often uneconomical) to drain, fill, or convert wetlands to other uses without first assessing the importance

For water managers, placing the words “ecologically sustainable” alongside their primary responsibilities—whether those entail generating hydropower, delivering irrigation water, or supplying cities with drinking water—requires that they make the protection of ecological health an even more central goal of their planning, operations, and management. To date, attention to ecological effects (e.g., through environmental impact assessments) has typically come after a project is conceived of and designed, with the intent of mitigating the most egregious harm to ecosystems. Protecting ecological health, however, demands a different framework, one that proactively integrates ecological goals into water planning and project design from

Long perceived only as an emergency response to drought, water conservation is now a proven strategy to achieve long-term demand reduction.

of the work they do and the potential value of what will be lost. The same is true for the alteration of rivers and other aquatic ecosystems.

Freshwater ecosystems must be in reasonably good health in order to provide the valuable goods and services that economies depend on. Ecological health refers to the condition or state of an ecosystem’s life-support functions and processes, which directly affects its ability to deliver goods and services to human communities. Just as doctors check blood pressure, cholesterol levels, and heart rate to see if these values fall within a range essential for good human health, scientists similarly assess certain ecosystem attributes to determine whether they fall within a range essential for good ecological health.

the start. In this way, effects on aquatic ecosystems can be minimized, not just mitigated. Moreover, by focusing on ecological goals early on, water planners and managers have a much greater opportunity to develop creative solutions to the challenge of meeting human and ecological water needs at the same time.

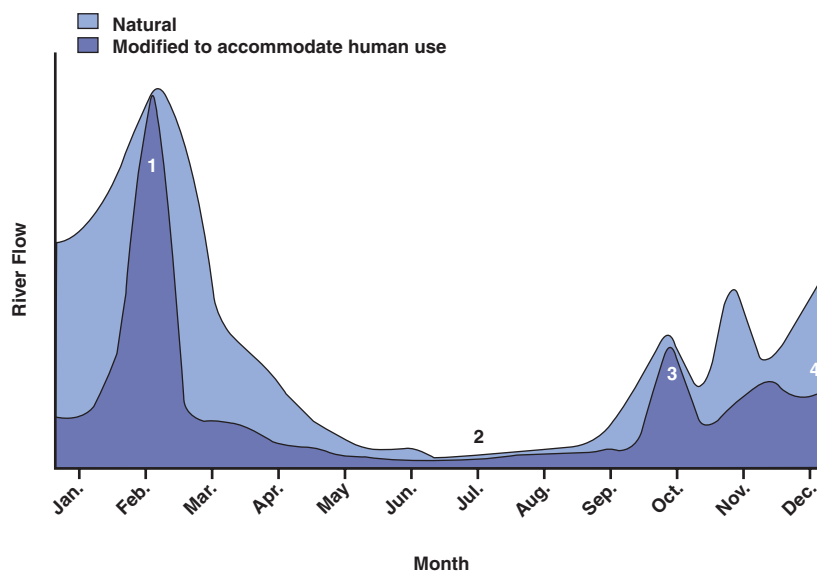
Ecological goals focus on four areas. In most cases, the ecological goals that water managers will need to integrate into their work fall into four broad (and to some degree, overlapping) areas: environmental flows, source water protection, water quality, and groundwater management.

Environmental flows. The health of rivers and streams depends to a large degree on water flows. Until

agement guidelines have concentrated on the maintenance of minimum flows during dry periods, i.e., making sure rivers and streams have at least some water in their channels. During the past decade, however, freshwater ecologists have demonstrated that this minimum-flow paradigm, although perhaps adequate to support recreational boating and fishing, is not sufficient to protect ecological health. Specifically, they have identified four major types of ecological consequences resulting from the alteration of river flows. First, flow alteration can impair or destroy the physical habitats of a river's channel (e.g., riffles and pools) and floodplain. Second, it can prevent aquatic species from receiving the cues or opportunities they need to fulfill their critical life stages, including reproduction. Third, flow alteration can disconnect rivers from their floodplains and fragment them longitudinally, depriving species of important habitats and disrupting ecological services. Fourth, altered flows can allow populations of exotic and introduced species to expand at the expense of native populations, which disrupts food webs and ecological functions (Postel & Richter, 2003).

Consequently, the minimum-flow paradigm is being replaced by a new approach to river management based on the natural flow paradigm. This approach calls for water managers to sustain or replicate a river's natural pattern of variable flows—the pattern of high and low flows, as well as periodic floods and droughts—that the river historically exhibited and to which the myriad life forms in the river have become adapted. (Postel & Richter, 2003; Poff et al, 1997; Richter et al, 1997). The approach does not call for or require a return to the “natural” state, but it does entail maintaining a flow regime that resembles the natural historical one to a sufficient degree to sustain the ecological functions of the aquatic system (Figure 1).

FIGURE 1 Composite natural and modified hydrographs developed at a workshop in South Africa



Source: Postel & Richter, 2003; adapted from Tharme & King, 1998

- ① Retain flood magnitude to scour channel and vegetation and recharge river banks and floodplains.
- ② Maintain base flow and thus aquatic habitat in dry season.
- ③ Retain spring flushing flow as cue to life cycles.
- ④ Vary base flow in wet season but with removal of some floods.

When modified to accommodate human uses, the river still retains a flow pattern that keeps it healthy and close to the natural flow regime.

Source water protection. The health of rivers, lakes, and other aquatic systems is closely tied to the condition of the watersheds that feed into them. The quantity, quality, and timing of runoff coming out of a watershed may vary greatly with land-use patterns, vegetative buffers around streams and reservoirs, and other landscape features. It is well accepted, for example, that watersheds with significant areas of protected or well-managed forests offer water purification services that are superior to other landscape types. For example, a survey of US water suppliers by the AWWA Source Water Protection Committee and the Trust for Public Land (TPL) found that water treatment costs are inversely related to the proportion of the watershed protected by forests (Barten & Ernst, 2004; Ernst, 2004).

Table 1 shows this relationship between forest cover and predicted treatment costs.

In addition to higher-quality source water, protected watersheds provide other valuable ecological services as well. Land-use activities in aquifer recharge zones can have severe consequences for groundwater, with implications for water supplies and ecosystems sustained by underground water flows. For all these reasons, water managers are increasingly being called on to protect source watersheds. Some hydroelectric producers and drinking water suppliers are even finding that it makes economic sense to pay for the protection of watershed lands they do not own or control because of the improved supply reliability or water quality this protection provides (Postel & Thompson, 2005).

TABLE 1 Forest cover and predicted water treatment costs

Watershed Forested—%	Treatment Costs per 3,785 m ³ —\$	Average Annual Treatment Costs—\$	Cost Increase Over 60% Forest Cover—%
60	37	297,110	—
50	46	369,380	24
40	58	465,740	57
30	73	586,190	97
20	93	746,790	151
10	115	923,450	211

Source: Postel & Thompson, 2005; adapted from Ernst, 2004.

Table reflects responses from 27 US water supply systems and is based on treatment of 22 mgd (83,270 m³/d), the average production of the water suppliers surveyed.

Water quality. Although many countries, including the United States, have made substantial improvements in water quality during the past several decades, pollution of various kinds continues to jeopardize the health of aquatic ecosystems. Concentrations of nutrients (primarily nitrogen and phosphorus) have increased substantially in rivers throughout the world, which is causing eutrophication, harmful algal blooms, and high levels of nitrate in drinking water sources. In many industrialized regions, riverborne nitrogen has increased up to fivefold from preindustrial levels. As rivers and streams carry these pollution loads to the sea, coastal zones are becoming overenriched with nutrients, leading to a growing number of hypoxic (low-oxygen) dead zones that pose serious threats to coastal fisheries. For example, more than half of the coastal bays and estuaries in the United States are degraded by excessive nutrients (Howarth et al, 2000). In addition, chemical contamination from pesticide use, industrial and military discharges, and other sources is a continuing problem in industrial countries and a growing problem in the developing world (Postel, 2005). The USGS recently established that pesticides are found in virtually all US rivers and streams, often at levels harmful to aquatic life and fish-eating wildlife (Gilliom et al, 2006).

Groundwater management. Although hidden from view, underground aquifers are inextricably linked to rivers, lakes, wetlands, and other aquatic ecosystems. Natural drainage of water from groundwater aquifers often provides the base flow that keeps rivers running during summer months and dry spells. Shallow groundwater often sustains essential wetland habitat either seasonally or year-round. Water stored underground is also an important reservoir during droughts. Water professionals have increasingly recognized the importance of managing surface water and groundwater as the interconnected systems they are, but conjunctive use and management have often been difficult to achieve.

As rivers, lakes, and streams become less available and more expensive to tap for new supplies, many water providers, farmers, and private enterprises are turning to underground aquifers. Signs of over-pumping, i.e., extracting water faster than it is being recharged, are pervasive and spreading. Water tables are dropping in many parts of the world, including important farming and urban areas of China, India, Mexico, the Middle East, north Africa, and the United States. As much as 10% of current global food production (and closer to 25% in India) may rely on the unsustainable

use of groundwater (Postel, 1999). Thus, managing groundwater to meet future human needs while also sustaining its important ecological functions constitutes a major challenge to water managers.

UTILITIES SIGNIFICANTLY INFLUENCE ECOSYSTEM HEALTH

The principal role of a drinking water provider is to supply water sufficient to meet the health and safety needs of the residents within its service area. Although many utilities are guided by an environmental ethic as they strive to fulfill this purpose, most will inevitably affect the river, stream, lake, or aquifer that serves as the source of supply.

Common water supply methods harm ecosystems. Most utilities draw water in one of four ways: directly from a river or stream, directly from a natural lake, through wells that tap underground aquifers, or from artificial reservoirs created by a dam. Each of these methods can cause significant ecological harm. For instance, direct withdrawals from a river can reduce flows to levels harmful to fish and other aquatic life. Such flow depletion may also concentrate pollutants and push important water quality parameters outside a river's healthy range. Similarly, withdrawals from a natural lake can lower lake levels, harm riparian and aquatic habitats, and increase pollutant concentrations. When groundwater is a primary supply source, pumping from wells may exceed rates of recharge, resulting in long-term depletion of the supply. Even if pumping causes only short-term depletion and aquifer levels recover during wet years, the temporary lowering of water tables may damage ecosystems dependent on that groundwater for base flows.

Dams built to create a reservoir to store water supplies have perhaps the most obvious ecological consequences and rank near the top of the list of causes of riverine habitat loss and impairment (Silk & Ciruna, 2005; Postel & Richter, 2003). Dams

transform part of a flowing river into a lake, an entirely different aquatic environment. Dams physically block the migration routes of various fish species, often preventing fish from reaching critical spawning grounds. Because dam operations alter flow patterns and the delivery of sediment, nutrients, and organic matter, they often influence river ecosystems for tens or hundreds of miles downstream of the reservoir. Consequently, even though a utility's supply concerns focus on water in the reservoir, the ecological effects can ripple out considerably above and below the reservoir.

To the extent that utilities draw on water bodies in watersheds other than their own, they can export ecological damage to other regions. This is a common occurrence among cities that have grown considerably in size. As their service areas and customer water demands grow, they reach out

species in the Etowah are now locally extinct; a nonnative trout fishery has developed in the Chattahoochee because of cold-water releases from Lake Lanier. There is concern that Atlanta's growing water demands will damage the prized fisheries of Florida's Apalachicola Bay (the source of 90% of Florida's oysters) as increased withdrawals from the Chattahoochee system reduce flows into Florida's Apalachicola River, which supports the bay.

- San Antonio, Texas, relies on the Edwards Aquifer as its principal source of drinking water. The aquifer is also a major source of irrigation water in south-central Texas. By the early 1990s, heavy groundwater pumping from the aquifer had reduced flows into San Marcos and Comal Springs, further jeopardizing seven species that were listed under the federal Endangered Species Act.

other local basins. The string of reservoirs the city built has greatly altered the flow regimes of Schoharie and Esopus creeks in the Catskills and of the Neversink River and east and west branches of the Delaware River. The ecological effects include the apparent disappearance of most mussels from the Delaware River and damage to the river's American shad run, once the largest shad run in the country.

The common theme running through these examples is that the ecological health of the rivers, lakes, and groundwater sources that were tapped to supply drinking water was not sufficiently taken into account at the time of project conception and planning. In some cases, the ecological ramifications of the water projects were simply not fully understood. Even today, however, knowledge of ecological effects rarely leads to adequate measures to minimize or avoid them. In addition, once the dams, reservoirs, diversion canals, or groundwater wells are constructed, all too often little consideration is given as to how this infrastructure might be operated to protect the health and functioning of aquatic communities.

There is a visible trend, however, toward policies and management strategies that place greater emphasis on ecological health and would in turn influence water utility operations. At the international level, much attention has been paid to South Africa's 1998 National Water Policy Act, which calls for the establishment of a "Water Reserve." The reserve consists of two parts—one intended to protect the health of people and the other to protect the health of ecosystems. The first part is a non-negotiable water allocation to meet the basic drinking, cooking, and sanitary needs of all South Africans (on the order of 20 L/d per person). The second part of the reserve is an allocation of water to support ecosystem functions so as to secure the valuable services they provide to South Africans. Specifically, the act specifies

To the extent that utilities draw on water bodies in watersheds other than their own, they can export ecological damage to other regions.

to sources farther away to augment supplies. A utility's total effect on ecological health and ecosystem services often increases in scale and severity commensurately.

Most drinking water systems affect the health of their source waters to some degree, and the impacts of large urban systems can be especially serious (Postel, 2005; FitzHugh & Richter, 2004). Here are a few US examples:

- Atlanta, Ga., draws most of its water from Lake Lanier on the Chattahoochee River and Lake Allatoona on the Etowah River. These multi-purpose reservoirs, constructed in the 1950s, have greatly altered the natural flow regimes of the two rivers. Many of the native aquatic

- Los Angeles, Calif., reached beyond the basin of the Los Angeles River to the Owens Valley and Mono Lake watersheds in order to meet the demands of its exploding population during the twentieth century. This expansion had dramatic consequences. Owens Lake completely dried up. Los Angeles's diversion of water from four of the five tributaries feeding into Mono Lake caused the lake's level to drop more than 40 ft, drained half of the lake's volume of water, and doubled its salinity. Ecological health and aquatic life in these ecosystems suffered accordingly.

- New York, N.Y., reached out to the Delaware and Catskills watersheds when it outgrew the water supplies available from the Croton and

that “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” (South African National Water Act, 1998). The water determined to constitute this two-part reserve has priority over licensed uses (such as irrigation), and only this water is guaranteed as a right.

Following South Africa’s lead, a number of national and international

tion’s largest and most economically important river system, have been capped in order to arrest the severe deterioration of the system’s health. After a tripling of withdrawals between 1944 and 1994, the Murray’s flow dropped to ecologically harmful levels, wetlands and fish populations decreased, and salinity levels and the frequency of algal blooms increased. The capping of withdrawals means that new water demands in the Murray-Darling Basin are met primarily through conservation, efficiency improvements, and water trading. Although scientists point out that the

strategies at hand to achieve these missions. Most utilities, however, have a long way to go in realizing the potential of these measures to improve ecological health, which is good news for aquatic ecosystems: there are untapped alternatives ready to be deployed.

TOOLS ARE AVAILABLE TO SAFEGUARD AQUATIC ECOSYSTEMS

Water planning and management have evolved considerably over the past two decades. Many of the concepts and ideas embedded in the

If future human needs are to be met without costly and irreparable harm to ecological health, new strategies will be needed that incorporate a broader set of ecological goals into water planning and management.

conferences, commissions, legislative directives, and laws have called for similar approaches. A significant development occurred in 2001 at the International Conference on Freshwater in Bonn, Germany. Delegates from 118 countries included in their recommendations to the following year’s World Summit on Sustainable Development that “the value of ecosystems should be recognised in water allocation and river basin management” and that “allocations should at a minimum ensure flows through ecosystems at levels that maintain their integrity” (International Conference on Freshwater, 2001). In effect, water authorities worldwide are being called on to overhaul water policies and management practices in order to safeguard freshwater ecosystems.

Several other international policy initiatives aimed specifically at improving ecological health are reshaping water management strategies as well. In Australia, for example, water withdrawals from the Murray-Darling River Basin, the na-

cap alone will not restore the river to health, it at least arrests the decline while other restoration strategies are put in place (Postel, 2005).

In the European Union, the 2000 Water Framework Directive established criteria for classifying the ecological status of water bodies and called on member countries to prevent any deterioration in this status and to bring all water sources to at least “good” status (European Parliament & Council of the European Union, 2000). In December 2005, US governors and Canadian premiers in the Great Lakes Basin approved agreements to implement the 2001 Annex to the Great Lakes Charter, which calls for no significant net degradation of the basin’s freshwater ecosystems (Postel & Richter, 2003; Council of Great Lakes Governors, 2001).

Given this growing need and expanding mandate to incorporate ecological health into traditional water supply planning, it is fortunate that water utilities already have a useful mix of tools, methods, and

emerging framework termed “ecologically sustainable water management” (ESWM) are similar to those in the integrated water resource management (IWRM) framework familiar to many water utilities. Just as IWRM expands on the least-cost planning philosophy of integrated resource planning by giving more attention to environmental assets (Beecher, 1995), so ESWM is a further evolution of planning concepts and goals that incorporates new scientific understanding about ecological health and ecosystem services (Richter et al, 2003). As discussed previously, attention to environmental flows, source water protection, water quality, and groundwater management will be key features in the implementation of ESWM strategies. Because many of the tools and strategies described in the following sections cut across these categories, they are purposefully not grouped under a specific one. This summary of ideas and examples is intended to be illustrative, not exhaustive, and includes only strategies that have demon-

strated potential to help meet ecological goals.

Reduce water demand through effective conservation. Perhaps the most powerful tool available to every water provider—regardless of whether its supply comes from a river, lake, artificial reservoir, or underground aquifer—is demand reduction through water conservation. Long perceived only as an emergency response to drought, water conservation is now a proven strategy to achieve long-term demand reduction (Vickers, 2001). By reducing the volume of water needed to adequately serve its customer base, a utility allows more water to be left in the natural environment to satisfy ecological needs. It may also eliminate the need for a new dam, permit the downsizing of a proposed dam, reduce the size or number of groundwater wells, and decrease the amount of energy and chemicals needed to treat and distribute the water supply.

The most effective conservation strategies to use vary from one city to another but almost always include attention to fixing leaks in the distribution system, reducing per capita household use (indoor and outdoor), and promoting conservation through pricing and rate structures, ordinances, and such incentives as rebates for installation of water-efficient appliances or payments to replace thirsty grasses with native landscaping (Vickers, 2001). The ecological benefits from these measures can be substantial, and they usually save consumers money as well. In Seattle, Wash., a conservation effort is helping keep more water in streams for salmon. In Massachusetts, an aggressive conservation program for the Boston metropolitan area, launched in 1987, brought water use to a 50-year low in 2004 and has indefinitely postponed the need for a diversion of the Connecticut River (Postel, 2005). In addition to aiding the restoration of Atlantic salmon populations and fisheries in the river, the conservation program saved Boston-area residents more than \$500 million (in 1986 dol-

lars) in capital expenditures alone (Postel & Vickers, 2004).

An expanding tool to guide conservation efforts is the establishment of benchmarks that help both utilities and consumers distinguish efficient water-use patterns from inefficient ones. For example, many AWWA utility members and some states have established 10% as their benchmark for distribution system water leaks and losses (nonrevenue water). This benchmark lets utilities know that if their percentage of nonrevenue water is 20 or 30% (and such rates are not uncommon), their operations are considerably outside the bounds of efficient water management. Similarly, in January 2006, the state of Massachusetts issued policy guidance for water permitting that sets a performance standard for residential water use of 65 gpcd in basins with medium to high water stress and 80 gpcd in others. This guidance also established nonrevenue water performance standards of 10 and 15% for the two basin categories, respectively. By tying the permit process to such benchmarks, state policymakers are attempting to build efficiency into municipal water systems and water use and thereby augment the volume of water available for aquatic ecosystems.

In a similar vein, water officials in the United Kingdom have identified benchmarks for water use in various types of public facilities, including offices, prisons, schools, and hospitals. Based on the water use levels of the most-efficient facilities in each category, these benchmarks provide useful and achievable targets. For instance, the United Kingdom study found that the benchmark for best water-use practice in offices was 31% lower than the median water use in offices. Similarly, water use in the most-efficient colleges and universities was 35% less than the median level. Overall, the differential among the various categories ranged from 17 to 47%, indicating substantial potential for water savings in these public facilities—water

that might then be made available to freshwater ecosystems (UK Environment Agency, 2003).

Manage water within the bounds of an ecological flow prescription. As utilities attempt to incorporate new ecological goals into their management process, many may find themselves asking, “How much water does a river (or lake or aquifer) need to sustain its ecological functions?” Ecological flow prescriptions attempt to answer this question. Some prescriptions can be stated fairly simply: for example, one river’s prescription might be that flows always remain within 20% of the natural flow. Other prescriptions may be quite complex, describing a range of flow targets to achieve for different times of the year. In the case of a heavily dammed river, the prescription might set target flows for five different components of the river’s flow regime (big floods, small floods, high-flow pulses, low flows, and very-low flows) because each component serves a different ecological purpose and is essential to the river’s overall health.

Implementing environmental flow prescriptions usually requires that water managers modify their operations to some degree, such as adjusting the schedule (timing and volumes) of reservoir releases, storing water differently, or withdrawing water at different times or in different places. One strategy, for instance, is to capture more water than needed during times of high flow, store it for later use, and then withdraw less water during periods of low flow. Such an approach can be particularly effective when the water that is skimmed off when flows are high is stored off-site (away from the natural river channel) rather than in an on-channel reservoir. Storing water off-channel typically causes less ecological harm than conventional dam-and-reservoir storage—there is no physical barrier to fish passage, less change in water temperature, and less entrainment of sediment and nutrients. As a result, off-channel storage can make

it easier to achieve ecological goals related to water quality, temperature, and fish habitat as well as to meet specific flow recommendations.

Prescriptions can also be established to ensure that groundwater pumping does not cause ecological harm. In the case of the Edwards Aquifer, this prescription took the form of a cap on groundwater withdrawals in order to sustain groundwater flows into surface springs that support the federally endangered Texas blind salamander and the fountain darter. In response to lawsuits, the Texas Legislature established the Edwards Aquifer Authority in 1993 and set a cap of 555.3 million cubic metres (mcm) on annual pumping from the aquifer through 2007 and a more stringent cap of 493.6 mcm by 2008 (Edwards Aquifer Authority, 2005). As in Australia's Murray-Darling Basin, this cap has fos-

Plan for ecosystem allocations during droughts. Ecologically sustainable water management requires that an ecosystem's water needs be met during times of drought as well as abundance. With forethought and innovative planning, utilities can meet both ecological flow requirements and consumer needs during droughts. Without such planning, however, utilities may respond to a drought in ecologically harmful ways, e.g., by completely eliminating outflows from their storage reservoirs in order to save as much water for their customers as possible, an approach that leaves the river downstream with little or no flow at all.

There are various ways utilities can ensure that both their customers and freshwater ecosystems receive the water they need to weather droughts. Perhaps the most important is to have in place an aggressive

mented lawn-watering restrictions during the month of July that lowered average demand to 18.1 mgd compared with 34 mgd for July of the previous year—a 47% reduction. As a result, the city's reservoirs stayed more than 80% full during the summer of 2002 (Vickers, 2005). Such a reserve not only helps weather a worsening of the drought (should that occur), it also provides a supply to help ensure that downstream ecosystems receive enough water during the drought as well.

Colorado also experienced one of its worst droughts on record in 2002, but Denver was slow to respond with effective measures (Harmon, 2004). Despite the fact that the water savings achieved during June, July, and August fell considerably short of the drought program's goals, tight water restrictions and a lawn-watering ban were not put in place until September 1 and October 1, respectively. With reservoir levels so low, Denver Water implemented cloud-seeding later that year to try to increase rainfall over its storage reservoirs. Despite this effort, on Feb. 10, 2003, Denver's reservoirs were only 44% full, compared with a normal level of 82% for that point in the year (Gardner, 2004).

Along with mandatory water-use restrictions and bans, a helpful drought-planning measure for some utilities is a dry-year option arrangement. This strategy usually involves a city arranging to purchase water from farmers who are willing to forgo irrigating crops during a drought (which often will mean fallowing cropland) and instead sell water on a temporary basis to the city. If arranged well and in advance, such short-term water transfers may be not only ecologically beneficial but also economically advantageous to both parties: the farmers receive extra income from both the option and the short-term water sale, and the city secures supplies for a drought without having to build extra reservoir capacity. In states where water rights remain with public entities, a regional water authority can help

Because most ecological services lie outside commercial markets and are not priced in conventional ways, they tend to be undervalued and underappreciated.

tered an active water market (typically irrigators sell water to San Antonio) and has also encouraged more conservation within San Antonio, where per capita domestic use is now considerably lower than in most Texas cities.

Coordinated management of surface water and groundwater offers another tool for some utilities to meet environmental flow prescriptions. Floodwaters can be directed to infiltration zones to recharge aquifers, for instance, and then this underground supply can be tapped during dry periods. This can ensure that enough surface water is available to prevent river flows from dropping below the prescribed level.

water conservation strategy specifically for droughts, one that is consistent with, but distinguishable from, the utility's long-term demand-reduction strategy. This drought strategy may begin with voluntary measures but must transition to mandatory measures if the drought persists and if reservoir capacity or stream flows drop to unacceptably low levels. Researchers have found that voluntary restrictions on outdoor water use are of limited value; it is the cities with the most stringent mandatory restrictions that realize the largest water savings (Vickers, 2006).

In response to a record-breaking drought during the summer of 2002, the city of Cheyenne, Wyo., imple-

arrange and execute these dry-season transfers.

Another useful tool, and one familiar to most utilities, is to establish a trigger level that in effect sounds the alarm to put the conservation strategy into motion. Utilities typically have a trigger tied to reservoir capacity levels; when capacity drops to a certain point, the drought plan kicks in. By adding a trigger tied to stream-flow levels, utilities can ensure that action is taken when ecological health is at risk. Massachusetts officials have set such a trigger for flows in the Ipswich River, which ran dry during the summers of 1995, 1997, and 1999. When flows in the Ipswich drop to a specified level, towns are required to institute water conservation measures. (Massachusetts officials are now in the process of requiring such triggers in much of the state.) Because it can be politically difficult to restrict water use, even during droughts, the existence of a publicized trigger level can be a useful tool for gaining public acceptance of drought measures.

It bears repeating that water-use restrictions, dry-year options, and other measures are necessary but not sufficient to ensure ecological health during periods of drought. Some portion of the water saved or acquired must be allocated to ecosystems at risk. There is an ethical dimension to this philosophy of sharing with nature: it implies that nonessential human uses of water, such as lawn irrigation, be curtailed before fish and other aquatic creatures begin to suffer and die.

Protect source watersheds. Compared with water used for irrigation or many industrial activities, drinking water must meet high standards of quality. The more polluted the raw source water, the more expensive and difficult it becomes to treat it and make it safe for drinking. As watershed lands are converted from forests and wetlands to urban and agroindustrial uses, there is increased potential for rivers, lakes, and aquifers that serve as drinking water sources to

become contaminated with pathogenic organisms, heavy metals, farm and lawn pesticides, and other health-threatening substances.

Because of these threats, the importance of watershed protection is growing. In their foreword to the 2004 report *Protecting the Source*, jointly published by AWWA and TPL, AWWA Executive Director Jack Hoffbuhr and TPL President Will Rogers stated, "For 60 years, the safety of most of America's drinking water has been dependent on technology. Today, water suppliers are revisiting the idea that watershed protection—the first barrier against contamination—needs to, once again, be an integral part of their water quality protection strategy" (Ernst, 2004).

Fortunately, protecting the ecological services provided by healthy watersheds can also protect water quality and, in some cases, water quantity as well. As mentioned previously, natural forests and wetlands are unequivocally effective at cleansing water supplies. They act as nature's water factories, churning out high-quality water that helps keep rivers and streams healthy and also lowers the cost of treating water for domestic use. Healthy watersheds also provide many other valuable ecosystem services at the same time, including recreational opportunities, biodiversity conservation, erosion control, and climate protection. As a result, there are creative synergies to tap when designing and financing watershed protection strategies.

Several major US cities, for example, have avoided the construction of expensive filtration facilities by investing instead in watershed protection to maintain the purity of



their drinking water. The US Safe Drinking Water Act requires that cities dependent on rivers, lakes, or other surface waters for their drinking supplies build filtration plants unless they can demonstrate that they are protecting their watersheds sufficiently to satisfy federal water quality standards. Boston, New York City, Portland (Me.), Portland (Ore.), Seattle, and Syracuse (N.Y.) are among the cities that have taken the watershed protection route and are saving their residents millions of dollars (and in the case of New York City, several billion dollars) in avoided capital expenditures (Postel & Thompson, 2005). Because the driving force behind these efforts is water quality protection, however, these cities are not necessarily maintaining the overall ecological health (including environmental flows) of their watersheds. As noted earlier, the management of New York City's reservoir system in the Catskills and Delaware watersheds has diminished and altered river flows in ecologically harmful ways.

An emerging strategy for watershed protection that is showing significant promise in some parts of the world is establishing mechanisms whereby the beneficiaries of a watershed's ecosystem services pay the providers of those services to protect them. In the absence of strong regulations and enforcement of

lution to upgrading wastewater infrastructure—in order to avoid the \$6 billion cost of a filtration plant (National Research Council, 2000).

Quito, the capital of Ecuador, has taken a different approach to paying for watershed services. The city draws about 80% of its drinking water from two protected ecologi-

ties. Contributors to the fund include Quito's electricity supplier (which generates about 22% of its hydro-power in the surrounding watersheds), a private beer company, and the city's municipal water supplier, which dedicates 1% of its monthly drinking water sales to the fund. The water agency works with The Nature

Estimates compiled by the US Geological Survey show that withdrawals for municipal water supplies are the fastest-growing category of withdrawals nationwide, rising 8% between 1995 and 2000, compared with a 2% rise for total withdrawals nationwide.

watershed activities, this approach can promote and finance watershed protection by creating a market for buyers and sellers of valuable ecosystem services. There are many variations on this approach. New York City's effort, for example, involves investing \$1.5 billion in an array of watershed activities—from forest management to controlling farm pol-

cal reserves, which, though part of the national park system, are also used for cattle, dairy, and timber production. With urging and support from local and international groups, Quito established a watershed trust fund to pool the demand for watershed protection among the various downstream beneficiaries and to finance watershed protection activi-

Conservancy (which also supports the fund) to identify projects that offer both high biodiversity values and water supply benefits (Postel, 2005; Echavarría, 2002).

Even where opportunities to combine water quality protection with other ecological services are not apparent or feasible, drinking water utilities usually still have ample rea-

REFERENCES

- Barten, P.K. & Ernst, C.E., 2004. Land Conservation and Watershed Management for Source Protection. *Jour. AWWA*, 96:4:121.
- Beecher, J.A., 1995. Integrated Resource Planning Fundamentals. *Jour. AWWA*, 87:6:34.
- Breunig, K., 2003. *Losing Ground: At What Cost? Changes in Land Use and Their Impact on Habitat, Biodiversity, and Ecosystem Services in Massachusetts*. Massachusetts Audubon Soc., Lincoln, Mass.
- Council of Great Lakes Governors, 2001. Great Lakes Water Management Initiative: Draft Annex 2001 Implementing Agreements. www.cglg.org/projects/water/annex2001implementing.asp.
- Echavarría, M., 2002. Financing Watershed Conservation: The FONAG water fund in Quito, Ecuador. *Selling Forest Environmental Services: Market-based Mechanisms for Conservation and Development* (S. Pagiola, J. Bishop, and N. Landell-Mills, editors). Earthscan, London.
- Edwards Aquifer Authority, 2005. www.edwardsaquifer.org (accessed Apr. 12, 2005).
- Ernst, C., 2004. *Protecting the Source: Land Conservation and the Future of America's Drinking Water*. Trust for Public Land and AWWA, Washington.
- European Parliament & Council of the European Union, 2000. Directive 2000/60/EC Establishing a Framework for Community Action in the Field of Water Policy. *Official Jour. European Communities*, (Dec. 22, 2000) L 327:1.
- FitzHugh, T.W. & Richter, B.D., 2004. Quenching Urban Thirst: Growing Cities and Their Impacts on Freshwater Ecosystems. *BioSci*, 54:741.
- Gardner, L., 2004. Surviving the Worst Drought in 300 Years. Proc. AWWA Water Sources Conf., Austin, Texas.
- Gilliom, R.J. et al, 2006. *Pesticides in the Nation's Streams and Ground Water, 1992–2001*. Circular 1291, US Geological Survey, Reston, Va.
- Harmon, R., 2004. Denver Water's 2002 Drought Response and Water Conservation Campaign. Colorado State University, Greeley, Colo.
- Howarth, R. et al, 2000. Nutrient Pollution of Coastal Rivers, Bays, and Seas. *Issues in Ecol.*, 7:1.
- Hutson, S.S. et al, 2004. *Estimated Use of Water in the United States in 2000*. Circular 1268, US Geological Survey, Reston Va. February 2005 revisions at <http://pubs.usgs.gov/circ/2004/circ1268/index.html>.
- International Conference on Freshwater, 2001. *Water—A Key to Sustainable Development: Recommendations for Action*. Bonn, Germany.
- Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Current State and Trends*. Island Press, Washington.

son to invest in watershed protection. Good watershed management offers an extra safeguard against microbial or chemical contamination that may not be removed by conventional treatment plants; keeping such contaminants out of drinking water sources in the first place reduces risks to human health. Therefore, it makes sense to include the cost of watershed protection in consumer water rates (just as routine operation and maintenance costs are included).

CONCLUSION

A new framework for water management is now taking shape. At its core is a reassessment of the value of freshwater ecosystems that considers water's worth not just when it is extracted from the natural environment but also when it is left in place to do the work of nature. These ecosystem services are rarely valued monetarily yet provide enormous benefits to society. Scientists have developed ways to incorporate ecological goals into the management and use of dams, reser-

voirs, watersheds, and groundwater systems that can help society make wiser choices and maximize the total value derived from freshwater ecosystems, including extractive uses, biodiversity conservation, and other ecosystem services.

As urban populations and water demands increase, drinking water utilities will be on the front line of efforts to rebalance water management to better protect ecological health. Fortunately, numerous tools and approaches are available to meet this challenge.

ABOUT THE AUTHOR



Sandra L. Postel is director of the Global Water Policy Project, 107 Larkspur Dr., Amherst, MA 01002-3440; e-mail

spostel@globalwaterpolicy.org. She is also a visiting senior lecturer in environmental studies at Mount Holyoke College in South Hadley, Mass., and a senior fellow with Worldwatch Institute

(Washington, D.C.), which published her 2005 book Liquid Assets: The Critical Need to Safeguard Freshwater Ecosystems. Her other works include Last Oasis: Facing Water Scarcity, Pillar of Sand: Can the Irrigation Miracle Last? and Rivers for Life: Managing Water for People and Nature (co-authored with Brian Richter). Through research, writing, consulting, teaching, and public speaking, Postel works to preserve freshwater ecosystems and the life they sustain. She studied geology and political science at Wittenberg University in Springfield, Ohio, and resource economics and policy at Duke University in Durham, N.C.

If you have a comment about this article, please contact us at journal@awwa.org.

National Research Council, 2002. *Watershed Management for Potable Water Supply: Assessing the New York City Strategy*. National Academy Press, Washington.

Poff, N.L. et al, 1997. The Natural Flow Regime: A Paradigm for River Conservation and Restoration. *BioSci.*, 47:769.

Postel, S., 2005. *Liquid Assets: The Critical Need to Safeguard Freshwater Ecosystems*. Worldwatch Inst., Washington.

Postel, S., 1999. *Pillar of Sand: Can the Irrigation Miracle Last?* W.W. Norton, New York.

Postel, S. & Richter, B., 2003. *Rivers for Life: Managing Water for People and Nature*. Island Press, Washington.

Postel, S.L. & Thompson, B.H., Jr., 2005. Watershed Protection: Capturing the Benefits of Nature's Water Supply Services. *Natural Resources Forum*, 29:98.

Postel, S. & Vickers, A., 2004. Boosting Water Productivity. *State of the World 2004*. W.W. Norton & Co., New York.

Richter, B.D. et al, 2003. Ecologically Sustainable Water Management: Managing River Flows for Ecological Integrity. *Ecolog. Applications*, 13:206.

Richter, B.D. et al, 1997. How Much Water Does a River Need? *Freshwater Biol.*, 37:231.

Silk, N. & Ciruna, K. (editors), 2005. *A Practitioners Guide to Freshwater Biodiversity Conservation*. Island Press, Washington.

South African Government Gazette, 1998. South African National Water Act No. 36 of 1998. Vol. 398, No. 19182, Aug. 26, 1998.

Tharme, R.E. & King, J.M., 1998. *Development of the Building Block Methodology for Instream Flow Assessments and Supporting Research on the Effects of Different Magnitude Flows on Riverine Ecosystems*. Water Research Commission, Cape Town, South Africa.

United Kingdom Environment Agency, 2003. Watermark Study of Water Use and "Best Practice" Benchmarks at Public Facilities in the U.K. Watermark, Liverpool, England.

US Bureau of the Census, 2004. US Interim Projections by Age, Sex, Race, and Hispanic Origin. www.census.gov/ipc/www/usinterimproj (release date Mar. 18, 2004).

Vickers, A., 2006. New Directions in Lawn and Landscape Water Conservation. *Jour. AWWA*, 98:2:56.

Vickers, A., 2005. Managing Demand: Water Conservation as a Drought Mitigation Tool. *Drought and Water Crises: Science, Technology, and Management Issues* (D.A. Wilhite, editor). CRC Press, Boca Raton, Fla.

Vickers, A., 2001. *Handbook of Water Use and Conservation: Homes, Landscapes, Businesses, Industries, and Farms*. WaterPlow Press, Amherst, Mass.