Chapter 9

ENVIRONMENTAL ISSUES AND WATER MANAGEMENT

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Arizona's environment and its water resources are inextricably linked. The ways we use water alter the environment, and changes in the environment affect our water resources. Surface water diversions and groundwater pumping have depleted or dried up much of the state's streams and rivers, causing the loss and alteration of extensive areas of aquatic and riparian habitat. Introduction of exotic species has altered grasslands, reduced xeric desert areas and altered species distributions.

A growing number of factors other than water use have contributed to major changes in landscapes and ecosystems over the last 150 years, and the rates of change appear to be accelerating. These land cover changes are affecting our water supplies in ways that we only partially understand.

While these wholesale land cover changes continue, demand for and uses of our state's limited water resources are shifting and increasing. Traditional water uses–agriculture, mining, domestic and industrial–increasingly are competing with new uses, many of them in-stream uses. These include preserving habitat under the Endangered Species Act, supporting water-based recreation and tourism and meeting tribal water claims and the requirements of interstate or international river compacts.

LAND COVER CHANGES AND WATER SUPPLIES

Land cover, soils and slope largely determine the *partitioning of precipitation* and thereby available water supplies (Figure 9.1). After rain and snow fall to the ground, much of it evaporates, but some runs off to streams and river channels and some infiltrates the soil. Soil moisture can evaporate, be absorbed by plant roots and transpired or infiltrate deep below the surface,

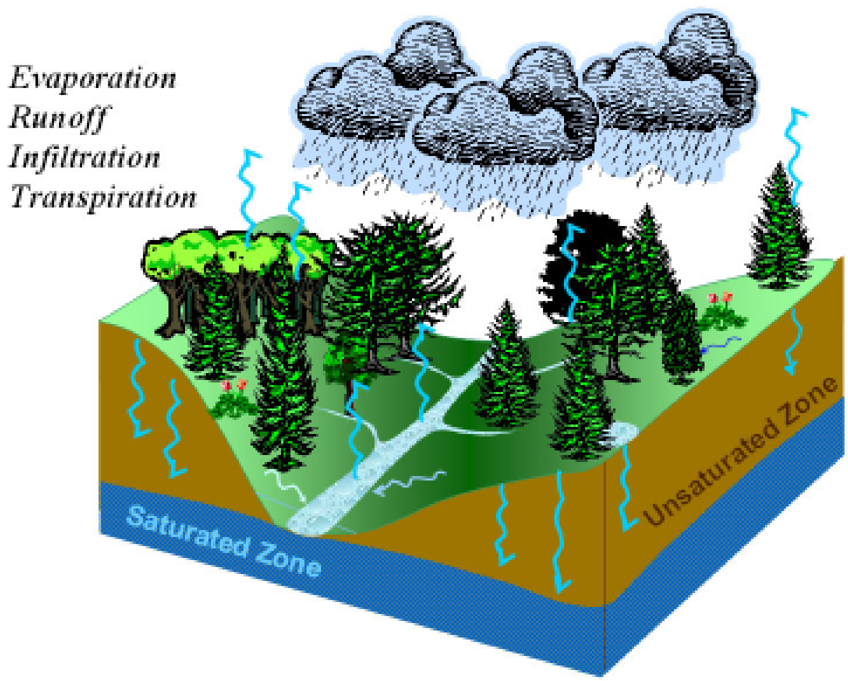


Figure 9.1 Partitioning of Precipitation.

eventually recharging aquifers. Runoff and deep infiltration are the sources of our renewable surface water and groundwater supplies. Evaporation and plant transpiration, collectively known as evapotranspiration or ET, is water lost to the atmosphere.

In most Arizona basins, precipitation and ET are very nearly equal to each other; nearly all precipitation is lost through evapotranspiration. Only a small percentage of precipitation recharges aquifers or runs off to streams and rivers. Because vegetation type and other ground cover characteristics affect ET, they largely determine the rates of runoff and recharge.

Land cover changes therefore affect the partitioning of precipitation, resulting in large increases or decreases in surface water and groundwater supplies. This in turn has major impacts on habitat, flood plains, water quality and nutrients reaching rivers and streams.

Natural and human-built land covers are undergoing rapid and massive change across the state. There are several causes of land cover changes, including:

- Climate fluctuations–drought and flood,
- Clear-cutting of forests in the past and re-growth,
- Wildfire suppression over the last 90 years leading to altered fire regimes,
- Insect infestations,
- Intentional or accidental introduction of exotic species,
- Carbon Dioxide increases in the atmosphere favoring woody species over grasses,
- Climate change increasing temperature, precipitation, evaporation and snow melt,
- Population growth and shifting socio-demographic patterns,

- Suburbs, exurbs, ranchettes and second homes which displace agricultural lands and natural vegetation and reduce infiltration,
- Impacts of farming and grazing, including abandonment of agricultural lands, and
- Damming and diverting surface waters.

Some of these changes, such as one vegetation type crowding out another, occur gradually over many decades or even centuries. Others, such as construction of suburbs or bark beetle infestations, occur in just a few years. High-intensity fire can alter a landscape in weeks or days. Some changes are natural, humans directly or indirectly cause some, and some are caused by a complex and only partially understood combination of anthropogenic and natural events.

LAND COVER CHANGES AND HYDROLOGIC IMPACTS

Examples of land cover change occurring in Arizona are described in the following sections, starting at the upper elevation of the basins and working downward to lower elevations.

Loss of Coniferous Forests

Over a century ago, Teddy Roosevelt succinctly described the critical importance of forests in water resource management:

> *The forests are natural reservoirs. By restraining the streams in flood and replenishing them in drought they make possible the use of waters otherwise wasted. They prevent the soil from washing, and so protect the storage reservoirs from filling up with silt. Forest conservation is therefore an essential condition of water conservation* (President Theodore Roosevelt, State of the Union Address, December 3, 1901).

Arizona's high-elevation coniferous forests, with Ponderosa pine being the most common species, have been described as our water towers. Natural, fire-influenced forests were relatively open, with large trees, meadows and abundant understories of grass and other groundcovers. Historic and more recent events have profoundly altered these forests and their ability to serve as natural reservoirs. Old-growth forests and biodiversity declined initially due to clear-cutting, which produced more runoff, floods and erosion from watersheds. This was followed by a century of fire suppression, in both logged and unlogged areas.

Figure 9.2 Old growth forests had large, well-spaced trees and understories; fire suppression created dense thickets.

But the old-growth forests were adapted to periodic low-intensity fires, which cleared out accumulated fuel loads without killing the larger trees. Over many decades, fire suppression in combination with high precipitation levels from 1975 through 1995 produced dense thickets of stunted trees, shading out understory grasses and forbs, which greatly decreased in abundance and diversity. Montane meadows shrank due to tree encroachment (Figure 9.2). Such forests produce less total streamflow, peak flows and base flows in streams. On the positive side, erosion and sediment loads in streams and rivers were reduced.

Over time, the high density of trees and accumulating deadwood increased fuel loads. Then, in the late 1990s, the current drought began. Many trees have died, or are dying, simply from lack of water. Drought-stressed trees cannot produce enough sap to ward off bark beetles, which have infested vast areas of the state, killing entire stands of trees. The combination of high forest densities, drought and beetles results in extreme fire danger and very large, especially severe forest fires. The last three years have seen an increase in the number, size and severity of stand-replacing fires. Should the current drought continue for two or more years, most of the mature coniferous forests in the state might well be lost.

The impacts of large, severe fires on watersheds are immediate and extreme, and difficult to forecast. In part, they depend on whether any grass or other groundcover can be established before intense summer rains begin. Runoff from previously forested areas that have been severely burned often is increased by a factor of 10 or even 100, resulting in serious flooding and erosion.

Downstream, runoff from burned areas often clogs stream channels with sediment and boulders. Water quality effects include severe short-term turbidity and near-zero dissolved oxygen in streams draining burned areas, which cause fish kills (Figure 9.3). Further downstream, increased nutrients and dissolved organics may promote algae growth in reservoirs. This can deplete oxygen levels, leading to fish kills, and may cause taste and odor problems for municipal water users. Sediments deposited in reservoirs decrease the volume of water that they can store (Figure 9.4).

Figure 9.3 Creek choked by sediment and ash after rain on Chedeski burn area, Arizona, 2002.

Flood plains—areas likely to be inundated by particular storm intensity—are immediately and greatly enlarged by these types of fires, and flash floods can cause property losses and even deaths. Over the ensuing years, as vegetation begins to become re-established, there likely will be more modest increases in runoff and stream base flow due to less water use by vegetation.

Pinyon-Juniper Expansion

Pinyon-Juniper woodlands have increased tremendously over the last several decades and continue to expand across the landscape of Arizona and the West (Figure 9.5). They are spreading both upslope and downslope and becoming denser. Today there are 50 to 60 million

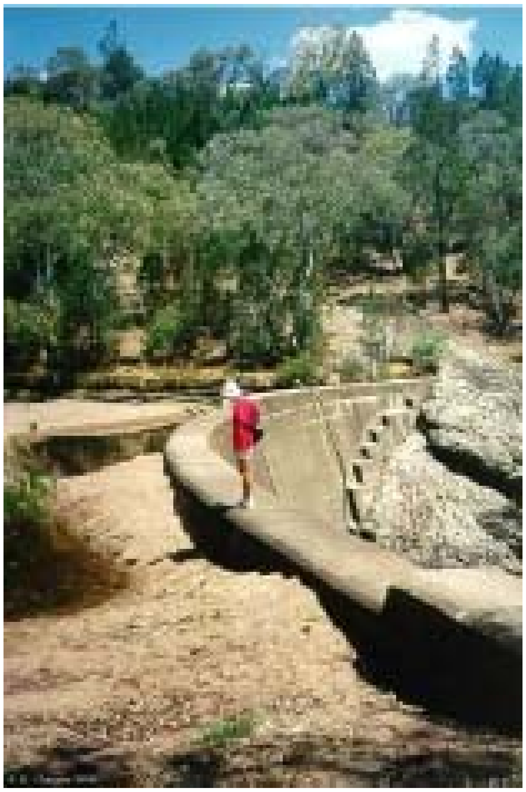


Figure 9.4 Sediments deposited downstream in reservoirs decrease the storage volume.

acres of pinyon-juniper in the western United States. There appear to be multiple causes of this land cover change:

> *[S]ubstantial changes have taken place in the pinyon-juniper woodlands in the past 150 years . . . this period was characterized by: (1) a warming climate following the Little Ice Age, (2) the period of heaviest use by European livestock, and (3) a decrease in wildfire frequency. These factors in combination, enabled [pinyon and juniper] trees to establish in and then dominate new communities, expand to higher and lower elevations, and, more recently dramatically thicken in tree densities and canopies of both existing and new stands* (Laycock, 1999).

The impacts of pinyon-juniper invasion of grasslands on basin hydrology include increased sediment fluxes during heavy precipitation events. Whether overall runoff increased is not clear. Some evidence suggests that periodic recharge events may be increased (Allen, nd; Wilcox *et al.*, 2003).

Woody Species Invasion of Grassland

Shrubs, such as creosote, have from the early 1880s to today invaded some 150 million acres of grassland in the Southwest, an area roughly the size of Arizona and New Mexico combined (Figure 9.6). Reasons include: overgrazing when

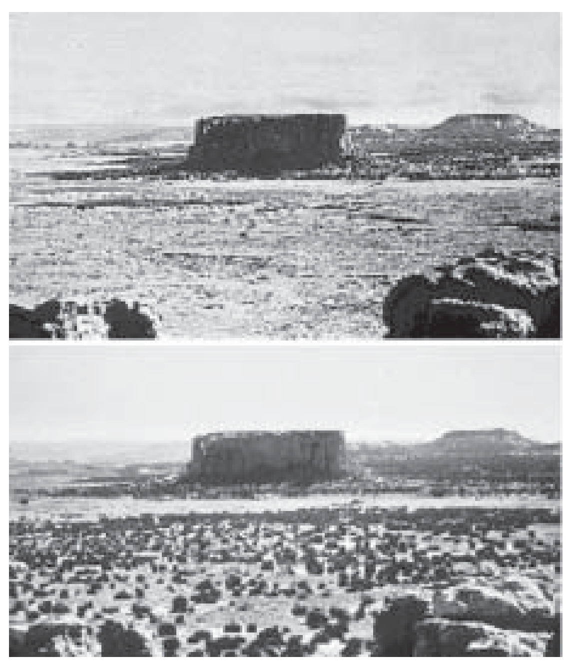


Figure 9.5 Spread of juniper near Acoma, New Mexico, 1899 and 1977.

Europeans first reached the area; periodic drought; and increased levels of atmospheric CO_2 that have benefited woody species more than grasses.

At somewhat lower elevations, mesquite rather than creosote is successfully supplanting grasses (Figure 9.7). Such incursions may take decades or occur quite rapidly. In the Upper San Pedro basin between 1973 and 1986, mesquite increased by 415 percent, at the expense of grasslands, which decreased by 15 percent. Runoff is increased with woody species, particularly during heavy precipitation events.

POPULATION PRESSURES AND DEVELOPMENT

On many desert basin floors, the most noticeable and rapid land cover changes are associated with development. Arizona's burgeoning population, shrinking household size, popularity as a location for second homes and relatively affordable housing, all are fueling a long-term boom in housing construction. Maricopa County continues to be one of the fastest-growing metropolitan areas in the United States, and Pima County is well above average. Some rural Arizona areas are growing even faster, including several communities along the Colorado River and the Mogollon Rim.

Traditionally, most housing developments occurred as urban in-fill or suburbs that displaced irrigated agriculture. Increasingly, development is occurring on raw desert land, often

Figure 9.6 Grasslands being supplanted by creosote in New Mexico.

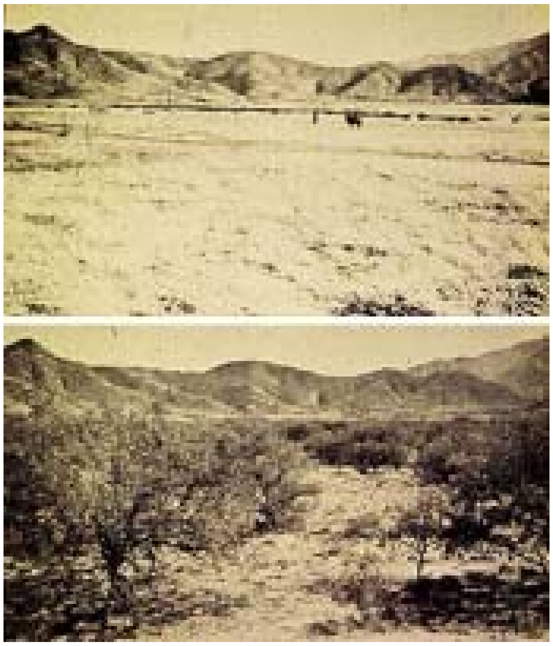


Figure 9.7 Less grass, more mesquite: changes from 1903 to 1941, Santa Rita range, south of Tucson.

well beyond the current urban fringe. Urban development of desert land does not have the benefit of offsetting an existing water use.

Changing Microclimates in Urban Areas

Urban areas create different microclimates than surrounding areas. Most notable is the "urban heat island" effect, caused by pavement, buildings and masonry walls absorbing heat during the day and radiating heat at night. Phoenix has a pronounced urban heat island effect, especially during the summer. This increases ET rates and the amount of water needed to maintain landscapes. It also significantly lengthens the growing season, and therefore the irrigation season, for a number of common landscape plants. To date, Tucson does not have a pronounced urban heat island effect.

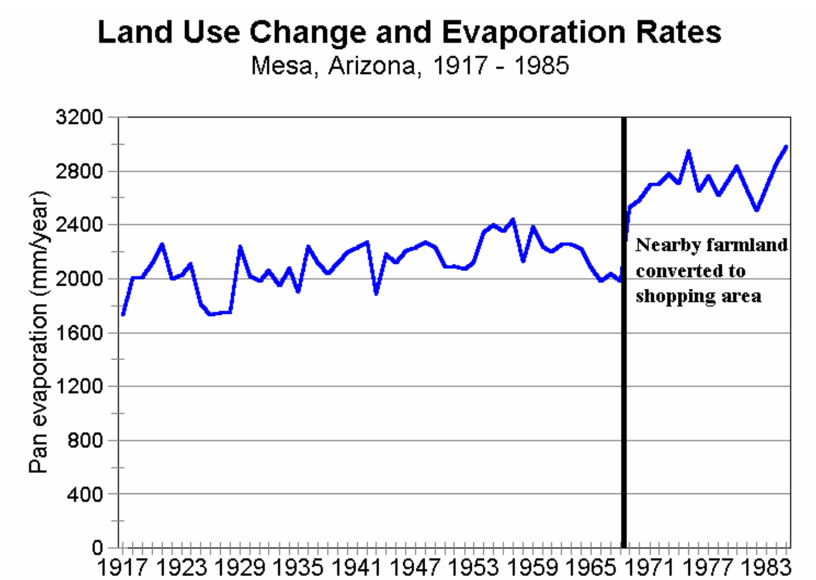


Figure 9.8 Evaporation Rates. Loss of nearby cotton field increased pan evaporation.

Loss of irrigated agricultural lands to development is creating warmer, drier microclimates. A classic example is recorded in pan evaporation data from Mesa, where conversion of a neighboring cotton field to strip mall increased evaporation rates 35 percent (Figure 9.8).

Pavement, rooftops, and other urban "hardscapes" also affect the partitioning of precipitation, increasing the amount and suddenness of runoff to washes and rivers, but decreasing area-wide infiltration. Recent research also suggests that urban areas like Phoenix can affect frequency and location of summer thunderstorms.

Impacts on Aquatic and Riparian Habitat

Dams, surface water diversions and groundwater pumping all have greatly reduced or eliminated the flow of water in many of Arizona's rivers. Not only does this deprive deeply rooted trees, such as mesquite, of water but under reduced flow regimes, native aquatic and riparian species such as fish, frogs, willows and cottonwoods often are unable to compete with introduced species such as tamarisk (salt cedar). The result is loss or severe degradation of most aquatic and riparian habitat in the state (Figure 9.9).

FRESHWATER BIODIVERSITY

Arizona's deserts, grasslands, forests and canyons attract visitors from around the world and delight those who live here. This variety of habitats supports one of the most diverse assemblages of plants and animals found anywhere in the United States. Arizona is an arid to semi-arid state with limited surface water. Nonetheless, freshwater systems, including rivers, streams, creeks, cienegas and other wetland types, and their associated riparian habitats, support a disproportionately high number of species relative to their aerial

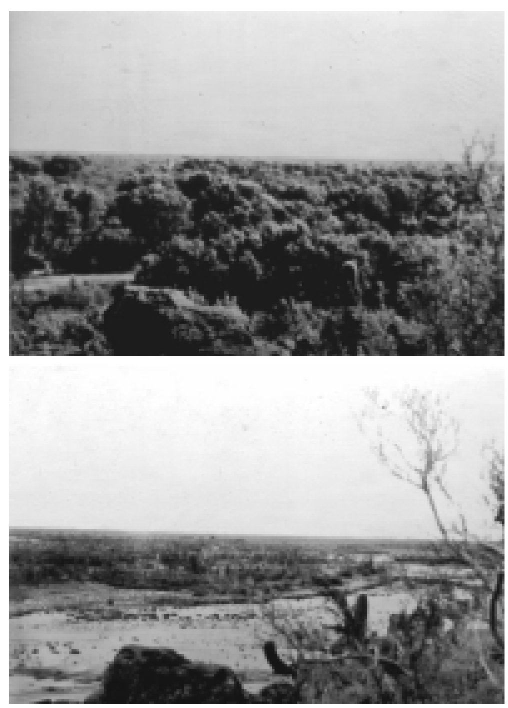


Figure 9.9 Santa Cruz River as seen from A Mountain, 1940 and 1975.

extent. In addition, riparian corridors provide migratory birds and pollinating insects and bats critical travel corridors.

Satisfying the water demands of a growing population while protecting aquatic ecosystems and ecological services requires a collaborative and informed water management approach that recognizes the value of aquatic and riparian ecosystems, develops the science to understand how water management choices may affect those systems, and works with stakeholders to derive water supply solutions that meet the needs of both human communities and natural ecosystems. Such a water management approach is challenged in Arizona by a lack of legal mandate to consider impacts to aquatic systems and by the legal separation of surface water and groundwater.

As a result, considerable damage has occurred to Arizona's freshwater ecosystems over the past 150 years (Figure 9.10). An estimated 91 percent of natural (unregulated) perennial flow reaches has been lost from Arizona's big rivers—the Salt, Verde, Gila, and Colorado Rivers—due to diversions, reservoir development and groundwater pumping. At least 35 percent of natural perennial flow miles have been lost state-wide (based on Brown, Carmony and Turner, 1981, Map of Perennial Streams). We have only recently begun to understand how natural freshwater ecosystems provide the myriad of services we rely on, including clean water, mitigation of droughts and floods, recharge of groundwater supplies, regeneration of soil and soil fertility, nutrient cycling and extensive recreational opportunities. Many of the top recreational attractions in Arizona are water-based, and hikers, birders, hunters and fishermen are a growing economic force.

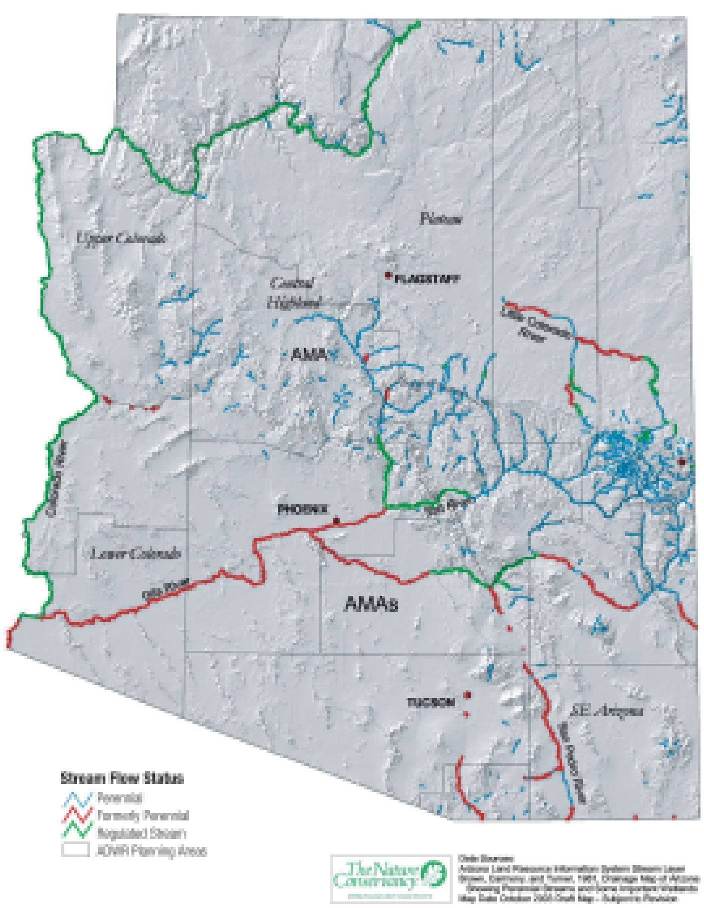
The distribution of freshwater biological diversity in Arizona may be illustrated by in part examining the number of native fish species in perennial streams. Arizona's native fish are found nowhere else on earth. They have survived droughts and flash floods for thousands of years. However, human-caused changes are taking a toll. One species, the Santa Cruz pupfish, is extinct and 20 of the 35 remaining native species or subspecies are federally listed as endangered, threatened or candidate for listing under the Endangered Species Act.

Arizona's rivers and streams also maintain Arizona's riparian systems, which support the highest densities of breeding birds found in North America. Riparian areas, particularly the cottonwood-willow forests, provide migratory corridors for birds, butterflies, bats and many other pollinators that winter in Central and South America and summer throughout the western United States and Canada. Depth to groundwater is a critical factor for many native riparian species.

The most basic need of fish is permanent water. Diverse riparian forests are maintained by the natural hydrologic cycle–floods, periods of base flow and shallow groundwater conditions. The majority of aquatic and riparian habitat in Arizona occurs in streams draining the Mogollon Rim and White Mountains. However, desert streams such as the Verde River, Aravaipa Creek and Eagle Creek exhibit the highest native fish diversity. Important riparian and aquatic diversity also occurs at locations in western and southeastern Arizona with permanent water.

Perennial flow in streams is maintained by discharge of groundwater from adjoining aqui-

Figure 9.10
Loss of Natural Flow in Arizona Streams



fers. Even streams supported by extensive aquifers may eventually be affected by groundwater pumping at locations distant from the streams. Examples include the Verde River and the San Pedro River, where rapid population growth is tapping groundwater aquifers whose discharge maintains high-diversity fish and aquatic habitat.

The National Research Council (2001) has stated that the capability of the nation to successfully meet challenges in water management while sustainably managing its water resources will depend, in large part, on employing new knowledge gained through research. Improved knowledge of groundwater recharge (water in) and discharge (water out) relationships and groundwater-surface water interactions is needed to better understand the consequences of groundwater use.

RIPARIAN PRESERVATION

There has been a growing awareness over the last 35 years that riparian habitats are important for more than biological diversity. They have measurable economic value, their aesthetics are increasingly appreciated and, in general, they enhance quality of life. Our understanding of how riparian areas work–the fluxes of water, carbon and energy, the relationship between surface water and groundwater and native plant communities, and how nutrients cycle through the systems–is incomplete, which makes preservation and/or restoration difficult. Riparian preservation and restoration efforts may include bank protection, fencing to exclude grazing, restoring the natural hydrologic regime, eradicating exotic species and restoring native species.

Experience and research reveal that knowledge of the system is required to avoid failure of preservation and restoration projects. For example, studies by researchers at Arizona State University have estimated the minimum depth to water and flow conditions needed to maintain a healthy cottonwood population. Riverine ecosystems are complex, yet our knowledge of the water needs of these systems, and their attendant services to humans, is increasing.

Restoring base flows can be difficult since Arizona’s water laws recognize and reward “development” of water, which means diverting it from a stream to further a traditional economic or domestic activity. In-stream flow rights were recognized only recently and have junior priority relative to other surface water rights. In addition to legal barriers, the costs of acquiring and converting senior water rights to in-stream rights can be high.

Social scientists have been tackling the issue of how to measure the value of the ecological services provided by riparian habitats with some success. Research a decade ago estimated the significant economic impacts of bird watchers along the Upper San Pedro River on the local economy. Other studies are examining what people are willing to pay to hike and camp in various river corridors. Research at the University of Arizona on the impact of proximity to and quality of riparian habitat on home values reveals a significant price effect.

Proactive water management planning and water supply development can protect and restore remaining aquatic and riparian systems and avoid costly and lengthy solutions that must be applied to highly degraded systems. The Multi-Species Conservation Plan (MSCP), developed over the last nine years for the Lower Colorado River by Arizona, California and Nevada is intended to avoid the potential economic and hydrologic consequences of protecting individual species. Although the proposed plan will cost $620 million over 50 years, with $77.5 million coming from Arizona water users, it likely will result in significant cost savings if implemented. Proactive planning to protect natural systems rather than individual species is clearly more effective in the longer term (National Research Council, 2004).

KEY REGULATORY AND INCENTIVE PROGRAMS

Some existing programs, both regulatory and incentive-based, provide tools for addressing issues involving environmental impacts on water resources and *vice versa*. Some of these key programs include:

- New federal programs for forest thinning aimed at reducing fire hazards and, in some cases, increasing available water supply,
- State and federal funds and non-governmental organization resources for eradicating exotic species, such as tamarisk, and re-establishing native species, especially in riparian corridors,

- Federal projects investigating the impact of altered dam releases on downstream flows and habitat, particularly in the Lower Colorado River,
- Arizona Water Protection Fund, which among other things, provides monies to groups seeking to preserve or restore riparian habitat (but legislation may sunset in 2005), and
- Heritage Fund, which allows for acquisition of habitat.

WATER QUALITY ISSUES AND ENVIRONMENTAL HEALTH

Water quality problems are not necessarily environmental problems, but some constituents do significantly affect habitat quality. Heavy metals generally are toxic at very low levels and can bioaccumulate or increase gradually within living tissues. This causes particular problems for long-lived fauna at the top of the food chain.

Mercury is a persistent, bioaccumulating toxin found in surface waters, making it both a public health and an environmental concern. It adversely affects the nervous system of both humans and wildlife. Found in lakes and rivers throughout the United States, eating fish is the single greatest source of exposure. The Arizona Department of Environmental Quality's strategy is to prevent new mercury from entering the environment and reducing contributions to surface water from existing sources.

Nitrate is a common groundwater pollutant, almost always from human sources, including fertilizers, septic tanks, sewage treatment plants and concentrated animal feeding operations. Large portions of some Arizona aquifers have nitrate concentrations that render the water non-potable. Nitrate can cause algal blooms in water and reduce dissolved oxygen that is required to maintain aquatic species.

Salinity is a large and growing water quality problem in Arizona surface water and groundwater. Measured as Total Dissolved Solids (TDS), salinity is composed of salts, minerals and metals. A natural component of all surface and groundwaters, low levels of salinity have negligible or even positive impacts. But undesirably high TDS levels affect virtually all water users. High TDS water harms plants and may limit biodiversity.

Endocrine disruptors (EDs) are compounds that disrupt the endocrine system by mimicking or inhibiting the effects of hormones. Sources include discarded and partially metabolized synthetic hormones and steroids, pesticides and industrial chemicals. EDs are persistent and can bioaccumulate. Since the common functions of the endocrine system are reproduction and metabolism, researchers are concerned that EDs accumulating in the environment may cause increased breast cancer, sterility, other endocrine illness, and changes in wildlife populations. Of particular concern are effluent-dominated waters, including flows in the Salt River through Phoenix. Current research is examining impacts of low-level exposure on native fish. The Environmental Protection Agency has made EDs a top priority and has established the Endocrine Disruptors Research Initiative.

The hydrologic cycle is strongly affected by land use and vegetation cover. To be successful, water sustainability efforts need to incorporate an understanding of the implications of changes in environmental conditions over time.