I. Introduction

A long history of conflict surrounds the Colorado River. Throughout the first part of this century, disputes generally arose over securing rights to use the river's water. Later, disputes centered on finding ways of developing and delivering water to support economic growth. The conflict-ridden process of "dividing" and then "developing" the waters of the Colorado preoccupied water planners throughout most of the 20th century.

As the end of this century approaches, the Colorado River basin is at a critical juncture. In 1990, for the first time, the lower U.S. portion of the basin (Arizona, California, and Nevada) used its full 7.5 million acre-foot (maf) legal entitlement,[1] spurring a time of unusual turmoil and transformation. Reaching this threshold has caused water officials to begin rethinking management strategies for the river. They are beginning to examine conservation, improved management, and voluntary transfers of water as strategies to promote more efficient use of water and to redistribute it toward higher-valued activities.

Because the upper basin currently uses approximately 50 percent of its basic entitlement and is not expected to use its full entitlement for some time into the future, water planners erroneously believe that there is enough water in the "system" to meet the needs of the lower basin for the next 50 years. It is thought that the single most important task facing lower basin water managers is to develop the mechanisms that will move water to its highest valued use, while continuing to satisfy the needs of current users. What many basin interests fail to recognize is that even at a time when a significant percentage of the river's flow has yet to be utilized for human purposes, the river's ecological systems are always in a state of deteriorating health because of major disruptions in the quantity, timing, and quality of the natural flows of the river.

Restoring and protecting these ecosystems will require that water be dedicated to these purposes. This will involve rethinking the way in which water use is planned, and incorporating concepts of sustainability into decisionmaking. For example, if water markets are to be created to help reallocate water to its highest valued use, then there needs to be a commitment to have them contribute to an environmentally sustainable river system. If dam operations are going to be modified to allow for more efficient use of water resources, then the impacts on aquatic ecosystems should be considered. To merely reallocate water towards the environment without a philosophical shift in water management is equivalent to treating only the symptom of a larger failure. Water for ecosystem restoration will need to come from existing uses or improved management practices. Fortunately, there are numerous ways of freeing up water that are not being widely utilized at this time.

At this juncture, there is a choice between conflict and fragmentation on the one hand, and cooperation and integration on the other. Throughout the history of the Colorado's management, piecemeal attempts have been made to solve the problems of water quality and scarcity. Years of conflict between basin states as well as severe environmental degradation show that this fragmented approach is ill-suited to the challenges that face the region. Stakeholders of the river are beginning to realize that the current predicament does not represent a "zero-sum game," and that solutions through cooperation are not only possible but desirable.

Stakeholders of the river are beginning to realize that the current predicament does not represent a "zero-sum game," and that solutions through cooperation are not only possible but desirable.

The historic series of compacts, treaties, and legislative acts that emerged from the piecemeal efforts to resolve conflicts in the basin is collectively known as the "Law of the

[1] Western United States water publications make use of the measure "acre-foot" rather than the more widespread metric equivalents for water volumes. Because all of the legal and institutional water allocations on the Colorado River are based on this unit, we will use it here. For our international readers, one acre-foot equals 1,233 cubic meters. Metric units are used for all other measures in this publication.

River." It constitutes the legal and institutional framework for Colorado River basin management, as well as the framework within which all parties now negotiate for the future. Because of the way the Law of the River was created, amended, and modified, each of the river's stakeholders now holds a different "hand of cards." For instance, due to agreements negotiated in the early 1920s and the mid-1930s, respectively, the urban areas of Nevada and California have limited rights to Colorado River supplies and are currently desperately seeking more water to meet growing demands. Arizona, on the other hand, currently has an abundance of Colorado River water rights, but more than half of them have an extremely junior priority due to concessions made in the early 1950s. During times of drought, Arizona's supply will be the first to be cut back, and for Arizona, reliability is its highest concern. In general, most farming communities of the lower basin are well endowed when it comes to water rights. Their rights are senior and entitlements are more than sufficient to meet their needs. However, as water laws are now structured, there is little incentive for them to conserve, due to a system that permanently takes away water that is not being put to beneficial use.

An understanding of the Law of the River is critical to considerations of how to achieve more sustainable patterns of water use within the lower Colorado basin. The following inset provides brief descriptions of the most important compacts, treaties, federal laws, legal decisions, and court decrees spanning nearly three-quarters of a century that determine how the waters of the Colorado River are now allocated and managed. Many believe that there is sufficient flexibility within the Law of the River to deal with the challenges that face today's water managers and stakeholders. The Law of the River, as it currently exists, provides a stable framework within which most parties feel comfortable working, and represents a sound and secure foundation from which to plan for the future. However, it should be pointed out that the Law of the River has been amended, modified, and refined throughout the century as unsolvable problems and unique circumstances have

Major Components of the "Law of the River"[2]

- ***The Colorado River Compact of 1922***

The 1922 Colorado River Compact, negotiated by the seven basin states and the U. S. government, divided the Colorado River basin into upper and lower portions and specified Lee's Ferry, Arizona, located at the mouth of Glen Canyon, as the dividing mark. At this time, the upper basin states worried that plans for Hoover Dam and other lower-basin water projects might deprive them of future use of the river because of the western water law doctrine of prior appropriation. The 1922 compact apportioned beneficial consumptive use of the Colorado's water on the basis of territory rather than prior appropriation, which allowed development to proceed in the lower basin while safeguarding supplies for the upper basin.

The compact negotiators assumed they were apportioning an average annual flow at Lee's Ferry of 18 million acre-feet (maf). They allocated 7.5 maf annually to both the upper and lower basins for beneficial consumptive use, and gave to the lower basin the right to the additional 1 maf annually assumed to be available from tributaries in the lower basin. Anticipating that dry cycles might diminish water availability in the lower basin, the Compact required the upper basin to release to the lower basin at least 75 maf during every consecutive ten-year period. The Compact also stipulated that any amount allocated to Mexico by future treaty would come equally from the upper and lower basins. Finally, the lower basin retained the right to use any water that the upper basin was not yet able to put to use.

- ***The Boulder Canyon Project Act of 1928***

The Boulder Canyon Project Act of 1928 provided congressional approval of the 1922 Compact, which had been ratified by all of the basin states except Arizona. The Arizona legislature did not ratify the Colorado River Compact until 1944. In approving the 1922 Compact, the Act implicitly endorsed the Arizona (2.8 maf), California (4.4 maf), and Nevada (0.3 maf)

[2] Sources: Howe and Ahrens 1988, Flug and Jackson 1993, Ingram et al. 1991, U.S. Bureau of Reclamation undated.

apportionment of the lower basin's 7.5 maf. The Act also authorized the construction of Boulder (later called Hoover) Dam for water supply, flood control, and hydropower generation in the lower basin, as well as the All American Canal for delivery of water to California. In addition, the Secretary of the Interior, through the Bureau of Reclamation, was authorized to enter into contracts for the storage of water in Lake Mead and the delivery of water for irrigation and urban use.

• *The United States - Mexico Water Treaty of 1944*

In 1944, the U.S. and Mexico signed a treaty on the Colorado River committing the United States to deliver 1.5 maf per year of Colorado River water to Mexico. It said nothing, however, about the quality of this water, which was not explicitly resolved until 1973 in a separate agreement. In times of surplus, it was agreed that Mexico would receive an additional 200,000 acre-feet per year. In accordance with the 1922 Compact, the upper and lower basins were each to supply half of the total amount obligated by treaty to Mexico.

• *The Upper Basin Compact of 1948*

The Upper Basin Compact of 1948 allocated Colorado River water among the upper basin states as percentage shares of the annual volume available, and based on each state's contribution to the river's flow: Colorado (51.75%), Utah (23%), Wyoming (14%), and New Mexico (11.25%). Arizona (a northern portion of which is in the upper basin) received a fixed allocation of 50,000 af per year.

• *The Colorado River Storage Project Act of 1956*

In 1956 the Colorado River Storage Project Act was signed, authorizing construction of several dams, including Glen Canyon Dam, which, when completed in 1963, formed Lake Powell on the Arizona-Utah border. The reservoir is able to hold the equivalent of two years of the Colorado's annual average flow. The dam was supposed to be the engineering solution to a problem that became evident during the decades following the signing of the 1922 Compact: the average flow of the river was considerably less than the Compact negotiators had assumed. Emerging hydrologic evidence suggested that if the upper basin were to consume its full 7.5 maf annual allotment, it would fail to meet its obligation to provide at least 75 maf to the lower basin during any consecutive 10 years. By building a large reservoir near Lee's Ferry, the upper basin could store water during wet periods and release it during dry periods, helping to meet its compact obligations while maximizing its own supply. Besides regulating the flow into the lower basin, Glen Canyon Dam, like Hoover Dam downstream, became a major generator of hydroelectric power and a "cash register" (through power sales) for constructing other water-supply projects.

• *Arizona v. California Supreme Court Decision and Decree, 1963-64,*

This major decision of the U.S. Supreme Court settled eleven years of litigation stemming from Arizona's desire to build the Central Arizona Project (CAP) so that it could use its full Colorado River apportionment. California disagreed with Arizona's contention that it was entitled to 2.8 maf of water from the mainstem of the Colorado River, claiming that Arizona's 2.8 maf basic apportionment included tributary flows from within the state. The Supreme Court rejected California's argument ruling that the Boulder Canyon Project Act of 1928 had determined Arizona's apportionment to be 2.8 maf not including tributary waters of the state. The Court's 1964 decree also enjoined the Secretary of the Interior from delivering water outside the framework of entitlements defined by law.

In its opinion in Arizona v. California, the Supreme Court also granted five Native American tribes along the Colorado River reserved rights to river water dating back to the establishment of their reservations, with the total amount of these rights to be quantified according to each reservation's "practicably irrigable acreage" (Ingram et al. 1991). Despite the 1908 decision Winters v. United States, in which the Supreme Court gave native American tribes priority to large amounts of water, the 1922 Compact negotiators had not addressed Indian water rights, leaving the issue to the courts and Congress. The issue continued to be ignored until this 1963 ruling. These native American entitlements are to be met from the water apportionment of the state in which the tribe is located. (Bates et al. 1993).

• *The Colorado River Basin Project Act of 1968*

The Colorado River Basin Project Act of 1968 authorized construction of the Central Arizona

Project (CAP) and other water development projects in the upper basin. However, in order to mollify California's concerns about reliability of supply in dry years and consequently gain California's support in Congress, Arizona agreed to subordinate CAP's entitlement to that of California's full basic apportionment of 4.4 maf. As a result, in times of shortage, deliveries to CAP will be eliminated before California's entitlements are affected.

- ***Minute 242 to the 1944 US-Mexico Treaty, 1973***

This addendum to the original 1944 U.S.-Mexico treaty was signed in an effort to resolve a dispute with Mexico over the deterioration in quality of the Colorado River water crossing the border. The water quality crisis was brought about in large part by the development of the Wellton-Mohawk Irrigation district in Arizona and the dumping of its agricultural drainage waters into the Colorado River. The salt content of river water entering Mexico rose from about 800 parts per million (ppm) to approximately 1500 ppm, with levels reaching as high as 2700 ppm in late 1961 (Wahl 1989). Minute 242 stipulated that the water received by Mexico should have salinity levels no more than 115 ppm higher than the water arriving at Imperial Dam.

- ***The Colorado River Basin Salinity Control Act of 1974***

This Act was passed by the U.S. Congress to help meet the Minute 242 obligation. Among the measures authorized by the Act were construction of a desalting plant at Yuma, Arizona, as well as a 10,000-acre reduction in irrigable acreage in the Wellton-Mohawk Irrigation District, either by purchase or through eminent domain (Wahl 1989).

- ***The Grand Canyon Protection Act of 1992***

The Grand Canyon Protection Act requires the Secretary of Interior to operate Glen Canyon Dam in such a way as to protect and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. This marked the first time that protection of downstream river resources were identified as a primary purpose of a Colorado River dam. The Act ensures that water releases from Glen Canyon Dam will stay within a range that protects the safety of Grand Canyon river rafters and boaters and that better maintains the sand beaches along the river uses by these boaters. The Act thus raised the priority of recreational values and lowered the priority of hydropower values in the operation of the dam.

Though not formally part of the "Law of the River," a number of federal statutes have bearing on how the Colorado River is, or could be, managed. The three most important are the **Clean Water Act**, the **Endangered Species Act**, and the **National Environmental Policy Act**, each of which may impose habitat maintenance or environmental protection mandates onto existing water rights allocations, dam operations, or river management procedures. They potentially could be used, for example, to strengthen the case for maintaining some levels of minimum in-stream flows to protect aquatic habitats and species. To comply with the National Environmental Policy Act — which requires that federal agencies consider the environmental impacts of their actions — the Secretary of Interior called in 1989 for a full assessment of the environmental impacts of the operation of Glen Canyon Dam. This led to an expanded Glen Canyon Environmental Studies research program, which could lead to specific recommendations for alternative dam operations that are more environmentally sensitive.

presented themselves. Thus, improving or modifying the Law of the River so that it can more efficiently address the new challenges facing the river's stakeholders is a viable option.

In sum, a golden opportunity now exists for water planners and diverse groups to work together to reform water policies and management procedures to promote more sustainable patterns of water use in lower Colorado River basin. The choice is increasingly clear: Down one road is the daunting task of trying to fix new problems within an existing framework that has proven not to work. Down the other is the opportunity for an innovative, comprehensive, and lasting approach to river basin management.

II. Current Water Planning and Management

The management and protection of water resources in the western United States have reached a crucial period. In the last several years, it has become obvious to many that traditional water policies, which permitted the region to become the agricultural and economic force it is today, are not up to the task of meeting the challenges of the 21st century. Yet water institutions and policymakers have shown limited initiative to develop new tools and approaches to try to understand and address the nature of these new challenges. Two trends exemplify the deadlock now gripping water management in many regions, including the Colorado: the conflict between urban, agricultural, and environmental water interests, and the inability of competing parties to agree upon adequate policies and standards that protect the renewability of the basin's freshwater resources.

During the 20th century, water-resources planning has typically focused on making projections of variables such as future populations, per-capita water demand, agricultural production, and levels of economic productivity to predict future water demands. As a result, traditional water planning always projects future water demands independent of, and typically larger than, actual water availability. Planning then essentially consists of suggestions of alternative ways of bridging this apparent gap between demand and supply.

The present method for projecting water demands assumes that future societal institutions and desires will be virtually identical to those in place today. Resource, environmental, or economic constraints are rarely considered. Even ignoring the difficulty of projecting future populations and levels of economic activities, there are many limitations to this approach. Perhaps the greatest problem is that it routinely produces scenarios with irrational conclusions, such as water demand exceeding supply and water withdrawals unconstrained by environmental or ecological limits.

In the past, the traditional response to these water balance deficits was to build major new facilities, but this option is rapidly closing because of federal and state budget problems, the perception that such structures often cause more problems than they solve, and the fact that few good sites remain. Yet efforts to explore non-structural alternatives have not been widely encouraged. Only a handful of water suppliers and planning agencies have explored demand-side management and improvements in water-use efficiency as a means of reducing the projected gaps. While this is certainly an improvement from the past, traditional planning approaches and a reliance on traditional solutions continue to dominate water management actions.

A major problem afflicting the lower Colorado River basin is the inability of water planners from seven different states and two different countries to gain consensus on priorities and values for the use of water. The current lack of agreement on a guiding ethic for water policy has led to fragmented decision-making and incremental changes that satisfy no one. Some suggest that the problem is primarily technical and that we only need more efficient technology and better management practices to satisfy the needs of all interests involved. Others believe that only a reorganization and integration of the region's now fragmented water planning process will rationalize water policy. Most likely the solution is a combination of the two beliefs.

What is needed for the coming decades is an integrated planning process that will resolve water conflicts by setting new goals and priorities for water-resource management.

Sound water policy for the 21st century will require solid planning, innovative thinking, and consensus building. Currently, there is no agreement on how the community of the lower Colorado River basin should be using its limited freshwater supply. There are only conflicts and litigation over every new proposed policy. What is needed for the coming decades is an integrated planning process that will resolve water conflicts by setting new goals and priorities for water-resource management. One goal of this report is to explore how water planners and stakeholders might begin to plan together for a sustainable water future. The following inset provides a description of the agencies and institutions of the lower basin that now play a major role in the region's water management.

Agencies and Institutions of the Lower Colorado

Arizona

Arizona Department of Water Resources (ADWR)

The Arizona state legislature established the Arizona Water Commission (AWC) in 1971, representing the state's first effort to manage water resources centrally. Assimilating the powers and duties of various state agencies, the responsibilities of the AWC included defending Arizona's rights and claims to interstate streams such as the Colorado River, planning the development of water, working with the federal government on water projects, supervising dam operations, collecting water data, and planning long-term water management at the statewide level (ADWR 1994). In 1980, largely due to sweeping changes in groundwater laws under the Groundwater Management Act (GWMA), the state legislature expanded the AWC to form the Department of Water Resources (ADWR).

Assigned the additional goal of eliminating long-term groundwater overdraft in the state, the ADWR was given an array of regulatory tools to arm it as the enforcer of the new Groundwater Code. In addition to serving as the primary agency responsible for groundwater management and regulation, the ADWR was assigned the task of providing technical assistance to the state courts then in the process of adjudicating the major streams of the state (ADWR 1994). The expansion of the ADWR's legal authority in 1980 made it the predominant influence in the quantification of surface and groundwater rights as well as the principal authority in deciding how water resources of the state were managed, planned, and protected. Unlike Nevada's Colorado River Commission and California's Colorado River Board, Arizona does not have a state agency that deals solely with Colorado River issues. Positions taken by the state of Arizona on matters concerning the Colorado are most often derived by the ADWR.

Long-term planning for the state occurs in two forms: 1) the Arizona Water Resources Assessment, which is a statewide assessment of present and projected future water resources by region and source type, and 2) the "Management Plans," which are a series of groundwater management plans geared towards the eventual elimination of groundwater overdraft in selected regions of the state. (For a more detailed description of Management Plans, see the discussion on groundwater overdraft.)

Central Arizona Water Conservation District (CAWCD)

The Central Arizona Water Conservation District (CAWCD) is a multi-county water agency created in 1971 to repay to the federal Treasury the reimbursable costs of building the Central Arizona Project (CAP). The CAWCD is also authorized to operate and maintain CAP and to collect charges for water deliveries. Encompassing Maricopa, Pima, and Pinal counties, the CAWCD is administered by a fifteen-member board which is popularly elected by residents of the three counties. Decisions made by the CAWCD regarding pricing structures for agricultural and urban water users will directly affect the rate at which Arizona moves toward utilizing its full Colorado River basic entitlement.

California

California Department of Water Resources (CDWR)

Currently, the CDWR's official mission is "to manage the water resources of California, in cooperation with other agencies, to benefit the state's people and protect, restore, and enhance the natural and human environments." Principal responsibilities of the CDWR include developing and managing the State Water Project, updating the California Water Plan, assisting local water agencies, educating the public, and providing flood control and public safety.

Primary responsibility for statewide water planning in California lies with the CDWR. For the last four decades, long-term water planning efforts have been focused in the "California Water Plan." The original California Water Plan was published in 1957 as Bulletin 3. Now officially known as Bulletin 160, updates to the California Water Plan have been published in 1966, 1970, 1974, 1983, 1987, and, most recently, 1993 (with an official final report released in the fall of 1994). While responsible for planning at the statewide level, the Department allows much of the planning specific to the Colorado River to be handled by the Metropolitan Water District of Southern California, the Colorado River Board of California, and irrigation districts of the region.

Colorado River Board of California (CRBC)

In 1937, the California state legislature established the Colorado River Board to represent California's interests on matters concerning the Colorado River. The ten-member Board is composed of representatives from the six public water agencies that receive Colorado River water, the directors of the Departments of Fish and Game and Water Resources, and two public members. Besides monitoring and analyzing the events in the Colorado basin, the agency also serves as the forum through which California's official position on Colorado River matters can be discussed and made public.

Nevada

Nevada Division of Water Resources (NDWR)

In the 1970s when federal money was being channeled towards statewide resource planning efforts, the Nevada Division of Water Resources (NDWR) created its first statewide inventory of water resources called "Water for Nevada" (NDCNR 1995). Developments in the early-1990s show a revived interest in statewide planning. "Nevada Water Facts," a statewide look at available and projected water resources and demands, was published by the Division of Water Planning in 1992; however, the report represents more of a resource assessment than a "plan." Efforts to develop a comprehensive statewide management plan are currently being undertaken.

A draft State Water Policy was released in March 1996 providing the framework and principles upon which a State Water Plan can be based. The State Water Policy "was prepared to guide the development, management, and use of the state's water and related lands" and will serve as the foundation upon which regional management plans, once they are completed, will bring the principles to fruition. In 1989 a governor-appointed 13 member Advisory Board for Water Resources Planning and Development (ABWRPD) was created "to provide local government involvement in the development of the water policy and water plans" (NDWR 1995). In developing the State Policy, the ABWRPD held 10 public meetings over a two and a half year period (NDWR 1995).

Colorado River Commission of Nevada (CRCN)

In 1935, the Nevada legislature created the Colorado River Commission of Nevada (CRCN) to serve as the state's watchdog over the Colorado River. Among its other statutory responsibilities, the Commission is required to "receive, protect and safeguard, and hold in trust for the state of Nevada" all the water and associated rights to which the state is entitled under federal law (NCRC 1990). While the CRCN does not hold any official planning responsibilities, it began producing a Colorado River Water Budget for Nevada's share of the Colorado River in 1983. The Budget is used as a planning tool providing "projected estimates for future water demands, supply capabilities, and return flow requirements through the year 2013" (NCRC 1990).

Federal and Other Agencies

US Bureau of Reclamation (Bureau)

Founded in 1902, the Bureau of Reclamation is a federal agency within the Department of the Interior that has historically been responsible for the construction of water development projects in the western United States. As of recent decades, the Bureau's role has evolved to include management of water resources and protecting fish and wildlife. Serving the role of "rivermaster" for the lower Colorado River, the Bureau is responsible for operating the Colorado River System of Reservoirs and authorizing contracts with water users.

Bureau of Indian Affairs (BIA)

The Bureau of Indian Affairs (BIA) serves as the point agency within the Department of the Interior, implementing the Secretary's trust responsibility for Indian tribes in the United States. The BIA works to ensure that the interests of Indian tribes are protected and acts as a facilitator between the federal government and Indian tribes. Concerning water issues, the BIA reviews technical studies, federal and state policies, and regulations making recommendations on the tribes' behalf.

US Fish and Wildlife Service (Service)

The principal responsibility of the Fish and Wildlife Service (Service) is to protect and enhance fish and wildlife and their habitats for the benefit of the public. The Service holds the primary authority for listing endangered and threatened species in accordance with the Endangered Species Act and developing and implementing recovery strategies for stressed ecosystems.

Colorado River Basin Ten Tribes Partnership

The Colorado River Basin Ten Tribes Partnership was formed in 1992 by the ten Indian tribes of the Colorado River basin that have quantified water rights to waters of the mainstem. Settlements were made through court decree, Congressional legislation, and statutory law. The Ten Tribes Partnership "seeks to protect and develop tribal water resources, advance tribal influence over the numerous aspects of river management that affect tribal interests, and stimulate dialogue with states, federal agencies, and non-Indian water users on matters of concern to tribes" (Checchio and Colby 1993). The tribes of the Partnership are:

Lower Basin	Upper Basin
Chemehuevi	Southern Ute
Fort Mohave	Northern Ute
Colorado River	Ute Mountain Ute
Quechan	Jicarilla
Cocopa	Navajo Nation

International Boundary and Water Commission (IBWC)

In 1889 an International Boundary Commission was established in accordance with the provisions of a Convention signed between the United States and Mexico in that year. Pursuant to the 1944 United States-Mexico Treaty, the Commission's name was changed to the International Boundary and Water Commission and was assigned the task of carrying out the principles of all past and present treaties. The IBWC maintains the status of an international body and is composed of two independent Sections — one in both the United States and Mexico (United States 1944).

Colorado River Salinity Control Forum (Forum)

During the 1960s and early 1970s, increasing salinity levels in lower reaches of the Colorado River became a concern for both lower basin users and users in Mexico. The Colorado River Salinity Control Forum was created within the United States in order to correct growing problems associated with water quality degradation — particularly salinity. The EPA, in 1974, required the Colorado River basin states, acting through the Forum, "to adopt and submit to the EPA water quality standards for salinity, including numeric criteria and a plan of implementation" consistent with the EPA's newly created regulations and policy for salinity control in the basin. Consisting of representatives from the seven basin states, the Forum worked to establish a policy for salinity abatement in the lower basin. Numeric criteria for allowable total dissolved solids levels and an implementation plan were developed by the Forum in an effort to control salinity in the basin.

Seven Colorado River Basin States/Ten Indian Tribes Group (7/10 Process)

Beginning in the early 1990s, representatives of the seven Colorado River basin states and the ten Colorado River Indian tribes began discussions to address the problems facing the Colorado River basin. Known as the "7/10 Process," state and Indian tribes officials have deliberated methods of improving water use efficiency, new river management strategies, and voluntary water transfers in order to extend supplies and reduce the risk of shortages.

While there are numerous other local, state, and regional agencies that affect the waters of the Colorado, they have mostly an indirect role in the planning and management processes. Water users of the Colorado River basin also play an important role in shaping how the river is managed and are discussed in more detail throughout the report.

III. Water “Imbalance” in the Lower Colorado River Basin: Present Supply and Demand

and planning.

While the upper Colorado River basin will play an integral role in the long-term management of the river, the focus of this report is the lower basin in the U.S. and the Republic of Mexico. We fully recognize that optimal solutions for a sustainable basin can only be achieved by considering the river as a whole, and through cooperation among all stakeholders within the basin. However, due to the fact that many of the more immediate and controversial issues are specific to the lower basin, much of our analysis centers on this region. The lower basin, as defined in this report, consists of southern Nevada (the Nevada Division of Water Planning’s Colorado River Basin Hydrographic Region — roughly the area of Clark and part of Lincoln Counties), southern California (the CDWR’s Colorado River and South Coast Hydrological Study Areas), the state of Arizona, and Mexico’s delta and Mexicali Valley regions in the states of Baja California, Norte and Sonora.

A. WATER SUPPLY IN THE COLORADO RIVER BASIN

A fundamental problem in the Colorado River basin is that the long-term planned use of the river’s water exceeds the reliable available supply. Because total legal entitlements to the river’s water are greater that the river’s average annual flow, the river has been deemed “over-apportioned.” The true average annual natural flow of the Colorado River is a subject of great debate. One of the principal assumptions at the time that the 1922 Compact was signed by the users of the upper and lower basins was that the long-term average flow of the river was close to 18 million acre-feet per year (Gleick 1988).

The Bureau of Reclamation currently estimates the average flow to be 15 million acre-feet (maf) measured at Lee’s Ferry, the official point dividing the upper and the lower portions of the basin, 17 miles south of Glen Canyon Dam (USBR 1995).[3] An additional 1 maf per year, mainly from Arizona tributaries, is estimated to join the river in the lower basin, making the officially estimated average flow approximately 16 maf per year. Using a variety of methods to reconstruct past climatic conditions, some scientists now believe that the long-term average runoff of the Colorado may be substantially below even this level. Numerous tree ring studies from around the basin suggest that the long-term average runoff of the river may be as low as 13.5 maf per year (Stockton and Jacoby 1976; Meko et al. 1995; Weatherford and Jacoby 1975; Kneese and Bonem 1986).

Even the higher estimates currently used by the Bureau of Reclamation are insufficient to meet total allocations under the Law of the River. The 1928 Boulder Canyon Project Act set a yearly apportionment of 7.5 maf of consumptive water use[4] for each the upper and lower basins.[5] At the same time, and later upheld by the US Supreme Court in 1963, Arizona was allocated an additional 1 maf. As part of the 1963 Supreme Court decision resolving Arizona’s dispute with California, it was determined Arizona’s additional 1 maf was to come from allowing Arizona the right to use the waters of its tributaries — this water was deemed supplemental to Arizona’s basic enti-

[3] During the 15 year period prior to the 1922 Compact, the Colorado’s annual flow averaged 18.1 maf. However, over the longer period of 1906-1990, the river’s annual flow averaged 15.2 maf at Lee’s Ferry. Tree ring studies suggest that the long-term historic flow may be as low as 13.5 maf.

4 Consumptive use on the river is defined as total diversions minus return flows.

5 The upper basin consists of the states Colorado, New Mexico, Utah, and Wyoming. The lower basin consists of Nevada, California, and Arizona.

tlement of 2.8 maf. The 1944 treaty with Mexico, which guaranteed that at least 1.5 maf be delivered to Mexico annually, puts total legal entitlements at 17.5 maf. Moreover, this amount does not include an estimated 1.5 maf of evaporation that occurs at reservoirs and along the river on an annual basis. Thus considerably more water is committed than the river can reliably deliver. However, since none of the basin states except for California and Mexico have yet utilized their full entitlements, current average annual consumptive use of water in the basin (including reservoir and mainstem evaporation and phreatophyte transpiration) plus deliveries to Mexico equals approximately 14.4 maf (CRBC 1996).

While the upper basin currently uses a little more than half of its basic entitlement, the lower basin is now facing the problem of approaching its legally apportioned limits. During three out of the last eight years, the lower basin has exceeded its basic entitlement of 7.5 maf. Table 1 illustrates the lower basin states' consumptive use from 1988 through 1995. Due to the upper basin's current underutilization, the lower basin's diversion of more than its apportionment has not yet become problematic.

B. WATER DEMAND AND USE IN THE LOWER COLORADO BASIN

Currently, some 23 million people of the lower basin are at least partially dependent upon the water resources of the Colorado River. Almost 74 percent, or 17 million people, reside in the greater Los Angeles and San Diego areas — outside of the actual boundaries of the basin, but supplied by a series of dams and aqueducts from the Colorado system. Growth rates in all three lower basin states are among the highest in the nation. Officials estimate that by 2020 there could be more than 38 million people living in the region. Table 2 depicts actual populations by lower basin subregion for 1990 and projected populations for 2020.

Table 1
Lower Colorado River Basin States' Consumptive Use of Colorado River Water
(Thousand acre-feet)

State	Entitlement	1988	1989	1990	1991	1992	1993	1994	1995 [a]	8 Yr. Avg.
Arizona	2,800	1,923	2,230	2,260	1,864	1,919	2,246	2,152	2,132	2,091
California	4,400	5,040	5,144	5,219	5,006	4,526	4,835	5,234	4,998	5,000
Nevada	300	129	156	178	180	177	204	228	225	185
Total	**7,500**	**7,092**	**7,530**	**7,657**	**7,050**	**6,622**	**7,285**	**7,614**	**7,355**	**7,276**

Source: years 1988-92 from GCAPAC 1993; years 1993-95 from USBR 1995 telefax.
[a] *Projection*

Table 2
Population Projections by Lower Colorado River Subregion

Planning Area	1990	2020 [a]	Percent Increase
Arizona	3,665,000	6,980,000	90
Southern California	16,757,000	26,318,000	57
Southern Nevada	800,000	1,630,000	104
Mexico (using Colorado River water)	1,700,000 [b]	3,240,000	91
Lower Colorado River	**22,922,000**	**38,168,000**	**67**

[a] *Arizona 2020 population estimates based on annual average percentage growth rates between 1990 and 2015. Nevada calculations based on annual average percentage growth rate from 2000 to 2030. Mexico calculations based on Baja California Norte growth rate from 1970-1990.*
[b] *Estimate is for 1993.*
Sources: CDWR 1993; CDWR 1994; ADWR 1994; UNLV Center for Business and Economic Research 1994; Reich 1984; CRBSCF 1993.

1. Water Use

Not only do each of the lower basin states and Mexico have a different degree of reliance upon the Colorado River, but subregions within the states do as well. Southern Nevada, for example, relies on the Colorado for almost two-thirds of its supply, while the urban areas of southern California depend on it for only 30 percent of their supply. At the extreme of dependence, California farming communities in Coachella and Imperial Valleys rely on the river for 95 percent of their annual supply. Table 3 and 4 show 1990 normalized water supply by source and demand by sector for each of the lower basin states and Mexico.

Table 3
1990 Water Supply by Source for Lower Basin States and Mexico
(Thousand acre-feet)

Source	Arizona	Southern California	Southern Nevada	Mexico	Regional Total
Local Surface	1,367	260	15	0	1,642
Colorado River	1,954	5,164	347 [a]	1,640 [c]	8,965
Other Imported	0	1,730	0	0	1,730
Reuse	119	89	22	0	230
Total Groundwater Use	3,334	1,260	147 [b]	823	5,704
Sustainable Pumping	2,334	1,163	96	727	4,320
Groundwater Overdraft	1,000	97	51	96	1,384
Region Total	**6,774**	**8,503**	**531**	**2,463**	**18,271**
Colorado as Percent of Region’s Supply	29%	61%	65%	61%	49%

[a] Southern Nevada’s Colorado River number is 1993-1995 average and are the total diversions for the region. Although there is a return flow credit system with wastewater returning to Lake Mead, diversions more accurately represent water supply for urban use.

[b] Based on perennial yields, sustainable pumping in the region is estimated at 80,570 af/yr with overdraft 65,962 af/yr. Due to groundwater artificial recharge programs in Las Vegas Valley Water District (average 13,360 af/yr) and North Las Vegas (1,640 af/yr)(15,000 af/yr total), sustainable pumping increases to 95,570 af/yr, while overdraft is reduced to 50,962 af/yr.

[c] 1952-1992 average annual diversion at Alamo Intake, Morelos Dam.

Sources: ADWR 1994, CDWR 1994, Eden and Wallace 1992, Southern Nevada Water Authority telefax undated, IBWC 1992, Comision Nacional Del Agua 1990.

Table 4
1990 Water Demand by Sector for Lower Basin States and Mexico
(Thousand acre-feet)

Source	Arizona	Southern California	Southern Nevada	Mexico	Regional Total
Urban	1,594	3,715	453	184	5,945
Residential	1,105	2,192	275	NA	3,572
Commercial	NA [a]	669	83	NA	752
Industrial	409	297	29	NA	735
Government	NA [a]	223	28	NA	251
Unaccounted/Other	80	334	38	NA	451
Agriculture/Livestock	5,180	4,083	77	2,279	11,619
Other/Environmental	NA	705	1	NA	706
Total	**6,774**	**8,503**	**531**	**2,463**	**18,270** [b]

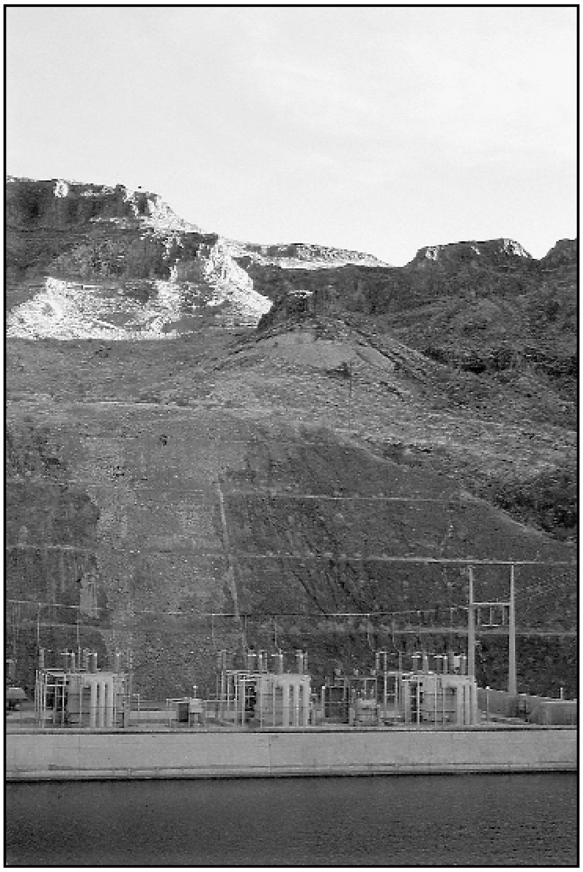
[a] Commercial and government included in Arizona’s industrial.

[b] Total supply and total demand difference due to rounding error.

Sources: CDWR 1994, Eden and Wallace 1992, Southern Nevada Water Authority telefax undated, Comision Nacional Del Agua 1990.

Arizona

The state of Arizona currently relies on the Colorado River for 29 percent of its water supply. Of the state's 2.8 maf Colorado River consumptive use entitlement, roughly 70 percent is currently being put to use. The remaining rights to the state's Colorado River apportionment lie with the Central Arizona Project (CAP), which, in 1992, delivered approximately a third of the project's 1.5 maf entitlement (see Table 5). As CAP diversions increase in the future, the Colorado River will represent a larger percentage of the state's water supply. The CAP represents the final piece in the water supply puzzle for Arizona water managers as all local surface and most accessible groundwater supplies have been fully appropriated. Providing the infrastructure that allows Arizona to fully utilize the remainder of its Colorado River apportionment, CAP's recent completion marks the conclusion of a 60-year effort to bring Colorado River water to the cities and farmers of Central Arizona.



CAP intake at Lake Havasu. CAP water is lifted nearly a thousand meters in elevation before reaching its terminus south of Tucson. (Photo by J. Morrison)

One of the major justifications for this massive project was to bring water that could substitute for existing agricultural groundwater overdraft (GCAPAC 1993a). The idea was that CAP water would initially be used to ease demand for mined groundwater and then gradually bring water to the cities to meet growing urban demands. Due to a series of complications and unforeseen additional costs associated with building CAP, Arizona's repayment obligation to the federal government rose substantially. While the amount Arizona will actually repay has yet to be determined (and appears will be decided in court), the additional costs have now made CAP water too expensive for most farmers to afford. Due to a provision in the contracts forcing payment even if water is not delivered, numerous irrigation districts have already or are considering filing for bankruptcy under federal law.

The issues surrounding the Central Arizona Project are relevant to the future management of the Colorado River for several distinct rea-

Table 5
Central Arizona Project Water Use 1988-1992
(Thousand acre-feet)

TYPE	1988	1989	1990	1991	1992	5 Year Average
Non-Indian Agriculture	325	544	479	272	135	351
Municipal & Industrial	79	109	151	77	104	104
Indian	64	62	115	72	71	77
Indirect Recharge	0	0	0	0	226	45
Total	**468**	**715**	**745**	**421**	**536**	**577**

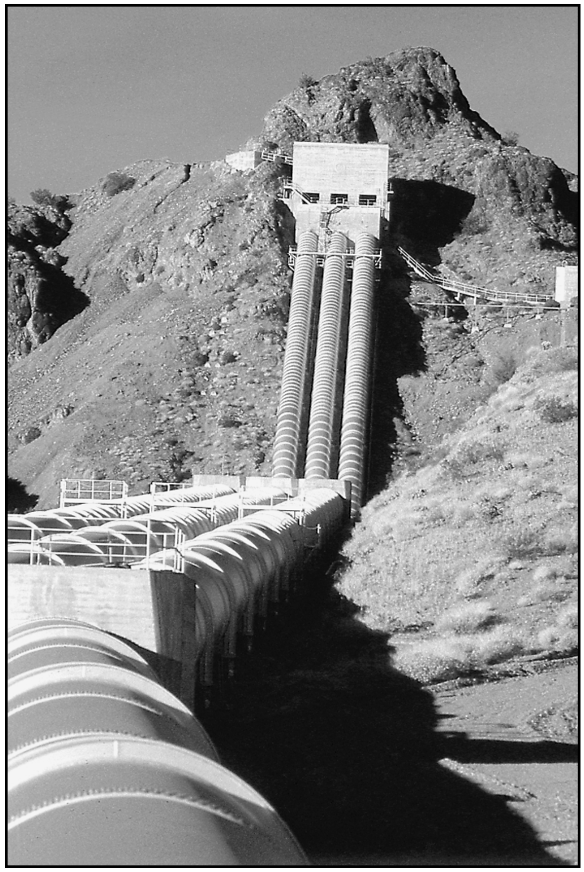
Source: GCAPAC 1993.

sons. Most immediately, how and to what extent CAP water is used will affect the pace at which the lower basin's total allotment is reached. For many years, Arizona Department of Water Resources (ADWR) projections estimated that CAP water would not be fully utilized until the 2040s (ADWR 1994). This underutilization of Colorado River entitlements has provided a cushion for other lower basin users, particularly southern California, which currently diverts Arizona's unused apportionment. However, recent developments in Arizona may lead to an increase in Arizona's use. In March 1996, Arizona's state legislature approved a bill establishing a groundwater recharge program that will ultimately use up to 25 percent of CAP's Colorado River entitlement for the next twenty years.

Specifically, the goal for the newly created Arizona Water Bank Authority (AWBA) is to recharge up to 400,000 af/year from 1996 to 2016 in an effort to provide protection against future droughts and shortages, meet the objectives of the 1980 Groundwater Code, which aims to eliminate groundwater overdraft in the state, and free up water to assist in resolving Indian water rights issues (ADWR 1996). The ABWA has set a short-term goal of recharging 100,000 acre-feet in 1997 via existing groundwater replenishment facilities (J. Holway, Arizona Department of Water Resources, personal communication, 1996). While the AWBA will surely speed up Arizona's quest to utilize its full Colorado River basic entitlement, as currently structured, other lower basin states stand to benefit as well. Water purveyors in California and Nevada will also be allowed to purchase and store water in Arizona. Similar to a forbearance agreement, accumulated credits for water stored in central Arizona will be able to be redeemed by those purveyors in the future by diverting directly from the river in proportion to water stored in the bank (ADWR 1996).

California

The Colorado River provides almost two-thirds of southern California's water supply. The river provides at least partial supply to almost 17 million southern Californians. The Colorado represents 30 percent of urban supplies and is one of the more dependable sources of surface water for urban Californians. When dry periods have affected water supplies imported from northern parts of the state, southern California has found the Colorado a stable source to meet its needs. The 60 million acre-foot storage capacity on the Colorado mainstem helps smooth out climatic variations, making it one of the more reliable sources of supply in the Southwest.



Gene Camp pump lift of MWD's Colorado River Aqueduct. In total, imported water accounts for almost 65 percent of Southern California's urban water supply. (Photo by J. Morrison)

Urban California water purveyors are concerned, however, that their current level of use of the river's water is in jeopardy. In terms of consumptive use, California currently accounts for as much as one-third of the river's annual average flow but its apportionment is only 27 percent. The Boulder Canyon Project Act of 1928 set California's basic consumptive use entitlement at 4.4 maf a year, but over the last decade, the state's average use has been over 5 maf per year. In 1931, California divided its Colorado River basic entitlement among the then seven southern California interests. Metropolitan Water District of Southern California (MWD), the wholesale water purveyor for the region's urban areas, was assigned a more junior priority water right than those of irrigation districts of the region, being allocated the last 550,000 of California's 4.4 maf apportionment. MWD currently has temporary contracts with the Bureau for 1.212 maf made possible by the fact that other lower Colorado River basin states have not historically used their full entitlements. But as demands increase in the lower basin and as California is forced to curtail its use to 4.4 maf, MWD's use of surplus flows will be the most significantly affected.

Farmers in southern California's Imperial Valley were among the first settlers to divert the river's water for irrigation in the lower basin. Due to their active presence during early negotiations that divided the waters of the river, California irrigation districts enjoy a secure right to almost 25 percent of the entire Colorado's annual average flow, irrigating over 400,000 hectares of farmland. In recent years, as a result of pressure from the State Water Resources Control Board to implement more efficient water use practices, irrigation districts in the region have entered into water conservation-and-exchange programs with neighboring urban water purveyors.

In addition to conservation projects with the MWD, negotiations for a long-term water transfer are currently being held between the San Diego Water Authority (SDWA) and Imperial Irrigation District (IID). Four of the five alternatives for the proposed agreement would involve the construction of a transfer facility to carry up to 500,000 acre-feet per year of water over various routes from the Colorado River to the city of San Diego. Estimated costs for the delivery system range between $1.9 and $3.5 billion depending on the route chosen (SDWA 1996). The fifth alternative would involve "wheeling" the water through the MWD-operated Colorado River Aqueduct (SDWA 1996).

Nevada

Total annual average precipitation of approximately 230 mm per year makes Nevada the most arid state in the nation (Geraghty et al. 1973). Water supply has long been a limiting factor in the state's development. Surface water resources of Nevada are nearly fully appropriated, meaning further development will have to come from groundwater supply or a reallocation of surface water rights (NDCNR 1992). Lacking dependable surface supplies, development in the southern portion of the state has historically been supported with the pumping of groundwater. Faced with severe groundwater overdraft conditions by the 1960s, Nevada looked towards the Colorado to augment its water supplies. In 1971, the completion of the Southern Nevada Water System (SNWS), a water distribution network, marked the first substantial diversions of Colorado River water in the state. Southern Nevada now relies on the Colorado for roughly two thirds of its water supply.

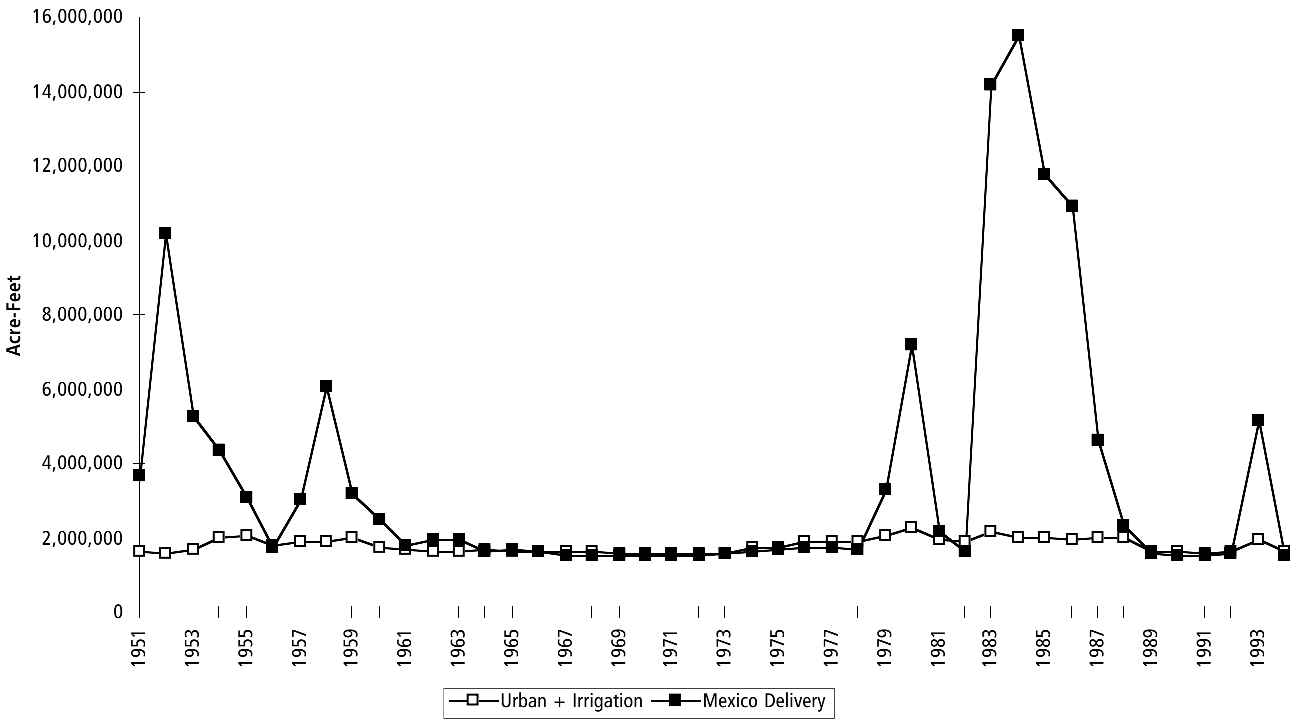
Historically, the "main player" in the distribution of Colorado water in Southern Nevada has been the Las Vegas Valley Water District (LVVWD). The agency is responsible, through a 1967 contract with the Colorado River Commission of Nevada, for maintaining and operating the SNWS. This state and federally funded water project is currently responsible for diverting more than 85 percent of southern Nevada's share of Colorado River water. Of the water delivered by the system, LVVWD consumes roughly 80 percent. In 1991, the Southern Nevada Water Authority (SNWA) was established to create a unified voice in regional water issues concerning the Colorado River. The SNWA consists of five formerly independent water purveyors in southern Nevada, and was created in response to the need for increased Colorado River supplies.

Mexicali Valley, Mexico

Communities of the Mexicali Valley region are heavily reliant upon the waters of the Colorado River. The river's water directly accounts for 60 percent of the region's annual average supply, with the remainder coming from groundwater pumping. A considerable portion of the groundwater supply, however, originates as Colorado River water which has been diverted and applied for irrigation. Water that does not evaporate or transpire when applied by farmers percolates into the aquifers. As a result, the Colorado represents an even higher portion of total supply for the region.

Pursuant to the 1944 treaty with the United States, Mexico is guaranteed the delivery of at least 1.5 million acre-feet of Colorado River water on an annual basis. In all but extremely

Figure 2
Colorado River Deliveries and Water Use in Mexico 1951–1994



high flow years when flood spills are released, 100 percent of the water reaching the northern international border is diverted for human purposes at the Alamo intake at Morelos Dam. Figure 2 depicts Colorado River deliveries and diversions to Mexicali Valley from 1951 to 1994.

C. CLIMATIC CHANGE AND FUTURE WATER SUPPLY AND DEMAND IN THE BASIN

The problem of global climatic change resulting from the buildup of "greenhouse" gases in the atmosphere greatly complicates the problem of hydrologic planning and management. All traditional hydrologic tools for evaluating the frequency and magnitude of extreme events or for allocating available water supplies assume that future conditions will look like past conditions. Global climatic changes, however, have the potential to significantly alter both water supply and demand in the Colorado River Basin, leading to new and unanticipated climatic regimes. While there is a broad scientific consensus that global climatic change is a real problem and that it will alter the hydrologic cycle in a variety of ways, there is little certainty about the form these changes will take, or when they will be unambiguously detected.

In spite of these uncertainties, the potential for severe impacts was noted by researchers in the mid-1980s and by international agencies by 1990:

> "The design of many costly structures to store and convey water, from large dams to small drainage facilities, is based on analyses of past records of climatic and hydrologic parameters. Some of these structures are designed to last 50 to 100 years or even longer. *Records of past climate and hydrological conditions may no longer be a reliable guide to the future. The design and management of both structural and non-structural water resource systems should allow for the possible effects of climate change.*" [italics added] (Proceedings of the Second World Climate Conference, Jager and Ferguson 1991.)

A separate study (Waggoner 1990) published in 1990 focused on the implications of global climate changes for the water resources of the United States. This study concluded:

> "Among the climatic changes that governments and other public bodies are likely to encounter are rising temperatures, increasing evapotranspiration, earlier melting of snowpacks, new seasonal cycles of runoff, altered frequency of extreme events, and rising sea level...*Governments at all levels should reevaluate legal, technical, and economic procedures for managing water resources in the light of climate changes that are highly likely.*" [italics in original]

Just last year the Intergovernmental Panel on Climate Change (IPCC) released a new study on the impacts of climate change (IPCC 1995). Among the most severe impacts they anticipate are effects on the hydrologic cycle and on human systems dependent on water. Reductions in snow depth and extent would affect the seasonal distribution of river flow and water supply for hydroelectric generation and agriculture. Inland aquatic ecosystems will suffer altered water temperatures, flow regimes, and water levels. Increases in flow variability, particularly the frequency and duration of large floods and droughts, would tend to reduce water quality, biological productivity, and habitat in streams. In regions like the Colorado Basin, they note that relatively small changes in temperature and precipitation, together with non-linear effects on evapotranspiration and soil moisture, can result in relatively large changes in runoff. Equally important as the geophysical impacts that may occur are the initial conditions of the water supply system and "the ability of water resource managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social, and legislative conditions (IPCC 1995)."

Recent major assessments of the impacts of global climatic changes specifically in the Colorado River Basin (Nash and Gleick 1991, 1993) concluded that water supply, hydroelectricity generation, reservoir levels, and salinity in the river were all extremely sensitive to both the kinds of changes that are expected to occur and to the policy options chosen to respond to them. For the purposes of this paper, we make no assumptions about how overall water supply and demand in the Colorado Basin will be affected by climatic changes. Until better information is available about the nature, direction, and severity of possible changes, important policy options are to improve the flexibility of the total system and reduce vulnerability to climatic variations. But this issue remains one of the greatest unsolved concerns in the region.

IV. Principal Challenges Facing the Lower Colorado River Basin

While the unsustainable nature of current water planning and management lies at the heart of the basin's problems, symptoms of the failing approach are visible throughout the basin. Prominent symptoms include decimated aquatic ecosystems, irreparably damaged groundwater aquifers, and heavily polluted agricultural and urban runoff. A comprehensive management plan aimed at achieving sustainable patterns of water use in the lower Colorado must, at a minimum, address three key challenges: revamp river management so as to protect endangered fish species and critical ecosystem values, free up water for restoration of the Colorado River delta, and eliminate long-term groundwater overdraft throughout the basin. Complicating the task of meeting these challenges is the need to maintain a vibrant agricultural sector, quench the thirst of growing urban areas, and fulfill the obligation of the federal government to settle unquantified, but potentially significant, Native American water entitlements.

A. STRESSED AQUATIC ECOSYSTEMS AND THE NEED TO REVAMP RIVER MANAGEMENT

Over the past 65 years, the Colorado River system has been stressed and transformed by water "development." Controlled by some 20 dams, the Colorado River ranks among the most heavily plumbed water systems in the world. Operation of the dams turns the river on and off like a faucet, and large-scale diversions deplete the river's flow. The result is a water environment dramatically different from pre-development conditions — including sediment balance, water temperature and flow, fish species composition, and riparian habitat and wildlife.

The river was given its current name by Friar Francisco Garcés, who looked over the rim of the Grand Canyon in 1776 and noted the muddy red color of the river below. The name Rio Colorado — "river colored red" — no longer suits the modern-day river, however. Dams have trapped virtually all of the river's sediment load, leaving the river clear and green. With sediment largely trapped behind Glen Canyon Dam, the lower half of the river is now mainly an erosive force: little sediment is deposited to replace what the river carries away. This has caused sandbars and beaches — key habitat for wildlife — to diminish or disappear. While perhaps an aesthetic plus, this clear water, according to Steven Carothers and Bryan Brown, authors of *The Colorado River Through Grand Canyon*, "is the single most significant factor in the development of a radically changed river and aquatic ecosystem" (Carothers and Brown 1991). To try to correct some of these problems, a test "flood" involving a "spring spike" release of water from Glen Canyon Dam, was conducted in March 1996. Secretary of the Interior Babbitt declared this test a success, with new beaches and fish habitat created downstream. It remains to be seen whether this kind of remediation will have long-term positive effects.

Storage infrastructure built along the Colorado has also evened out and cooled the river's temperature. Before construction of Glen Canyon Dam, for example, the water temperature through the Grand Canyon varied with the seasons and ranged from about 0 to 5 degrees C (32-40 degrees F) in winter to 24 to 30 degrees C (75-85 degrees F) in summer. Today, water released from Lake Powell comes from a depth of about 60 meters (200 feet) and is fairly uniform in temperature at about 9 degress C (48 degrees F). The steady temperature favors only a few species, but those

1992 federal legislation protecting the Grand Canyon has led to changes in river management. One example of this was a test flood release from Glen Canyon Dam in Spring 1996 that was conducted in an effort to recover aquatic habitat in the canyon.

species are abundant due to a surplus of food supplies. With the disappearance of sediment, the sun's energy no longer reflects off the water surface but rather penetrates the river to considerable depth. This has promoted the growth of algae, the base of the aquatic food chain, and greatly increased the river's biological productivity. Thus, biomass production on the river is high, but species diversity is low (Carothers and Brown 1991).

A third major change is in the composition of fish species. The Colorado boasts one of the most unique collections of fish fauna in North America, with as many as three quarters of its roughly 32 freshwater species recognized as endemic (Minckley 1991). Some of its species have persisted for more than 20 million years. Relative isolation and special river basin conditions allowed this unique assemblage to develop. The native fish tend to have bodily characteristics that suggest evolutionary adaptation to a severe habitat — including, for example, large and streamlined bodies, expansive fins, and thick, leathery skin (Minckley 1991).

Catfish and carp were introduced into the Colorado River drainage in the late 1800s, and by 1963 were the most common fishes in the river (Carothers and Brown 1991). Rainbow trout replaced carp as the dominant species in the late 1970s, after Glen Canyon Dam created river conditions ideal for its expansion. Today, the Lee's Ferry trout fishery is one of the best in the country. In one of the most outrageous stream "management" programs ever implemented, the U.S. Fish and Wildlife Service sponsored an attempt in 1962 to eradicate (by poisoning) all the native fishes in 500 miles of the Green River and its tributaries with the aim of cleaning the river of "trash" fish so that introduced rainbow trout could thrive (Carothers and Brown 1991).

Many native fish species have not adapted well to cold, clear water and have fared poorly under the post-development conditions. Since these species have been found in a variety of different habitat types in the Colorado system, however, dams may have played a lesser role in their decline than the introduction of non-native species to the river system. Some 50 fish species have been introduced throughout this century, either purposefully or accidentally, to bring the total number in the Colorado basin to about 80 (Minckley 1991). Many introduced species both preyed upon and competed with the natives, and combined with the physical changes brought about by Glen Canyon and other dams, have drastically reduced native species populations.

A fourth major change in the river system, although not entirely negative, has been the alteration of riparian vegetation, insects, and wildlife. Prior to construction of Glen Canyon Dam, the river deposited nutrients and sediment in the riparian zone, which provided an excellent substrate for vegetation. However, the high flood flows of the uncontrolled river regularly scoured this vegetation from the river banks and riparian zone. Once the flooding was controlled and the scouring effect reduced, plants took root and grew on the river banks, which provided more food and habitat and was a boon to insects and wildlife (Carothers and Brown 1991). Plants and wildlife also benefited from a more constant water supply year-round (Johnson 1991). As Johnson (1991) of the University of Arizona notes, "The Colorado River in Grand Canyon is the only major riverine ecosystem in the lowland Southwest where there has been an appreciable increase rather than a decrease in riparian vegetation and associated animal populations during the 1900s."

The number of bird species, for example, has risen sharply. The first Grand Canyon bird species checklist, published in 1937, showed 180 species. By 1978, the number of bird species known to exist in the Grand Canyon region had climbed to 284. By 1987, the number had grown to 303 species, of which 83% had been recorded in the Colorado River corridor. While the presence of more observers has played a role in this increase, there has also been an increase due to changes in habitat. Studies suggest that many of the newly seen species prefer to nest in non-native tamarisk bushes rather than native vegetation (Johnson 1991). Among the newcomer bird species is the threatened Bald Eagle, which was attracted by the abundant trout that it could easily see in the clear waters of the post-Glen Canyon Dam river (Carothers and Brown 1991). The Grand Canyon is also believed to support the highest concentration of breeding Peregrine Falcons in the lower 48 states. The peregrines like to feed on the abundant birds they catch over the riparian zone and the river itself (Johnson 1991). In addition to the peregrines, the California condor, Brown pelican, Yuma clapper rail, and Southwestern willow flycatcher are listed as endangered (USFWS 1995a).

In contrast to the changes in fish populations, it appears that no native riparian plants have been extinguished in the Grand Canyon region by post-dam conditions or the introduction of non-native species. Both indigenous and exotic vegetation have proliferated in the Canyon's riparian zone since 1963, but exotics still appear to be a relatively minor component overall. There are, however, three plant species in the greater lower basin that are endangered — the Arizona cliffrose, Brady pincushion cactus, and Sentry milk vetch (USFWS 1995a). There is concern that further habitat disturbance could weaken the native species and allow non-natives — particularly tamarisk, camelthorn, and Russian olive — to invade more aggressively (Johnson 1991).

1. Current Efforts to Prevent Species Extinction in the Lower Colorado River System

Most experts agree that without further action, it is almost certain that a number of fish species in the Colorado River system will become extinct. As a result of U.S. Endangered Species Act (ESA) listings, steps are now being taken to try to increase stressed populations and to prevent their extinction. Whether these actions will succeed, however, and whether they are the most appropriate ones to take, remain open questions. Appendix A provides a summary of federally-listed endangered and threatened species, proposed and candidate species, and species "at risk" in the Lower Colorado Ecoregion.

Four of the native "big river fish" of the Colorado River are now close to extinction — the humpback chub, bonytail chub, Colorado squawfish, and razorback sucker. Of these, only the humpback chub has a population able to reproduce in the lower basin. The Colorado squawfish appears extirpated in the lower Colorado, while the bonytail and razorback sucker are represented by only a few older fish in the wild. The Colorado squawfish and humpback chub were first listed as endangered under the U.S. Endangered Species Act in 1967; bonytail was listed in 1980; and the razorback sucker was listed in 1992 (Wigington and Pontius 1995). Speckled dace, flannelmouth sucker, and bluehead sucker are still fairly common (Minckley 1991). Table 6 depicts native and introduced species in the Grand Canyon stretch of Colorado River.

Without further action, it is almost certain that a number of fish species in the Colorado River system will become extinct.

The "critical habitat" for an endangered species is supposed to be designated within two years of that species' listing under the ESA, but the final designation of critical habitat for the four endangered Colorado River big fish species was not published until March 1994. The Fish and Wildlife Service (FWS) designated 3,186 kilometers of the Colorado River and tributaries as critical habitat for their survival (MacDonnell and Driver 1995), but the meaning of this designation remains vague. The FWS issued no specific prescriptions of flow regimes or other parameters. (This is not unusual. Of the 41 critical habitat designations for aquatic species on record as of 1994, just one prescribed a specific instream flow, for example.) The recovery plan for the humpback and bonytail chub were last revised in 1990, and that for the Colorado squawfish in 1991; no recovery plan has yet been developed for the razorback sucker. As with the critical habitat designation, the recovery plans, according to Robert Wigington and Dale Pontius (1995) "do not offer specific prescriptions on how the habitat must be protected, restored or managed."

Two important factors will affect future river management decisions — sections 7(a)(1) and 7(a)(2) of the Endangered Species Act. The first of these states that all federal agencies have an "affirmative duty" to use their authorities to help conserve a listed species — even when the agency is not actively reviewing a permit. Thus, the Bureau of Reclamation may have a responsibility to try to conserve listed endangered species through the flexibility it has in operating federal dams along the Colorado and its tributaries. Section 7(a)(2) says that all federal agencies must consult with FWS about

Table 6
Fishes of the Colorado River in the Grand Canyon, and Their Status

Fish	Family	Native or Introduced	Status of Native Species
Humpback chub	minnow	N	threatened with extinction; listed as endangered under ESA in 1967; a reproducing population exists in the Little Colorado River
Bonytail chub	minnow	N	threatened with extinction; listed as endangered under ESA in 1980; no natural reproduction; only a small number of older fish remain
Roundtail chub	minnow	N	classified as a "species at risk" of being listed as endangered under ESA
Colorado squawfish	minnow	N	appears extirpated in lower Colorado; listed under ESA in 1967
Speckled dace	minnow	N	classified as a "species at risk" of being listed as endangered under ESA
Common carp	minnow	I	
Red shiner	minnow	I	
Golden shiner	minnow	I	
Fathead minnow	minnow	I	
Redside shiner	minnow	I	
Flannelmouth sucker	sucker	N	classified as a "species at risk" of being listed as endangered under ESA
Bluehead sucker	sucker	N	classified as a "species at risk" of being listed as endangered under ESA
Razorback sucker	sucker	N	threatened with extinction; listed as endangered under ESA in 1992; no reproducing population; only a small number of older fish remain
Threadfin shad	shad	I	
Apache trout	salmon/trout	I	
Cutthroat trout	salmon/trout	I	
Silver salmon	salmon/trout	I	
Rainbow trout	salmon/trout	I	
Brown trout	salmon/trout	I	
Brook trout	salmon/trout	I	
Black bullhead	bullhead catfish	I	
Channel catfish	bullhead catfish	I	
Plains killifish	killifish	I	
Mosquitofish	livebearer	I	
Green sunfish	sunfish	I	
Bluegill	sunfish	I	
Largemouth bass	sunfish	I	
Striped bass	temperate bass	I	

Sources: Minckley 1991; Wigington and Pontius 1995.

whether any of their proposed actions will likely jeopardize the survival of a listed species or harm its designated critical habitat. If the FWS finds that the proposed action will likely jeopardize the species, it must suggest alternative ways for the federal agency to proceed without causing harm. Clearly, this section has implications for federal water and power projects in the Colorado system since operation of these projects may further jeopardize a number of listed species (Wigington and Pontius 1995).

In September 1994, FWS informed the Bureau of Reclamation that the Bureau's operation of water projects in the lower basin, either individually or cumulatively, would lead to formal consultations under Section 7 of the ESA if listed species or their critical habitat are found to be adversely affected by project operations. With the likelihood that FWS would issue a "jeopardy" finding, water users and the lower basin states elected to begin developing a Habitat Conservation Plan (HCP) under Section 10 of the ESA as an alternative for listed species recovery in the lower basin. Although the four big river fish species were the main motivation for initiating this HCP, over 100 other species have since been included in the conservation planning process. The program's study area includes the Colorado mainstem, reservoirs, and the 100-year floodplain (but not tributaries) from Glen Canyon Dam south to the border with Mexico.

Efforts to recover endangered species were formalized in August 1995, when the three lower basin states signed a Memorandum of Agreement (MOA) to develop a species conservation plan over a three-year period. This undertaking, now referred to as the Lower Colorado River Multi Species Conservation Program (MSCP), was originally intended to postpone section 7 consultations between the FWS and the Bureau and more ideally to obviate the need for a "jeopardy" finding by the FWS. However, due to the fact that section 7 federal consultations were resumed between the FWS and Bureau of Reclamation in early-spring 1996 as a result of pressures from environmental groups, the goal of the MSCP has changed. The MSCP is now working primarily to identify and develop conservation measures that the lower basin states hope will be adopted as Recommended Plans of Action (RPAs) by the FWS when it comes time for the agency to specify actions that must be taken to avoid a jeopardy opinion.

It is too early in the MSCP process to judge its likelihood of success. Lingering technical problems include the lack of specific knowledge about instream flow requirements and the degree of relief from predation needed for big river fish species recovery and protection. In the upper basin, even five years of research did not produce flow prescriptions that could be defended adequately against attacks by water developers and the states (Wigington and Pontius 1995). And if such flow requirements should be established for the lower basin, it remains uncertain whether and how they would be met, since augmenting flows would likely require cutbacks in current water use (Smith and Vaughan 1994).

Political problems center upon environmental groups' concerns that interim conservation measures being considered by the MSCP Steering Committee appear to focus more on augmenting hatcheries and adding more "grow out" facilities for the fish off-river, rather than on changes in river management or efforts to increase river flows. In order to appease fears that the MSCP was slanted more toward water development than species recovery, a Memorandum of Clarification was signed by lower basin states that addressed the environmental groups' concerns with the original MOA. Also as a result of the negotiations, environmental and tribal representatives were added to the MSCP Steering Committee, but the threat of litigation challenging the adequacy of the modified MSCP under the ESA remains.

B. RESTORATION OF THE COLORADO RIVER DELTA

The second challenge that must be dealt with in a transition toward sustainable river management is the need to find increased water supplies for restoration of the Colorado River delta. Only fairly recently has much attention been focused on the delta and the extensive changes it has undergone with the damming and diverting of the river. The Colorado delta is the result of one of the greatest accumulations of silt in the world. In its natural state, the river carried a huge load of sediment toward the sea: Between 45 million and 455 million metric tons of silt per year was transported through the Grand Canyon between 1922 and 1935 (Minckley 1991). The upper end of this range is extraordinarily high. For comparison, the Mississippi, with an average annual flow more than twenty-five times greater than the Colorado's, is estimated to transport an average of 200 million tons of sediment per year (Milliman and Meade 1983). Historically, about 20-30 percent of the Colorado's silt load was deposited in the river's floodplain and along its channel, the rest being transported to the river mouth, where it built up the delta.

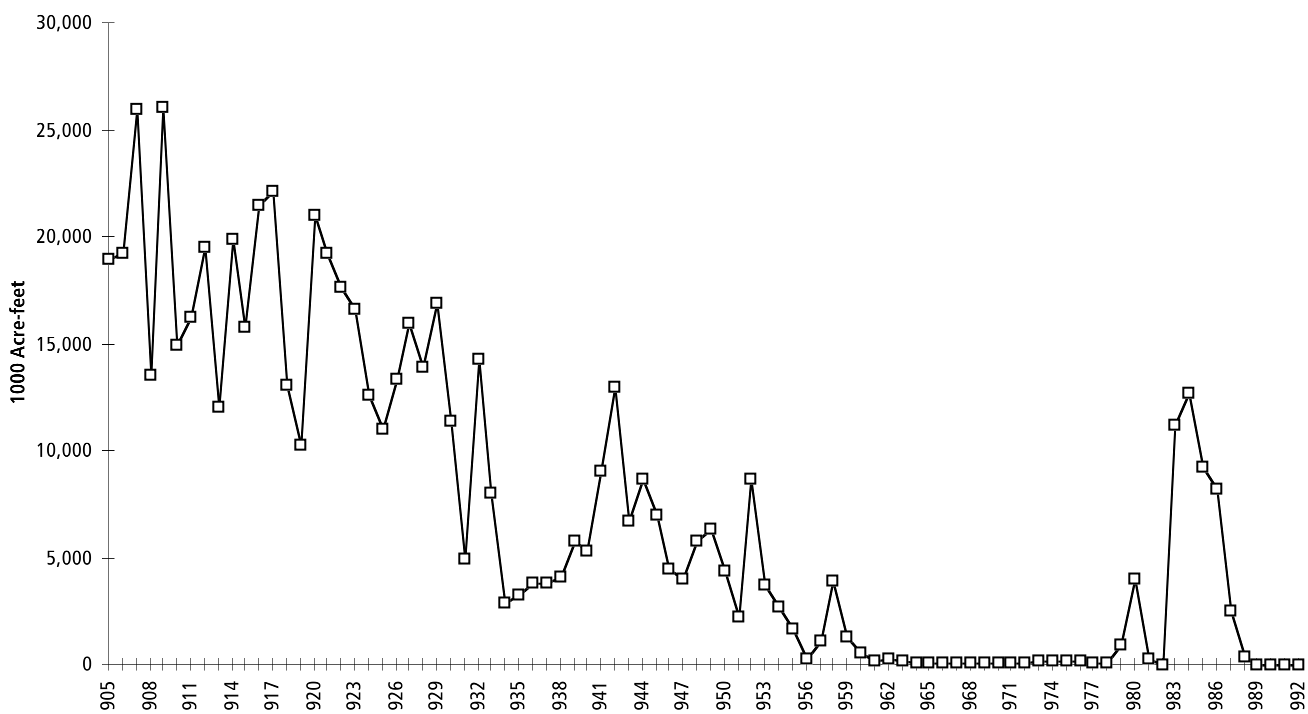
Prior to major dam construction, the delta was lush with vegetation. It supported some 200-400 plant species, along with numerous birds, fish, and mammals (Glenn et al. 1992). A substantial amount of flow reached the river's mouth at the Sea of Cortez. This flow not only replenished the delta with silt, but delivered nutrients that helped support fish and other life in the sea. Although much of the delta has been converted into irrigated farmland, some 250,000 hectares of delta land remain at its southern end (Glenn et al. 1992). The delta and upper Gulf comprise the largest and most critical desert wetland in the American Southwest, as well as one of the world's most diverse and productive sea ecosystems.

Dams and upstream diversions have dramatically reduced the natural flow of water, silt, and nutrients to the delta. Except for unusually high flood years, virtually the entire flow of the river is now captured and used — and has been since about the early sixties, when Glen Canyon Dam was completed.[6] (See Figure 3) This loss of inflow has desiccated the delta — turning the area below the farmland into a patchwork of salt and mud flats. Wetlands have shrunk, and now exist mainly where agricul-

[6] Flow readings at El Meritimo, the southernmost measuring station on the Colorado, were discontinued in 1968 because there was nothing to measure (Wilson 1994).

Figure 3

Flow of Colorado River Below All Major Dams and Diversions 1905–1992



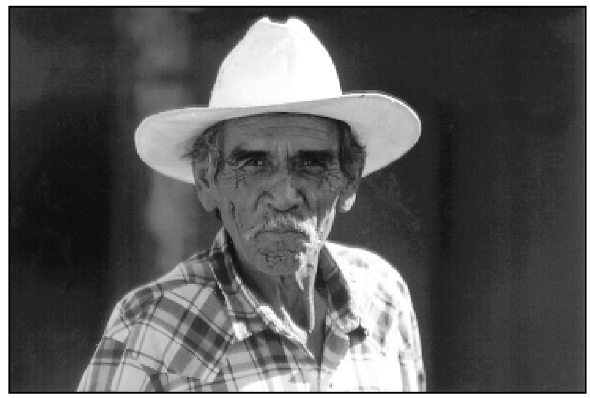
tural drainage water is discharged or where groundwater upwells onto the mud flats (Glenn et al. 1992).

The reduction in freshwater flow has also cut the influx of nutrients to the sea and reduced critical habitat for nursery grounds. Catches from the upper Gulf shrimp fishery have dropped off steeply, and other fisheries are in decline as well. While there is little hard data to correlate these declines with the drop in river flows, local fishermen and most biologists working on these issues believe that the lack of nutrient-rich water inflow is a major cause. Indeed, the "golden days" to contemporary fishermen in the upper Gulf apparently refer to the mid-1980s, after the high flood year of 1983, when huge snowmelts in the upper Colorado basin caused the river to flow at rates not seen for several decades. According to Alejandro Robles, executive director of Conservation International's Mexico program, many upper gulf fishermen believe that the rare flood flows of January 1993 temporarily brought back substantial numbers of fish species that had become scarce in the region (A. Robles, Conservation International, personal communication, 1995).

Such rare events, however, will not halt or reverse the long-term decline of the ecosystem — or the economic, social, cultural, and ecological toll that is following on its heels. A large number of species that depend on the lower Colorado-upper Gulf ecosystem are now threatened or endangered, including the green sea turtle, the Yuma Clapper Rail, and the desert pupfish. Much attention has focused on the vaquita, the world's smallest porpoise and most endangered sea mammal, whose population in the upper Gulf is believed to number just a few hundred. Also of special concern is the totoaba, a steel-blue fish that grows up to more than 2 meters in length and 140 kilograms in weight, that once supported a popular sports and commercial fishery. The fish used to breed in large numbers in the formerly brackish, shallow waters of the Colorado estuary while spending most of its adult life in the deeper waters of the upper Gulf. Between habitat degradation and overfishing, the totoaba is now on the verge of extinction (Wilson 1994).

The Cocopa Indians, a 2,000-year old culture of fishers and flood-recession farmers, are suffering badly. Traditionally, these "people of the river" ate fish three times a day, but now they are lucky to have fish once a week. Since the water is too salty to grow certain traditional crops like melons and squash, their diets have become less healthy. There is little work for the younger tribal members, and the number of families in the settlement has declined (Carrier 1991). Anita Williams, a Mexicali-based expert on the Cocopa, wrote in 1983: "By the end of the twentieth century, the [Cocopa] may no longer be river people at all" (Williams 1983). That prediction is showing signs of coming true.

Several communities of the upper Gulf — including El Golfo de Santa Clara, San Felipe, and Puerto Peñasco — were initially founded as fishing camps, and fishing remains the basis of their economic and cultural viability. According to researchers Marcela Vásquez León, Thomas McGuire, and Hernan Aubert, shipyards are closed, packing plants are operating well below capacity, local businesses are suffering, and households are struggling to survive. "The most direct way to revive the economies of the upper Gulf," they write, "is to revitalize the upper Gulf itself..."(León et al. 1993). And most believe this will require more freshwater inflows from the Colorado River itself.



The livelihood of the Cocopa Indians has been threatened by a lack of water reaching the Colorado River delta region. (Photos courtesy of Deborah Fryer)

1. Wetlands Protection and Restoration: A Clear Priority

Although it would take the removal of the entire Colorado River system of reservoirs to restore the delta to anything like what it was 70 years ago, valuable wetland systems remain in the delta and are an urgent priority for protection. Modified management of flood waters and agricultural drainage water in the delta region could restore a substantial area of critical wetland habitat. Actions to protect and restore delta wetlands would benefit a number of endangered species, waterfowl and other birds, and, potentially, the Cocopa. Figure 4 shows the remaining wetland areas of the Colorado River delta.

Figure 4
Map of the Colorado River Delta Region

1 = Rio Hardy wetlands, 2 = Cienega de Santa Clara, 3 = El Doctor wetlands

Source: Glenn et al. 1996.

- The Cienega de Santa Clara, in the eastern portion of the delta, covered only about 200 hectares in the early seventies, when it was fed solely by artesian springs and some agricultural drainage water from Mexico's San Luis Irrigation District. Then, in 1977, the United States constructed a large canal, known as the M.O.D.E. (Main Outlet Drain Extension) drain, extending from the Wellton-Mohawk irrigation district to the Cienega de Santa Clara. Previously the Wellton-Mohawk drainage had emptied into the lower Colorado and contributed substantial quantities of salt and chemicals to the river just before it crossed into Mexico. The 80-kilometer, concrete-lined canal was constructed to rechannel the drainage until the Yuma desalting plant came on line as a permanent solution to the problem of the quality of the river water entering Mexico.

Although highly saline, Wellton-Mohawk drainage is now the largest source of water supply for the Cienega de Santa Clara. (Courtesy of Dale Pontius)

  Because start-up of the Yuma plant has been delayed, this agricultural drainage water has continued to flow into the Cienega. Based on satellite images, the area of brackish wetland has grown to some 20,250 hectares (50,000 acres) and, ironically, is now the largest wetland bird habitat remaining in the delta. Among the species documented there are the endangered Yuma clapper rail, Virginia rails, least bitterns, American coots, dowitchers, white-faced ibis, green-backed heron, and black-crowned night heron (Glenn et al. 1992). The Cienega may be home to the largest remaining populations of endangered Yuma clapper rails and desert pupfish (Glenn et al. 1996). Also of note is the presence of Palmer's grass, one of only two endemic grasses in the Sonoran Desert. This grass formerly covered large areas of the lower delta and produced a grain harvested by the Cocopa. Because Palmer's grass requires only 24 hours of freshwater to germinate and can survive in salty water thereafter, it could prove an important future grain crop in dry, water-short regions of the world.

  Should the Yuma desalting plant come on line and the Wellton-Mohawk drainage be channeled to it rather than to the Cienega, these vital wetlands could largely disappear. The Cienega could be protected by a commitment from the U.S. Department of Interior to continue to provide Wellton-Mohawk drain water to it.

- The Rio Hardy wetlands, on the western side of the delta, had historically been described as a gallery forest of cottonwoods and willow transitioning at its southern end into a plain influenced by tides from the upper Gulf. This is the area that American naturalist Aldo Leopold visited in the early 1920s and described as a "milk-and-honey-wilderness," and the area of the "green lagoons," abundant with wildlife (Leopold 1949). It was also one of the areas where the Cocopa lived and thrived.

  From about 1947 through 1983, the Rio Hardy wetlands were sustained by the backing up of freshwater behind a natural dam in the Colorado River channel (the Hardy joins the Colorado before it enters the Gulf). Despite the fact that no water from the Colorado entered this area from 1963 to 1980, the wetlands covered some 18,200 hectares (45,000 acres). The principal sources of the freshwater were discharges from geothermal wells near the source of the Hardy as well as agricultural drainage. After the major flooding on the Colorado in 1983, the Rio Hardy wetlands grew to some 66,400 hectares (164,000 acres). Since then, the wetlands have shrunk considerably, in part because the 1983 floods destroyed the natural dam that had backed up the freshwater inflows. Their area has dropped as low as about 1,200 hectares (3,000 acres), although they expand considerably during flood periods, as during the 1992 floods on the Gila River (Glenn et al. 1996).

Ducks Unlimited has recommended that a structure be put in place to re-create the effect of the natural earthen dam that had backed water into the lower Rio Hardy wetland and helped sustain it. They estimate the cost at about $250,000, and believe this would restore much of the former wetland area below the confluence of the Hardy and Colorado. No decision or action has been taken on this as yet (Glenn et al. 1996; E. Glenn, Environmental Research Laboratory, personal communication, 1996).

- The El Doctor wetlands, named for a small settlement on the eastern side of the delta, are supported by artesian springs that bubble up onto the salt and mud flats. Because the water that sustains them is of much lower salinity, these "pozos" have greater plant species diversity than either the Rio Hardy or Cienega wetlands. They cover an area of about 500 to 700 hectares (1,250 to 1,750 acres), and have been fairly stable over the last two decades, although they are subject to overgrazing by local cattle (Glenn et al. 1996).

In sum, the remaining wetlands of the Colorado River delta are high priority conservation sites. They not only support rare and endangered species, but serve as vital population reservoirs for a wide variety of species. Today, the wetlands are threatened primarily by potential water management decisions that may not treat them as important natural assets.

In an effort to protect remaining aquatic habitat, Mexico created the Upper Gulf of California and Colorado River Delta Biosphere Reserve in 1993. (Courtesy of Dale Pontius)

C. ELIMINATION OF LONG-TERM GROUNDWATER OVERDRAFT IN THE LOWER COLORADO BASIN

A third major challenge to sustainable management of the lower Colorado River basin is the elimination of long-term groundwater overdraft. Freshwater is a renewable resource — it can be used in a manner that maintains its long-term availability. Groundwater stocks are renewable on timelines that depend upon the rate of inflow of water, the rate of withdrawals of water, and the geophysical characteristics of the aquifer. In some instances, overpumping of groundwater — the extraction of groundwater at a rate that exceeds the rate of natural recharge — can continue for some time with no adverse consequences if the aquifer is permitted to be recharged during wet periods. Thus a short-term nonrenewable use may still be compatible with long-term renewability. There are, however, ways in which renewable freshwater resources can be made nonrenewable, including mismanagement of watersheds, overpumping of groundwater, land subsidence, and aquifer contamination. Water policy should explicitly protect against these irreversible activities.

Not only is groundwater mining fundamentally unsustainable, but there are numerous practical reasons why water managers of the basin should act swiftly to eliminate the practice. One problem with mining groundwater is that it gives the illusion of a healthy supply-demand equilibrium. However, as water quality degrades at lower levels and becomes less economically attractive due to high energy costs, water users who currently rely on that water will be forced to find new sources of supply. The potential turmoil this can cause in the lower Colorado River basin is considerable.

Another problem is that overdrafting can lead to permanent losses in groundwater storage capacity — one of the potentially cheapest ways of storing water for dry years. Groundwater depletion that leads to irreversible aquifer compaction limits future storage options, limiting the flexibility of conjunctive use programs. An illustration of this in California is a USGS (1992) study estimating that over 16 million acre-feet of groundwater storage capacity has been permanently lost due to aquifer compaction in the Central Valley. The number of dams — and their economic and environmental cost — that would have to be built in the Sierra Nevada to provide that same capacity is an open question.

Lastly, the negative economic and human health consequences of overdraft need to be considered. For example, land subsidence and earth fissures caused by groundwater depletion in southern Arizona have damaged a variety of engineering structures including buildings, roads and highways, railroads, earthen dams, water wells, water distribution systems, and sewage disposal facilities (Schumann, Laney and Cripe 1985). Furthermore, substantial aquifer compaction can decrease the gradient of stream channels leaving subsiding regions and can lead to increased flooding. Agricultural and urban lands in southern Arizona that had subsided between 1 and 4 meters by the early 1980s were flooded to record depths in 1983, with more than $50 million in damage reported (Federal Emergency Management Agency 1983). Fissures in the earth's surface as a result of land subsidence can also lead to aquifer contamination. Fissures that extend to water table depths can provide a direct path for pesticides, herbicides, chemical fertilizers, and animal wastes that may be contained in surface runoff from agricultural lands (Schumann, Laney and Cripe 1985). Lacking the sediment filtration that accompanies natural percolation, this groundwater represents potential human health risks.

Groundwater overdraft currently takes place on an annual basis in all three of the lower basin states and also in Mexico's Mexicali Valley. This problem persists despite legislation and other efforts to bring it under control. If the transition to long-term sustainable management of the basin is to take place, the problem of long-term groundwater overdraft will have to be resolved. It is in the interests of lower basin stakeholders and water managers to do so.

1. Arizona

Both the construction of the Central Arizona Project (CAP) and passage of Arizona's landmark 1980 Groundwater Management Act (GWMA) were aimed at correcting the state's long-standing problem with groundwater overdraft. As a result of the GWMA, three types of area designations with varying levels of water management were created in response to the varying groundwater conditions of the state. Most regions of the state fall into the lowest tier of management and are minimally regulated. They include most of the central highlands, the Little Colorado River Plateau, and northwestern and southeastern Arizona.

The second tier of management applies to the Irrigation Non-expansion Areas (INAs). There are currently three INAs in Arizona — Douglas, Joseph City, and Harquahala Valley. While not heavily monitored and restricted, these three areas have had their total allowable irrigated acreage set at the historic levels leading up to the GWMA's implementation. Active Management Areas (AMAs) represent the third tier and are the most extensively managed hydrologic regions of the state. Regions classified as AMAs were those with severe overdraft problems. Pursuant to the Groundwater Code, four regions — Tucson, Phoenix, Prescott, and Pinal — were created and were ordered by the state to have their groundwater resources closely managed and regulated. A fifth AMA, the Santa Cruz AMA, has since been added.

Most long-term groundwater planning in Arizona focuses on the AMAs and manifests itself in the form of "Management Plans." According to the GWMA, the Arizona Department of Water Resources (ADWR) is required to produce a series of five Management Plans for each of the AMAs spanning the forty-five year period from 1980 to 2025. Each AMA has different management goals. For example, the Phoenix, Tucson, and Prescott AMAs are hoping to reach "safe yield" — the condition where extractions do not exceed recharge — by 2025. The goal of the Pinal AMA, an area primarily dependent on agriculture, "is to allow the development of non-irrigation water uses, extend the life of the agricultural economy for as long as feasible, and preserve water supplies for future non-agricultural uses" (ADWR 1991).

If the transition to long-term sustainable management of the basin is to take place, the problem of long-term groundwater overdraft will have to be resolved. It is in the interests of lower basin stakeholders and water managers to do so.

Historically, average groundwater withdrawals in the AMAs have exceeded recharge by approximately 2 maf per year (ADWR 1994). Largely due to Colorado River water delivered through the CAP, current groundwater mining in the AMAs has been reduced to a rate of approximately 1 million af/year. Despite their "safe yield" goals, current programs and planned measures will alleviate only a portion of the groundwater overdraft in the AMAs by the "safe yield" deadline. Based on current Management Plan projections, groundwater overdraft in the AMAs will exceed 620,000 acre-feet per year in 2025. Table 7 shows water supply and demand by AMA for 1990 and 2025.

Table 7

Water Demand and Supply by Arizona Active Management Area 1990 and 2020

Active Management Area	Phoenix [a]		Pinal		Prescott		Tucson	
Year	1990	2025	1990	2025	1990	2025 [f]	1990	2025 [h]
Population	2,277,957	5,335,649	70,000	146,000	52,200	128,400	751000	1693000
Water Demands (1000 Acre-feet)								
Agricultural								
Indian	NA	NA	162	209	NA		NA	NA
Non-Indian	NA	NA	963	635	NA		NA	NA
Total Agricultural	1,773	1,015	1,125	844	17.8	5.4	113	99
Municipal	749 [b]	1,419 [b]	14	26	7.4 [e]	17.7	143	297
Industrial	69	106	25	53	2.4	3.3	69	98
Other	87	87	181	141 [d]	2.2	2.2	5	5
Total Demand	**2,677**	**2,627**	**1,345**	**1,064**	**29.8**	**28.6**	**330**	**499**
Water Supply (1000 Acre-feet)								
Surface Water								
Local Surface	892	940 [c]	182	172	0.7	0.7	0	10 [i]
Imported Surface (CAP)	264	601 [c]	604	441	0	7.6	0	215
Total Surface	1,156	1,541	786	613	0.7	8.3	0	225
Groundwater								
Natural Recharge	41	41	26	26	7	7	62	62
Incidental & Artificial Recharge	783 [c]	373 [c]	339	128	9.6	8.7	58	52
Overdraft (Groundwater Mining)	587	245	190	287	10.7	-1.1 [g]	200	90
Total Groundwater	1,412	660	555	441	27.3	14.6	320	204
Reclaimed Water	109	426	4	10	1.8	5.7	10	70
Total Supplies	**2,677**	**2,627**	**1,345**	**1,064**	**29.8**	**28.6**	**330**	**499**

[a] *Phoenix AMA data are projections based on Second Management Plan Programs being fully implemented. It is the expected scenario.*

[b] *Phoenix AMA includes urban irrigation.*

[c] *Phoenix supply data are modified such that the Augmentation classification given in their Second Management Plan is distributed to the appropriate categories. In 1990, 5 thousand acre-feet (taf) artificial recharge. In 2020, 25 taf artificial recharge, 10 taf from weather modification to CAP, 48.2 taf from Plan 6 to Local Surface, 22 taf added to CAP, 73.5 taf water transfers added to Imported Supply.*

[d] *Includes 29 taf to satisfy a water transfer that will send water in 2000 to the city of Mesa, Phoenix AMA.*

[e] *Includes Exempt Wells.*

[f] *2025 projections assuming conservation and CAP water.*

[g] *Negative number signifies recharge to aquifer.*

[h] *Projections assuming Second Management Plan Conservation.*

[i] *Supply augmentation project designed to trap surface runoff currently not being utilized (Rillito River Project).*

While there are numerous reasons for the continuing shortfall, the method in which groundwater pumping rights were established within the AMAs as a result of the Groundwater Management Act in 1980 is surely a contributor. Grandfathered irrigation rights were based on the amount of acreage irrigated *with groundwater* from the years 1975 to 1980 (ADWR 1987). The land must have been irrigated with groundwater some time during that timespan in order to have the "rights" to irrigate it in the future. While grandfathered irrigation rights do not specify how much groundwater can be pumped, they do determine which acres have the rights to be irrigated into the indefinite future.

The problem is that the aforementioned time period dedicated to establishing the grandfathered rights were some of the highest years of groundwater withdrawals in the history of the state. 1975, 1976, and 1977 were, respectively, the second, fourth, and third highest years of statewide groundwater withdrawal since pumping rates began being recorded in the early 1900s (USGS 1994). This means that grandfathered irrigation rights were established at a time when farmers were either intentionally or unintentionally irrigating with groundwater the majority of the land they owned, disproportionately representing the historical practices of the farmers. The law is now structured so that these farmers are entitled to irrigate the same land with groundwater even if it contributes to overdraft.

2. California

Groundwater overdraft in the southern California portion of the basin is estimated at some 97,000 af/year (See Table 8) (CDWR 1994). Of that, 80 percent occurs in what the California Department of Water Resources calls the Colorado River Hydrological Study Area (HSA) — an area predominantly supporting agriculture. Unlike the state of Arizona, very little is being done at the state planning level to abate long-term overdraft conditions. Groundwater withdrawals in the state, with the exception of certain adjudicated basins in the greater Los Angeles and Central Coast areas, are largely unregulated and unmonitored.

Table 8
Groundwater Overdraft in Southern California 1990 and 2020

Region	1990	2020
South Coast HSA	22,000	0
Colorado River HSA	75,000	70,000
Southern California	**97,000**	**70,000**

Source: CDWR 1994, CDWR 1993

According to official CDWR estimates, 70,000 acre-feet are expected to be mined in the Colorado River HSA in the year 2020 (CDWR 1993). While the CDWR has excluded overdrafted groundwater as a source of supply when conducting water balances and making future projections, there is no explicit plan to reduce long-term groundwater overdraft in the state (Gleick et al. 1995).

3. Nevada

Groundwater overdraft conditions have existed in southern Nevada for many decades. Until 1971, when surface supplies were diverted from the Colorado River, groundwater was the main source of water for the region. The Colorado River Basin Planning Area is one of fourteen major hydrological areas in the state and consists of 27 sub-basins that underlie Clark and Lincoln Counties. Like the Colorado River itself, groundwater resources in the region have been over-apportioned. Groundwater pumping permits issued by the State Engineer's Office grossly outstrip estimated perennial yields in almost half of the sub-basins in the region.[7] The sum of "total volume of permitted, certified, and vested groundwater rights which are recognized by the State Engineer and can be withdrawn in a groundwater basin in any given year" is classified as committed resources for the sub-basin (NDCNR 1992). Out of the 27 sub-basins in the Colorado River Basin Planning Area, 12 have committed resources that exceeded the perennial yield of the sub-basin. Table 9 shows the estimated perennial yield and 1992 committed resources for the 12 sub-basins of southern Nevada that are over-apportioned. In total, legal rights to use groundwater in those sub-basins exceeds the sustainable yield by almost 300 percent.

[7] The perennial yield is the amount of usable water from a groundwater aquifer that can be economically withdrawn and consumed each year for an indefinite period of time (NDCNR 1992).

Table 9
Over-Apportioned Groundwater Sub-Basins of Southern Nevada as of 1992

Sub-Basin	Estimated Perennial Yield	Committed Resources	Difference
Las Vegas Valley	30,000 [a]	91,257	-61,257
Lower Meadow Wash	5,000	29,680	-24,680
Panaca Valley	9,000	28,134	-19,134
Virgin River Valley	3,600	13,307	-9,707
Dry Valley	1,000	7,207	-6,207
Piute Valley	600	6,612	-6,012
Black Mountains Area	1,300	6,612	-5,312
Clover Valley	1,000	3,690	-2,690
Rose Valley	100	1,660	-1,560
Colorado River Valley	200	1,606	-1,406
Patterson Valley	4,500	5,435	-935
Garnet valley	400	930	-530
Total	**56,700**	**196,130**	**-139,430**

[a] Revised estimate for Las Vegas Valley perennial yield based on personal communication with Bob Coache, State Engineer's Office, 1996.

Source: NDWR 1992.

Committed resources, however, do not represent the amount of water actually pumped in a given year. Water officials in southern Nevada have little idea how much water is currently being pumped in the region. Since "inventories" are conducted by the State Engineer's Office in only a few of the sub-basins of the Colorado River Basin Planning Area, there is no clear idea what percentage of permitted water rights (committed resources) is actually being pumped in the region. Very few of the wells outside the Las Vegas Valley sub-basin are metered and use is sporadic. Farmers in the northern portion of the Colorado River planning area, for example, may only exercise a groundwater right to supplement irrigation during dry years. During times of above average rainfall, no pumping will occur in those areas. However, if groundwater rights are not exercised through the pumping of groundwater at least once every five years, the State Engineer has the authority to revoke the permit, though groundwater permits have seldom been revoked.

Statewide, a gross estimate of the percentage of committed resources that is actually pumped is 50 percent (H. Ricci, Nevada State Engineer's Office, personal communication, 1996). With the exception of the Las Vegas Valley sub-basin, which utilizes closer to 75 percent of its water permits, this rough average also holds true for sub-basins in the Colorado River planning area (B. Coache, Nevada State Engineer's Office, personal communication, 1996). Given that almost half of the over-apportioned basins are thought to utilize more than 50 percent of committed resources (B. Coache, Nevada State Engineer's Office, personal communication, 1996), this planning area estimate can be seen as a conservative number for determining groundwater use. Table 10 shows estimates for groundwater overdraft in the region.

4. Mexico

Due to a paucity of data in Mexico on groundwater use and the geo-hydrology of the region, it is difficult to determine with certainty whether, or to what degree, water is being overdrafted. Preliminary calculations here estimate groundwater overdraft to be roughly 96, 000 af/year in the Mexicali Valley and Mesa Arenosa aquifers. This estimate is based upon the difference between known supply and 1988 to 1989 demand for the region. (See Table 11).

Table 10
Groundwater Use in Nevada's Colorado River Planning Area

	Sub-basin	Perennial Yield	Committed Resources	Estimated Pumping	Estimated Overdraft[a]
212	Las Vegas Valley	30,000	91,257	68,443	38,443
205	Lower Meadow	5,000	29,680	14,840	9,840
203	Panaca	9,000	28,134	14,067	5,067
222	Virgin River	3,600	13,307	6,654	3,054
214	Piute	600	6,612	3,306	2,706
198	Dry	1,000	7,207	3,604	2,604
215	Black Mountains	1,300	6,612	3,306	2,006
204	Clover	1,000	3,690	1,845	845
199	Rose	100	1,660	830	730
213	Colorado River	200	1,606	803	603
216	Garnet	400	930	465	65
207	White River	37,000	25,007	12,504	0
209	Pahranagat	25,000	9,714	4,857	0
219	Muddy River	37,000	8,328	4,164	0
220	Lower Moapa	16,500	5,660	2,830	0
202	Patterson	4,500	5,435	2,718	0
201	Spring	4,100	1,164	582	0
211	3 Lakes	5,000	521	261	0
218	California Wash	2,200	506	253	0
200	Eagle	300	297	149	0
223	Gold Butte	500	92	46	0
208	Pahroc	21,000	7	4	0
224	Greasewood	300	5	3	0
221	Tule Desert	1,000	4	2	0
206	Kane Springs	0	0	0	0
210	Coyote Spring	18,000	0	0	0
217	Hidden	200	0	0	0
	Total	**224,800**	**247,435**	**146,532**	**50,962**[b]

[a] Assumes no incidental recharge from irrigation.

[b] Due to artificial groundwater recharge programs in the Las Vegas Valley sub-basin (LVVWD 13,360 af/yr and North Las Vegas 1,640 af/yr (15,000 total annual average)), sustainable pumping in the region increases from 80,570 to 95,570, while overdraft is reduced from 65,962 to 50,962 af/yr.

Source: NDWR 1992, H. Ricci and B. Coache, State Engineer's Office, personal communication, 1996.

Table 11
Mexicali Valley Water Balance 1988-1989

Water Supply	**Acre-Feet**
Local Surface	0
Colorado River[a]	1,640,000
Other Imported	0
Sustainable Groundwater Extractions[b]	727,400
Direct Reuse	0
Total	2,367,400
Water Demand (1988-1989)	
Urban	184,500
Agriculture (Irrigation District No. 14)	2,278,600
Total	2,463,100
S&D Balance (Groundwater Overdraft)	**-95,700**

[a] Alamo intake 1952-1992 annual average (IBWC 1992).
[b] Mexicali and Mesa Arenosa aquifers.
Source: Waller 1993; CNDA 1990.

Sustainable groundwater extractions in the region are said to be 727,400 af/year (Waller 1993), with another 1,640,000 af supplied by the Colorado River in an average year. The total urban and agricultural demand of 2,463,000 af exceeds supply by almost 100,000 af/year. However, more research is needed in order to gain a better understanding of the state of groundwater levels and long-term overdraft in the region.

5. Lower Basin Summary

Serious groundwater overdraft in the lower Colorado basin persists despite legislative and other efforts to bring it under control. In Arizona, groundwater mining continues at a rate of approximately 1 million af/year. Despite the state's landmark 1980 Groundwater Management Act, which called for "safe yield" to be reached in the four Active Management Areas by 2025, groundwater overdraft in the AMA's is now projected to total more than 620,000 af/year in 2025. Groundwater overdraft in the southern California portion of the basin totals an estimated 97,000 af/year. In southern Nevada, some 51,000 acre-feet — over a third of the region's current groundwater supply — comes from groundwater overdraft. Thus, approximately 1,244,000 af of groundwater mining is occurring annually in the lower Colorado basin, and must be eliminated to bring groundwater pumping into a sustainable equilibrium. Table 12 shows present and projected lower basin totals for groundwater overdraft.

Table 12
Groundwater Overdraft in the Lower Colorado Basin 1990 and 2020

Region	1990	2020
Arizona	1,000,000	621,000[a]
Southern Nevada	51,000	NA
Southern California	97,000	70,000
Mexicali Valley, Mexico	96,000	NA
Lower Basin Total	**1,244,000**	**691,000**

[a] *ADWR estimate for 2025 in Active Management Areas only.*

V. Moving Toward A Sustainable River Basin

A. DEFINING SUSTAINABLE WATER USE

This report began with the premise that current water planning in general, and in the Colorado River basin in particular, represents a failure of water-resource institutions to forge common goals and suitable management practices for sustainable water use. Also lacking are attempts to seek agreement on principles to resolve conflicts over water in an integrated way. The twentieth-century water-development paradigm, which has been driven by an ethic of growth powered by continued expansion of water-supply infrastructure, has been stalled for the last two decades as social values and political and economic conditions have changed. Meaningful change towards a new ethic has to begin with a dialogue on the ultimate ends of water-resource policy.

Sustainability and equity are primary goals from which to begin. Simply stated, these goals place a high value on maintaining the integrity of water resources and the flora, fauna, and human societies that have developed around them. In related work, the Pacific Institute has defined sustainable water use as *the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it* (Gleick et al. 1995, Gleick 1996). Rather than trying to find the water to meet some projection of future desires, it is time to plan for meeting present and future human and ecological needs with the water that is available, and to determine what desires can be satisfied within the limits of our resources. This is an essential change.

It is time to plan for meeting present and future human and ecological needs with the water that is available, and to determine what desires can be satisfied within the limits of our resources.

Water is a common good and community resource, but it is also used as a private good or economic commodity; it is not only a necessity for life but also a recreational resource; it is imbued with cultural values and plays a part in the social life of our communities. The principles of sustainability and equity can help bridge the gap between such diverse and competing interests. Table 13 presents a set of sustainability criteria that can be used as the basis for guiding sustainable water resource management. The sustainability criteria provide a framework for prioritizing competing interests and for making decisions about water use. They are not, by themselves, recommendations for actions; rather they are endpoints for policy — they lay out specific societal goals that could, or should, be attained. While debate on how to attain these goals will be regionally specific, having a set of clear targets will help focus future policy decisions.

Table 13
Sustainability Criteria for Water Planning

1. A basic water requirement will be guaranteed to all humans to maintain human health.
2. A basic water requirement will be guaranteed to restore and maintain the health of ecosystems.
3. Water quality will be maintained to meet certain minimum standards. These standards will vary depending on location and how the water is to be used.
4. Human actions will not impair the long-term renewability of freshwater stocks and flows.
5. Data on water resources availability, use, and quality will be collected and made accessible to all parties.
6. Institutional mechanisms will be set up to prevent and resolve conflicts over water.
7. Water planning and decision-making will be democratic, ensuring representation of all affected parties and fostering direct participation of affected interests.

These criteria lay out human and environmental priorities for water use, taking into account not only the needs of the current populations, but also those of future generations. The first two criteria set out basic allocations for humans and ecosystems, which are to be satisfied before other demands. In this respect, we followed a strategy of defining "basic needs" requirements similar to that laid out by Agenda 21, the United Nations Programme of Action (UN 1992), developed at the 1992 Earth Summit. Agenda 21's "call to action" sets as immediate objectives the integration of ecosystem requirements into water-resources management, the satisfaction of basic human needs, the incorporation of rational economic approaches for human uses of water, and the design, implementation, and evaluation of sustainable water programs with both economic and social components.

The sustainability criteria not only set out quantity and quality requirements, but also set an upper limit to water use and provide some institutional guidance. As long as the minimum needs are met, then all remaining demands on water are acceptable as long as they do not impair the renewability of the resource and as long as allocations are equitable between present and future generations. The criteria do not provide strict rules for how best to allocate these remaining demands — rather they lay out guidelines for a process of how to decide among conflicting demands. Because these remaining demands often conflict, social value judgments will be required to set standards or even decide which demands should come before others. It is easier to agree on and quantify minimum standards for human health, which have some biophysical basis, than it is to determine how much water should be allocated for irrigation or for industrial use, but these decisions need to be made as well.

New ways of managing water and, quite likely, some reallocation of water will also be needed in order to restore and maintain aquatic ecosystems on the Colorado mainstem, its tributaries, and in the delta.

B. FREEING UP WATER THROUGH MORE SUSTAINABLE PATTERNS OF USE

As was discussed in detail previously, serious groundwater overdraft in the lower Colorado basin persists despite efforts to bring it under control. More than 1.2 million acre-feet of groundwater overpumping is occurring annually in the lower basin and relevant parts of Mexico and must be eliminated to bring groundwater basins into a sustainable equilibrium. Satisfying current and future demands without depending on non-renewable groundwater supplies is an essential component of a sustainable basin-wide management strategy. Long-term management plans that do not address this issue will eventually fail when non-renewable groundwater supplies are no longer economically available and water users are forced to find alternative supplies elsewhere.

Additionally, new ways of managing water and, quite likely, some reallocation of water will also be needed in order to restore and maintain aquatic ecosystems on the Colorado mainstem, its tributaries, and in the delta. In many instances, threatened and endangered species on the mainstem are not necessarily negatively impacted by the quantity of water in the Colorado River, but rather by the timing of the flows. The delta, however, will most likely require an increased volume of water inflow for its restoration.

Determining what values — ecological, cultural, and economic — can and should be restored in the delta is no easy task. Clear priorities would seem to include securing water for the Cienega de Santa Clara and enhancing fresh water flows in the Rio Hardy portion of the delta, both for wetlands restoration and for use by the Cocopa Indians. Beyond these, however, is the issue of whether greater annual flows to the Sea of Cortez are needed to restore the fisheries there. Perhaps a flushing out of the delta once every few years would provide substantial ecological benefits.

The science does not yet exist to adequately answer these questions. Long-term studies are necessary to determine how much water is needed, and definitive answers may not be available for some time. For purposes of illustration, we assume here that 500,000 acre-feet per year is required to restore some degree of ecosystem health to the delta. This flow — 3 percent of the Colorado's average annual flow — could be used, for example, to re-create additional wetland areas for birds and wildlife, to supply the Cocopa Indians, and to allow for some minimal discharge of river water to the upper Sea of Cortez. It is possible, of course, that meaningful restoration of ecological values could require much more. It is also possible that substantial ecological and cultural values could be restored with less water. In order to gain a general understanding of what types of changes in water use patterns would be necessary to improve ecosystem health in the basin, 500,000 af/yr divided proportionally among basin states' respective basic entitlements is chosen for the sake of simplicity. Table 14 summarizes the water use reductions needed in each region of the basin to arrive at our hypothetical water obligation to the delta, as well as to eliminate groundwater overdraft.

From market-based approaches to amending the Law of the River, there are numerous mechanisms that can be implemented in order to redirect water toward ecosystem restoration and maintenance. The following are possible tools that can be used alone or together for freeing up water for environmental needs, including restoration of the delta:

- *Increased assessments for all Colorado River water* A fee could be instituted on all uses of Colorado River water to help pay for "public good" uses of the river such as ecosystem restoration and maintenance. Funds would be collected and managed by the Bureau of Reclamation or an overarching river basin commission, whose board would include representatives of all stakeholders. All stakeholders would play a role in setting the fee and in deciding how the funds get used. Revenues generated from the increased assessments would be used to purchase water in long-term lease arrangements with Indian tribes or with other willing sellers. For example, based on current consumptive uses in the upper and lower basins, over $21 million in revenues could be generated annually if a $2.00 per acre-foot assessment were added for environmental restoration and maintenance.
- *Water surcharges on all voluntary water transfers of Colorado River water* Through this

Table 14

Water Use Reductions Needed to Eliminate Groundwater Overdraft in the Lower Basin and to Satisfy Hypothetical Water Obligation to Colorado River Delta

(acre-feet per year)

Basin Entity Overdraft	To Eliminate Groundwater	To Meet Environmental Obligation to the Delta [a]	Total Water Use Reduction
Southern Nevada	51,000	9,000	60,000
Arizona	1,000,000	85,000	1,085,000
Southern California	97,000	135,000	232,000
Mexico	96,000	45,000	141,000
Basin totals	**1,244,000**	**274,000**	**1,518,000**

[a] *Environmental obligation to delta assumed to be a minimum of 500,000 af/year. Each basin entity's contribution is assumed to be proportional to its respective Colorado River water entitlement under the "Law of the River." Not shown here is the upper basin's environmental obligation to the delta, 226,000 af, which makes up the remainder of the 500,000 af/year requirement.*

scheme, a certain percentage of marketed Colorado River water would be set aside for environmental restoration. For example, a 5 percent water surcharge on a voluntary transfer of 30,000 af/year would free up 1,500 acre-feet for ecosystem recovery.

- *Surcharges on water banked in the Colorado River system of reservoirs* Currently, there is considerable discussion about various strategies for water banking on the Colorado mainstem. Under this scheme, water conserved by a basin user, that is in turn banked on the Colorado mainstem, would be subject to either a one-time surcharge or a lesser fee on an annual basis. This charge could be in the form of dollars or water. For example, a one-time 5 percent water surcharge on the 185,000 af now banked by the Metropolitan Water District of Southern California in Lake Mead, would generate 10,000 acre-feet for restoration purposes. All water that is acquired by the Bureau of Reclamation or a river basin commission through these various surcharges can be stored within the Colorado River system of reservoirs until critical periods when marginal additional flows will result in significant environmental benefits.
- *Amend the Law of the River so that each basin state contributes water in proportion to current river entitlements* As opposed to the market-oriented approaches above, this scenario would involve a federal mandate setting each party's contribution to an environmental restoration fund proportionally to each party's respective entitlements to Colorado River water. For example, assuming that 500,000 af/yr was the amount of water determined by experts to be needed for significant ecosystem restoration in the delta, the upper basin would contribute 225,000 af or 45 percent of the 500,000 af needed.[8] This would be the case since, under the Law of the River, it has been granted 45 percent of all annual entitlements (7.5 maf/16.5 maf). Under this scenario, California, with 27 percent of the river's annual entitlements, would contribute 135,000 af; Arizona, 85,000 af; Mexico 45,000 af; and Nevada, 9,000 af.

It should be noted that if this scenario were to come to fruition, it would be politically infeasible and socially undesirable for junior water rights holders in each state to assume the full burden for delta restoration. For example, California currently uses some 600,000 acre-feet more than its basic entitlement, with the Metropolitan Water District of Southern California (MWD) as its most junior water rights holder. As the upper basin, Indian tribes around the basin, and other lower basin states reach full utilization of their entitlements, MWD will already be forced to reduce its use of the river's water. Ongoing Indian tribes water settlements within California will also be taken from MWD's apportionment. For MWD to be fully responsible for meeting California's obligation toward delta restoration efforts out of its remaining entitlement is both unrealistic and inequitable.

Reallocated water to meet the environmental obligations would have to be shared equitably among the water users of each state. Colorado River water users in each state would have to negotiate a just method of distributing the obligation. Due to provisions included in the Law of the River, unsettled Indian tribes water claims are to be met through the state's basic apportionment in which the tribal lands are located. Their contributions will have to be quantified during such negotiations in order to determine their delta obligation.

C. ACHIEVING THE NEEDED WATER SAVINGS

Freeing up nearly 1.5 maf of water in the lower Colorado basin to stabilize groundwater resources and support minimal delta restoration will not be easy. Already the region (including Mexico) is tapping the Colorado River for some 8.9 maf/year (USBR 1995 telefax; IBWC 1992), virtually its entire allotment.

[8] No specific amount of water has yet been identified as vital to restoring some of the ecosystems of the delta. The amount described here is speculative, but evaluating how to meet any future delta water demands can provide insight into appropriate policies and likely problems.

Population in the region is projected to grow by more than 66 percent between 1990 and 2025, from just over 23 million to more than 38 million. Satisfying new water demands will be difficult enough; returning nearly 1.5 maf to groundwater basins and the environment would seem close to impossible. We believe such a goal can be achieved given new priorities, policies, and planning procedures. More importantly, while people may argue about specific issues, such as the actual amount of water that needs to be reallocated toward the environment, we believe the overarching principles advanced here — such as committing some amount toward restoration of the delta — are more important.

With the potential for new water source development extremely limited (see section on Water Supply and Demand in the Lower Colorado Basin), efforts to achieve ecologically sustainable water use will depend on reducing and managing water demand. Conservation, increased efficiency, recycling, reuse, changes in the agricultural crop mix, and the retiring of agricultural land are among the cost-effective measures for saving water. Slowing the rate of population growth, while politically more difficult, is likely also essential for achieving sustainable patterns of water use in the region.

1. Reducing Agricultural Water Use: Arizona as an Illustrative Example

Agriculture currently accounts for approximately 64 percent of total water demand in the lower Colorado River basin, and a considerably higher share of total water consumption. Balancing groundwater use with recharge and achieving increased river flows to the delta will require that farm water use decline. Like all good business people, farmers in the region generally attempt to maximize their net profits, and select crops and growing methods that help them do this. Perhaps more than most business people, however, many farmers give weight in their decisionmaking to family traditions in farming, personal experience with particular crops, and community values. Thus, how to restructure agriculture to enable the region to achieve sustainable patterns of water use is a complex issue. Our analysis here of Arizona agriculture is intended to shed light only on what is possible, not necessarily what should be done. The latter can only be decided through a process of political consensus-building that includes all stakeholders.

There are three principal ways agriculture can reduce its demand on the region's water resources — by investing in improved irrigation efficiency, by switching to crops that have a lower water requirement, and by removing land from irrigation. At the moment, farmers' decisions regarding how much land to irrigate, what crops to grow, and what kind of irrigation methods to use, while perhaps rational at the farm level, are skewed by the failure of public policies to provide proper signals regarding water's scarcity value. As a result, water is misallocated; more is used in agriculture than is efficient and desirable from a broader social perspective.

In the arid and semi-arid climates of the American Southwest, crop production is even more water-intensive than in most parts of the world. Over 1.2 million hectares (3 million acres) of cropland are irrigated in the lower basin and Mexico, and much of this land is growing highly water-intensive crops. Reliable estimates of the water consumption requirements for many of the crops grown in this climate were derived through studies conducted over 50 years on private and university farms near Tempe, Mesa, and Phoenix, Arizona (Erie et al. 1982) (see Table 15). In general, crops with long growing seasons tend to require more water than those with shorter growing seasons, but other crop characteristics influence water needs as well. Alfalfa, with a growing season 75 days shorter than oranges, needs nearly twice as much water — and is the most water-intensive crop grown in the region, measured by water consumed per acre.

Matching water requirements for various crops with the area harvested by crop in a given region leads to estimates of the total water consumption requirement for a particular crop in that region. Table 16 shows these results for Arizona. With 145,000 hectares (360,000 acres) in Arizona planted in cotton in 1994, cotton consumed more than 1.2 maf. Together, cotton and alfalfa hay consumed 2.2 million af of the state's water — equal to more than three-fourths of Arizona's Colorado River entitlement and twice the level of unsustain-

Table 15
Seasonal Water Consumption for Selected Crops, Southwestern United States

Crop	Crop Water Consumption (acre-feet/acre)	Growing Season	Length of Growing Season (days)
Alfalfa	6.19	Feb.-Nov.	285
Grapefruit	4.00	Jan.-Dec.	360
Sugarbeets	3.57	Oct.-July	300
Cotton	3.43	April-Nov.	225
Navel oranges	3.26	Jan.-Dec.	360
Wheat	2.15	Nov.-May	210
Barley	2.08	Nov.-May	180
Potatoes	2.03	Feb.-June	120
Dry Onions	1.94	Nov.-May	195
Soybeans	1.85	June-Oct.	135
Cantaloup, early	1.71	April-July	120
Broccoli	1.64	Sept.-Feb.	165
Cauliflower	1.55	Sept.-Jan.	150
Cantaloup, late	1.40	August-Nov.	120
Carrots	1.38	Sept.-March	180
Lettuce	0.71	Sept.-Dec.	105

Source: Erie et al. 1982.

Table 16
Estimated Total Water Consumption by Selected Crops in Arizona, 1994

Crop	Area Harvested (thousand acres) [a]	Crop Water Consumption (acre-feet/acre)	Estimated Total Crop Water Consumption (thousand acre-feet)
Cotton	359.9	3.43	1,234.5
Alfalfa Hay	160.0	6.19	990.4
Wheat	122.0	2.15	262.3
Lettuce	59.2	0.72	42.6
Barley	33.0	2.08	68.6
Cantaloup	14.4	1.56 [b]	22.5
Oranges	10.6	3.26	34.6
Broccoli	9.4	1.64	15.4
Grapefruit	5.9	4.00	23.6
Cauliflower	5.7	1.55	8.8

[a] *One acre equals 0.405 hectares.*
[b] *Average of the early and late cantaloup water consumption requirement.*

Sources: Arizona Agricultural Statistics Service 1994; Erie et al. 1982.

able groundwater overdraft statewide.

More water is actually consumed in irrigated crop production than these crop water requirements suggest because of inefficiencies in the methods used to deliver water to the crops. The vast majority of Arizona's cropland requires irrigation in order to satisfy crop water needs, with over 360,000 hectares (about 906,000 acres) under irrigation in 1993 (*Irrigation Journal* 1994). On nearly 90 percent of this irrigated land, water was delivered using surface or gravity systems (See Table 17). These are generally the least efficient irrigation methods, unless laser leveling of fields or other efficiency-enhancing methods are practiced. Nine percent of Arizona's irrigated area used sprinkler systems of some type, which tend to be more efficient than the gravity methods. Just 1 percent was watered by drip systems, which deliver water directly to the roots of crops through surface or subsurface tubing. When operated properly, drip systems can achieve efficiencies in the range of 95 percent (Postel 1992), but they are not effective on all kinds of crops.

In Table 18, we estimate the total volume of irrigation water consumed by crop, assuming a statewide average irrigation efficiency of 60 percent and that three-quarters of the 40 percent not used beneficially is lost irretrievably through evaporation or other means. Table 18 also provides a useful measure of economic water productivity — the economic value (as determined by average price) derived from each acre-foot of water consumed. Lettuce, cantaloupe, cauliflower, and broccoli yield far more value per unit of consumed water than any of the other major crops grown in Arizona. Alfalfa, the most water-intensive crop and one of low economic value, has the lowest economic water productivity — just $95/af consumed.

Given the projected population growth for Arizona, much if not all of the 1.2 maf of water use reductions needed to achieve balanced groundwater use and to meet environmental water obligations to the delta will need to come from agriculture. This assumption is supported by the official state projections for 2025, which show increasing CAP deliveries and decreasing agricultural water use. Producing these savings can be far less painful than one might think

Table 17
Area Irrigated by Type of Irrigation Method, Arizona, 1993

Irrigation Method	Area Irrigated (thousand acres)	Typical Efficiency[a] (percent)
Surface/Gravity	**810.0**	**40-60**
Flooding from ditches	410.0	
Open ditch, siphon tubes	391.0	
Other	9.0	
Sprinkler	**84.0**	**65-80**
Center pivot	50.0	
Solid set	30.0	
Side roll/wheel line	4.0	
Microirrigation	**12.0**	**90-95**
Surface drip	8.8	
Subsurface drip	3.2	
Total Area Irrigated	**906.0**	

[a] *Efficiency ranges are typical on-farm application efficiencies with use of these systems, and are not specific to Arizona.*
[b] *One acre equals 0.405 hectares.*

Source: Areas irrigated by method from 1993 U.S. Irrigation Survey, Irrigation Journal, January-February 1994.

Table 18
Estimated Irrigation Water Consumed and Value per Acre-Foot Consumed for Selected Crops, Arizona, 1994

Crop	Estimated Total Irrigation Water Consumed[a] (1,000 acre-feet)	Value of Harvested Crop (1,000 dollars)	Economic Value Per Acre-Foot Consumed (dollars)
Cotton	1604.9	308,486	192
Alfalfa hay	1287.5	122,400	95
Wheat	341.0	46,290	136
Lettuce	55.4	183,719	3,316
Barley	89.2	8,935	100
Cantaloup	29.3	51,322	1,752
Oranges	45.0	12,563	279
Broccoli	20.0	21,817	1,091
Grapefruit	30.7	4,626	151
Cauliflower	11.4	20,748	1,820

[a] *Assumes average irrigation efficiency of 60 percent and that three-fourths of the 40 percent not used beneficially is lost irretrievably through evaporation or other means.*

Source: Crop value from AASS 1994.

Water to grow livestock feed accounts for at least 40 percent of agricultural water use in the lower basin and Mexico.

under a strategy combining irrigation efficiency improvements, crop switching, and land fallowing.

Substantial room exists to raise the efficiency of irrigation water delivery systems. Drip irrigation is suited to many of the crops grown in Arizona, including cotton. With drip methods, water is delivered through porous or perforated piping or tubing, installed on or below the soil surface, to the crops' roots. This keeps evaporation and seepage losses extremely low. Because water is applied frequently at low doses, optimal moisture conditions are maintained for the crop, which often boosts yields, and salt is prevented from building up in the root zone. Farmers typically save energy, as well, because water is applied not only in smaller amounts, but at lower pressure (Postel 1992).

Studies have shown that cotton farmers in the arid Southwest can cut their water needs by 30-50 percent by switching from conventional gravity irrigation methods to drip irrigation, while often increasing cotton yields at the same time (Wilson et al. 1984). Howard Wuertz, owner of Arizona-based Sundance Farms, has demonstrated the benefits of subsurface drip irrigation coupled with minimum-tillage techniques on cotton and a variety of other crops. The Sundance system combines drip tape or tubing placed 8-10 inches below the soil in every row of crops, along with minimum-tillage field equipment designed to leave the shallow drip system undisturbed. Tests show that this method can cut water and energy use by 50 percent compared with conventional systems, while often producing better quality crops and higher yields (Murphy 1995).

A strategy to reduce agricultural water use is to encourage a shift in the overall cropping pattern from water-intensive crops to less water-intensive ones.

Although gravity irrigation methods date back thousands of years, new techniques can also boost their efficiencies. One that has spread rapidly in northwest Texas, where farmers confront declining well yields from the long-term depletion of the Ogallala Aquifer, is surge irrigation. Instead of releasing water in a continuous stream down the field channels, irrigation under the surge method alternates between two rows at specific time intervals. The initial wetting somewhat seals the soil, allowing the next application to advance more quickly down the furrow. This surging effect reduces percolation losses at the head of the field and distributes water more uniformly. Farmers who adapt conventional furrow systems to this surge technique — which typically involves purchase of a valve and timer — have reduced water use by 15-50 percent. For farmers in the Texas High Plains, where savings have averaged 25 percent, the initial investment has usually had a payback of one to three years (Postel 1992).

Finally, sprinkler systems, which tend to be more efficient than gravity methods but less efficient than drip, can also be improved. A relatively new sprinkler design called low-energy precision application (LEPA) delivers water closer to the crops by means of drop tubes extending vertically from the sprinkler arm to just above the soil surface. This greatly reduces losses from evaporation and wind drift. When used in conjunction with water-conserving land preparation methods, LEPA can achieve efficiencies as high as 95 percent, competitive with drip (High Plains Underground Water Conservation District 1995). Northwest Texas farmers have also widely adopted this technique, and have had paybacks of two to four years on LEPA retrofits of their conventional sprinklers (Postel 1992).

Substantial water savings are possible from adoption of such measures in Arizona. For example, if half of the land area planted in cotton in 1994 were placed under drip irrigation, and this reduced evaporative losses from 30 percent to 5 percent, some 310,000 acre-feet would be saved. Placing half of the vegetable and citrus crops under drip irrigation, with similar reductions in evaporative losses, would save an additional 37,000 acre-feet. Further, if alfalfa, wheat, and barley fields were to be equipped with surge irrigation or modified

Table 19
Potential Water Savings Under Environmentally Sustainable Agricultural Water Use Scenario, Arizona

Measure	Assumption	Estimated Water Savings (acre-feet/year)
Improvements in irrigation efficiency	Half of all irrigated cotton and major vegetable and citrus crops is placed under drip irrigation, reducing consumptive water losses from 30 percent to 5 percent; half of irrigated alfalfa, wheat, and barley is upgraded through surge, LEPA, or other means to reduce average consumptive water losses from 30 percent to 15 percent.	445,000
Shifts in Cropping Patterns	One-quarter of cotton and alfalfa irrigated areas is shifted to higher-value citrus and vegetable crops with an average total consumptive use of 2.76 af/acre.	362,000
Fallowing of irrigated land	15 percent of irrigated cotton and alfalfa area is fallowed or retired permanently.	433,000
Total		**1,240,000**

LEPA systems, and this reduced consumptive losses from 30 percent to 15 percent, an additional 100,000 acre-feet of savings would result. Together, such measures could save on the order of 445,000 acre-feet per year, without reducing crop production (See Table 19)

A second key component of a strategy to reduce agricultural water use is to encourage a shift in the overall cropping pattern from water-intensive crops to less water-intensive ones. Our estimates suggest that each acre of cotton produced with conventional irrigation systems results in a consumptive water use of 4.46 af (3.43 af to meet cotton's water consumption requirement and 1.03 af because of irrigation system inefficiencies). An acre of alfalfa takes 8 af, including irrigation system inefficiencies. By contrast, the crop water requirements of the vegetables and citrus crops listed in Table 16 averages 2.12 af/acre; adding an extra 30 percent of consumptive losses brings the total irrigation water consumed to 2.76 af/acre. Thus, if one-quarter of the 1994 cotton and alfalfa irrigated areas were switched to a mix of higher-valued fruits and vegetables that averaged 2.76 af/acre of consumptive water use, total water savings would amount to 150,000 af/year from the cotton switch and 210,000 af/year from the alfalfa switch. Total savings from this shift in the cropping pattern would amount to 360,000 af/year (See Table 19). Moreover, total crop revenues would increase because of the shift to higher valued crops. Little can be said, however, about farmers' profits and overall net farm revenues without a more detailed analysis of market conditions and changes in production costs and crop prices that would accompany the shift.

Land fallowing makes up the third part of our sustainable agricultural water use scenario. By the early 1990s, 31,000 hectares (77,000 acres) of agricultural land had already been removed from production in Arizona because of farm purchases by Phoenix, Tucson, and other cities seeking to secure additional water supplies for future urban growth (Eden and Wallace 1992). Known popularly as "water farming" because the cities are interested in the water rights rather than the land, this practice has proven highly controversial in the state, particularly because of its negative impacts on the rural economy and tax base, and community health overall. In 1992, a Groundwater Transfer Bill was passed by the state legislature limiting the extent to which additional water farming could take place

(Eden and Wallace 1992). Nonetheless, Arizona's irrigated area is likely to contract further as declining groundwater levels, the lure of profitable water rights sales, and other factors play out. If 15 percent of irrigated cotton and alfalfa land is retired from production over the next twenty-five years, our analysis estimates water savings of 240,000 af/year and 190,000 af/year, respectively, for a total savings from land fallowing of 430,000 af/year.

Our sustainable agricultural water use scenario for Arizona — including irrigation efficiency improvements, shifts in cropping patterns, and land fallowing — results in a total estimated water savings of 1,241,400 af/year — enough to satisfy both the "no net groundwater depletion" criterion and the state's environmental water obligation to the delta under our hypothetical case. This of course implies no net increase in water use in non-agricultural sectors, which we will turn to shortly.

We have shown in this discussion that achieving more ecologically sustainable agricultural water use in Arizona is possible. If there is consensus among the public that this is desirable, a variety of public policy actions will likely be required to make it happen. While these changes are not likely given current policies, there are a variety of public policy options that would make them more attractive to farmers and communities, including low-interest loans or tax incentives to encourage investments in irrigation efficiency, tiered energy pricing that limits excessive groundwater pumping, other economic incentives to shift crop types, hefty taxes on groundwater depletion, and the creation of an environmental water bank. Some of these are discussed at greater length in later sections.

2. Agriculture in California and Mexico

Like Arizona, a large percentage of crops grown in these two regions is low in value and water-intensive. Tables 20 and 21 show the crop mix and estimated consumptive water use by crop for southern California and the Mexicali Valley. Alfalfa and irrigated pasture

Table 20
Estimated Water Consumption by Selected Crops in Southern California, 1990

Crop	Irrigated Acreage (thousand acres)	Calculated Average Consumptive Use (af/acre)	Total Consumptive Use (thousand acre-feet)
Grain	87	1.77	154
Cotton	37	3.27	121
Sugar Beets	35	3.83	134
Corn	13	2.08	27
Other Field	59	2.61	154
Alfalfa	266	6.09	1,620
Pasture	52	4.44	231
Tomatoes	22	2.36	52
Other Truck	274	1.58	433
Other Deciduous	4	3.25	13
Vineyard	26	2.85	74
Citrus/Olives	193	2.10	405
Regional Total	**1,068**	**3.20**	**3,418**

Source: CDWR 1994

Table 21
Estimated Water Consumption by Selected Crops in Mexicali Valley, 1990

Crop Type	Area Planted (thousand acres)	Consumptive Use (af/acre)	Total Consumptive Use (thousand acre-feet)
Alfalfa	46	5.44	252
Asparagus	10	5.82	61
Barley	22	1.87	40
Canola	12	2.46	31
Corn	6	2.48	15
Cotton	114	4.50	514
Fruits	1	5.38	7
Onion	8	2.26	17
Rye Grass	35	2.26	78
Sesame	23	3.19	73
Sorghum	21	3.02	62
Soy	0	3.22	0
Vineyard	4	4.87	20
Wheat	148	2.47	366
Various Fall/Winter	17	2.26	39
Various Spring/Summer	18	3.22	57
Regional Total	**485**	**3.36**	**1,633**

Source: CNDA 1991

Table 22
Southern California and Mexicali Valley Alfalfa Fallowing Scenarios

Region	Water Use Reduction[a]	Average Alfalfa Consumptive Use (acre-feet/acre)	Alfalfa Acreage Reduction	Percent Acreage Reduction
Southern California	232,000	6.09	38,095	14%
Mexicali Valley	141,000	5.44	25,919	56%

[a] *To eliminate groundwater overdraft and meet hypothetical environmental obligation to the delta.*
Source: Calculations based on data provided in CDWR 1994 and CNDA 1991.

account for 54 percent of the water consumed by southern California farmers, and 15 percent of consumptive agricultural water use in Mexico. Fallowing 14 and 56 percent of the alfalfa acreage in the two areas respectively would allow both regions to eliminate long-term groundwater overdraft and meet environmental obligations for the restoration of the delta (see Table 22). However, fallowing of land, as was discussed in the Arizona case study, is only one option for reducing agricultural water use. Increased irrigation efficiency and shifts in crop types could also be employed to produce water savings.

Figures 5 and 6 provide revenue per water use by selected crop type for California and Mexicali Valley. As these figures illustrate, certain crops are very water-intensive from an economic point of view. These disparities lead to enormous differences in water productivity. Sunding et al. (1994) have estimated that, for California, the least productive 20 percent of irrigation water in terms of farm value produced less than five percent of total agricultural revenues. Conversely, the most productive 20 percent of water accounts for nearly 60 percent of total farm revenue. These data alone suggest that crop substitution and changing

Figure 5
Revenue Per Acre-Foot of Consumed Water, California (1988)

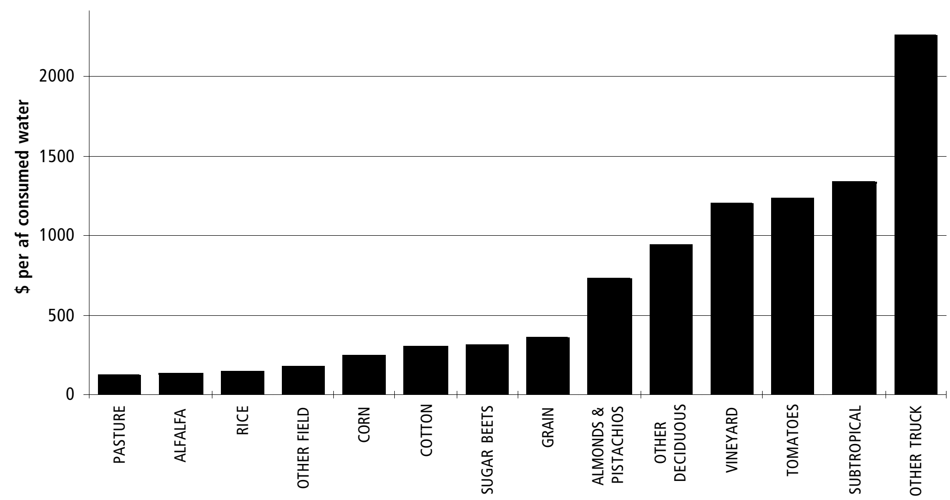
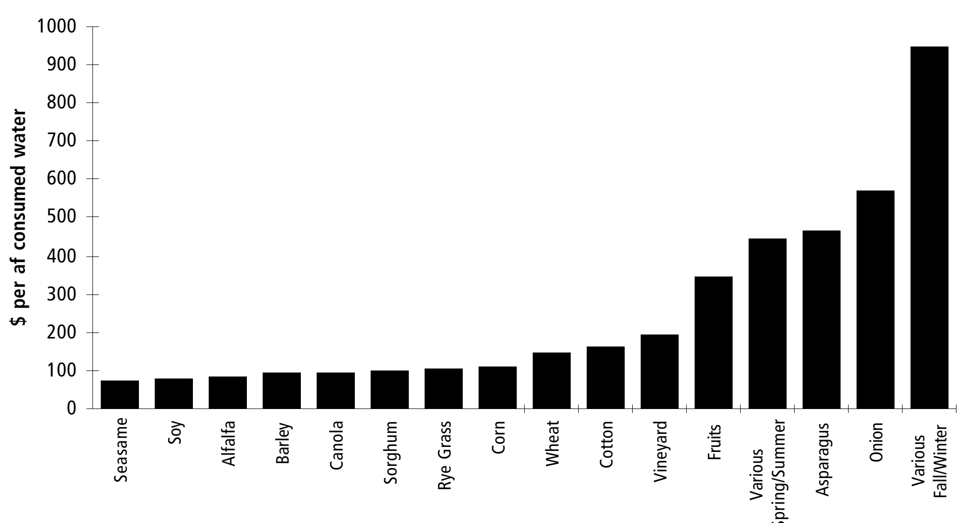


Figure 6
Revenue Per Acre-Foot of Consumed Water, Mexicali Valley (1989)



patterns of irrigation can produce substantial water savings. Under certain conditions, net farm revenues could be expected to rise significantly at the same time that total water use drops, as higher-valued, but less water-intensive crops are grown. Such results have also been demonstrated in a comprehensive study for California by Gleick et al. (1995).

3. Conservation in Cities

Although agriculture claims the largest share of water used in the lower Colorado River basin, water use in cities is growing most rapidly. Municipal use is determined primarily by two factors — the number of people living in an urban area and the amount of water that is used for industrial purposes. Population growth alone will considerably increase urban demand over the next several decades. The total population within the U.S. regions served at least in part by water supplies from the lower Colorado River basin is projected to climb from 21.2 million in 1990 to nearly 38 million by 2020, an increase of two-thirds. This includes a projected 90 percent increase in Arizona, a 104 percent increase in Southern Nevada, a 57 percent increase in southern California, and a 91 percent increase in Mexico.

Balancing water supply and demand in the face of such growth would be difficult anywhere; in a dry climate like the Southwest, it would seem a Herculean task. Each of the major urban centers in the lower Colorado region depends on water imported from considerable distance to meet current demand, but few additional external sources remain to tap. Achieving sustainable patterns of urban water use in the region will require substantial reductions in per-capita water use, and quite likely, a braking of population growth.

Urban conservation, once viewed as just an emergency response to drought, has been transformed over the last two decades into a sophisticated package of measures that offers one of the most cost-effective and environmentally sound ways of balancing water budgets and moving toward more sustainable patterns of water use. In a select but growing number of cities in the U.S. and worldwide, water planners have demonstrated that an assortment of water efficiency measures can yield permanent water savings and thereby delay or avert the need for expensive new dams and reservoirs, groundwater wells, and treatment plants. The idea is spreading that managing demand, rather than continually building new supplies to meet it, is a more certain path to water security — while protecting the environment and often saving money at the same time (Postel 1992, Vickers 1991, Gleick et al. 1995).

Achieving sustainable patterns of urban water use in the region will require substantial reductions in per-capita water use, and quite likely, a braking of population growth.

In almost every case, successful efforts to curb domestic water use permanently will include some combination of economic incentives, regulations, voluntary retrofits, and public outreach that together promote the use of water-saving technologies and behaviors. These measures are mutually reinforcing, and work in concert to reduce per-capita water demand. A successful conservation program will not only yield cost-savings because of reduced or delayed capital and operation and maintenance expenditures, but can keep fresh water in rivers, streams, and aquifers.

Many cities in the lower Colorado River basin have taken steps to encourage conservation. However, the vast differences in per-capita water use among them suggest that substantially greater gains can be made. And a comparison of even the lowest levels of per-capita urban use in the region with the levels currently achievable with available technologies and measures suggests that much of the conservation potential remains untapped.

Tucson: An Illustrative Case

Tucson, one of the early cities to break the historical rise in per-capita water use, is an instructive case because it now boasts one of the lowest levels of per-capita water use among large western cities. Water use per person in Tucson rose steadily during the early seventies, and in 1974, climbed to 205 gallons per-capita per day (gpcd)(total urban demand divided by population). Like most water systems, Tucson's was designed to meet the city's peak day demand, which typically occurs on one of the hottest days of summer and can be 2-4 times greater than the year-round average daily demand. This fast-growing peak demand spurred the city to action, since continuing to meet it would have required large capital outlays for drilling new groundwater wells and building larger transmissions pipes (Tucson Water undated).

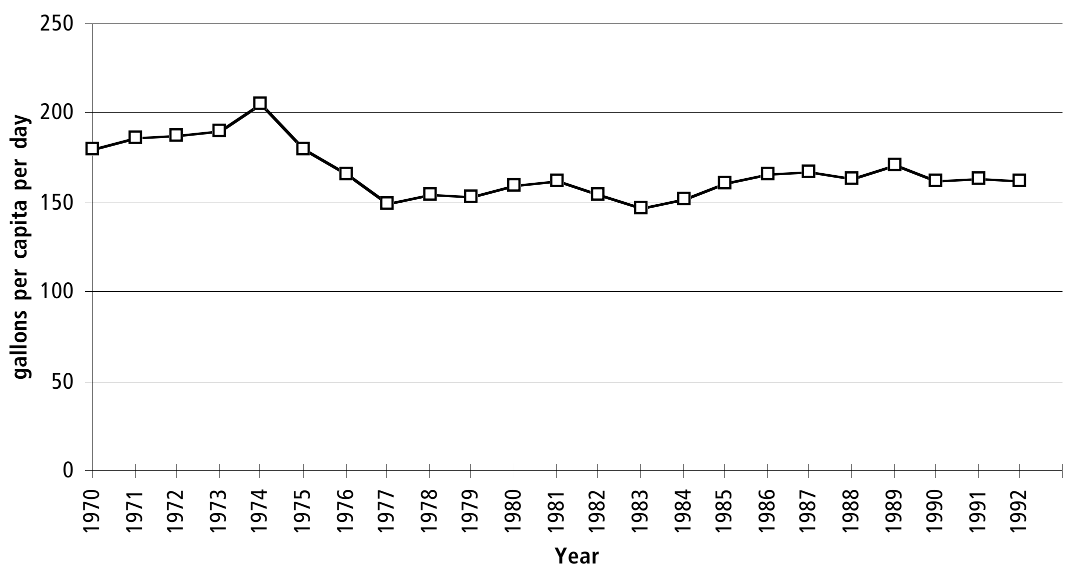
A 52 percent increase in water rates over a three-year period in the mid-seventies began to bring water use down (Kuranz 1996). In addition, in June 1977, the city initiated its "Beat the Peak" program aimed at cutting outdoor water use by promoting desert landscaping and limiting lawn watering. Together, these measures slashed per-capita water use from 205 gpcd in 1974 to 150 gpcd in 1977 — a 26 percent drop in three years. (See Figure 7). Besides helping slow the depletion of its aquifers, Tucson's relatively modest investment in conservation allowed it to defer $45 million in capital costs that would have been needed to meet an otherwise unmanaged demand (Postel 1985).

Since the mid-seventies, the city has implemented a three-pronged conservation program focused on water rate structure incentives, ordinances, and education-information. Tucson Water sets its rates on a cost-of-service basis and, until recently, applied an inverted block rate structure, according to which the price per unit of water rises with each successive higher block of usage. In 1993, the city switched to a summer surcharge rate schedule, which was believed to provide a more effective and equitable inducement to conserve. (For more on these rate structures, see the section on "Pricing" below).

Tucson also makes use of ordinances to promote conservation. Plumbing codes adopted in 1989 called for water-efficient fixtures in all new residential and commercial construction. These standards, which included 1.6 gallon per flush limits for toilets and 2.5 gallon per minute limits for showerheads and faucets, were similar to the national water efficiency standards that were later passed as part of the National Energy Policy Act of 1992, and which became effective in January 1994. Thus, Tucson began benefiting from these standards about 5 years earlier than otherwise would have been the case. The plumbing ordinance is expected to account for half of the city's projected water savings between 1990 and 2100 (Tucson Water telefax undated).

In February 1991, the city passed a comprehensive landscape code that encourages Xeriscape (a term trademarked by the National Xeriscape Council) in landscape design. After the Greek term *xeros*, meaning dry, Xeriscape designs draw on a variety of attractive indigenous and drought-tolerant plants, shrubs, and ground cover as a substitute for the thirsty green lawns found in most U.S. suburbs. A Xeriscaped yard typically requires 30-80 per-

Figure 7
Daily Per-Capita Water Use, Tucson, Arizona, 1970–92



cent less water than a conventional one, and cuts fertilizer and herbicide use as well (Postel 1992). The Tucson ordinance, which applies to new multifamily, commercial, and industrial development, requires the use of drought-tolerant plants from a published list and limits non-drought tolerant plants to small "oasis" areas. For commercial properties, for example, the oasis area is limited to 2.5 percent of the site (Tucson Water telefax undated). A third Tucson ordinance makes it illegal to allow water to run off private property. A full-time "water cop" enforces the ordinance, usually with warnings for first-time offenders and then with citations if water waste continues. By law, fines of up to $1000 can be issued (Tucson Water telefax undated).

The final prong of Tucson's program — public information and education — is coordinated by a special office within Tucson Water, the city's water service provider. The "Beat the Peak" campaign, for example, was largely a public information program that helped cut the daily peak demand by asking citizens voluntarily to water on alternate days and to avoid watering between 4 p.m. and 8 p.m. during the summer months. In 1992, the program refocused its message to emphasize more efficient water use both indoors and outdoors during the summer, when water use averages three times greater than in the winter (Tucson Water telefax undated).

Through this mix of economic incentives, regulations, and public information, Tucson has largely checked the rise in per-capita water use. However, the city's conservation measures have not been sufficient to reduce per-capita use further — a prerequisite to achieving sustainable water use in the face of shrinking resources and increasing population. Indeed, per-capita urban water use has crept back up slightly since the mid-seventies, averaging 161 gpcd between 1982 and 1992. While this is still low by comparison to most other sizable western cities, further reductions are necessary to stabilize total water use.

Tucson Water projects that, with its baseline conservation program, per-capita water use (from total urban demand) will fall from 160 gpcd to 142 gpcd by 2025 — an 11 percent drop. Because of a projected 70 percent increase in population over the next 30 years, however, total demand under this scenario would rise by nearly 60 percent. If population growth remains as projected, achieving a goal of no net increase in water use by 2025 would require that water use drop to 89 gpcd, 37 percent less than projected under the current program.

Potential Commercial/Industrial Water Savings

Businesses and industries account for more than 20 percent of municipal water use in Tucson. The potential for commercial and industrial water savings varies case-by-case, but substantial savings are clearly possible with existing technologies. Replacing once-through cooling systems with recirculating ones can produce some of the largest water savings in many industries, and typically offers a rapid payback on the investment (Vickers 1991). Spalding Sports Worldwide, a Massachusetts-based sporting goods manufacturer, cut its water use by 96 percent in just three years, largely through installation of a system to recycle cooling water (Sweetman 1992, MWRA 1991). A study of 15 companies in the San Jose, California area — including several electronics firms, a food processor, and a metal finisher — showed that a variety of cost-effective conservation measures produced water savings ranging from 27-90 percent (Manzione et al. 1991, City of San Jose 1990).

Indeed, in response to the severe drought of 1987-92, California industries generally have invested more heavily than most in water conservation, and collectively they demonstrate substantial water-savings potential. A 1990-91 survey of 640 manufacturing plants in 12 California counties found a 19 percent reduction in water use between 1985 and 1989. These savings were in addition to impressive conservation gains already made during the previous 15 years in response to increasingly stringent environmental standards. Moreover, the study also found that if all California manufacturing plants achieved the level of the most efficient ones of their type, total water use in all the industry groups surveyed would drop another 19 percent (Wade et al. 1991).

For the state as a whole, the California Department of Water Resources estimated that water use by 1990 in the industrial sector had dropped to about 620,000 acre-feet (or nine percent of total urban water use) — representing an absolute decline of 300,000 af from 1979 (CDWR 1994; CDWR 1994a). During the same period, total gross industrial production rose 30 percent in real terms (DOF 1994). In 1979, on an industry-wide level, it took an average of 11 acre-feet of water to produce a million dollars of industrial output. By 1990, this figure had dropped to under six acre-feet. While details explaining how this improvement in industrial water-use efficiency occurred are sketchy, two important trends are evident: (1) an improvement in the efficiency with which water is used by many of the industrial sectors, and (2) a shift in the industrial structure of the state away from water-intensive industries. These changes were partly driven by new water-quality standards, the cost of water, the cost of treating water, and technological improvements.

Between 1985 and 1990 seven major industrial groups (fruits and vegetables, beverages, paperboard and boxes, refining, concrete, communications, and motor vehicles) showed positive annual growth rates and absolute declines in annual water use. Six of these groups improved water-use efficiency more than 40 percent (Gleick et al. 1995). Five other major industries increased their economic output at rates substantially higher than the rates at which water use increased (meat, bakery, foods, metal cans, computers, computer components, and missiles/space).

Given these examples of real savings, it seems feasible to look for commercial and industrial water savings of 20-40 percent in urban areas. In the specific case of Tucson, a 30 percent reduction would reduce the base per-capita water demand of 160 gpcd (approximately 20 percent of which is commercial/industrial) by nearly 10 gpcd, or down to 150 gpcd.

Potential Residential Water Savings

With the passage of the federal National Energy Policy Act of 1992, all toilets, faucets, and showerheads manufactured for residential water use in the United States must meet specified standards of efficiency, which took effect in January 1994. Today, the average U.S. resident's use of these fixtures takes an estimated 46 gallons per day; within 30 years, this is expected to drop by more than half (to 21 gallons per day) as the more efficient models replace the existing stock (Vickers 1993). U.S. water utilities can thus plan on lower indoor water use per-capita over time. As long as the standards stay in place and are enforced adequately, a substantial amount of water conservation will take place automatically.

In many states and municipalities, standards comparable to the federal ones have already been in effect for some years. As noted earlier, in the case of Tucson, comparable standards were passed in 1989. Thus, Tucson's level of residential use — 111 gpcd in 1994 (Kuranz 1996) — reflects several years worth of new housing stock that incorporates these efficient plumbing fixtures. Over time, thanks to these standards, indoor residential use will drop further. By 2025, the vast majority of plumbing fixtures will likely be of the efficient variety as a result of new construction, remodeling, and replacement.

How much lower could residential use in a city like Tucson go? At least one answer is near at hand through a demonstration house in Tucson called Casa del Agua (CDA). CDA is a single-family home that was designed and retrofitted in 1985 by researchers at the University of Arizona to serve as an experimental and demonstration house for water conservation. It includes water-efficient plumbing fixtures, native landscaping, rainwater harvesting, and reuse of greywater (water used first in bathroom sinks, tubs, showers, or laundry and reused, typically for landscape irrigation) (Karpiscak et al. 1990).

Water use was carefully measured over four years, during which two different families lived in the home, each consisting of two adults and one child. During this period, *total* water use at CDA averaged 81 gpcd, 28 percent less than the 113 gpcd used by a typical three-person household in a detached Tucson home in the mid-eighties. *Municipal* water use at CDA, averaged only 49 gpcd, 57 percent less than the average Tucson home; of the total water used, 25 gpcd was recycled greywater and 7 gpcd was harvested rainfall (Karpiscak et al. 1990).

Thus, CDA demonstrates that with a major effort, residential water use in Tucson could be reduced 50 percent more. The municipal water utility could thus plan on substantially lower per-capita water demand for its services — which means reduced groundwater pumping, less river water diverted, and less energy and chemicals expended on water treatment and conveyance. Although with this approach total residential water use would fall by less than half, the difference is made up by the recycling of greywater and the capture of rainwater on site, which help increase the efficiency of water use overall.

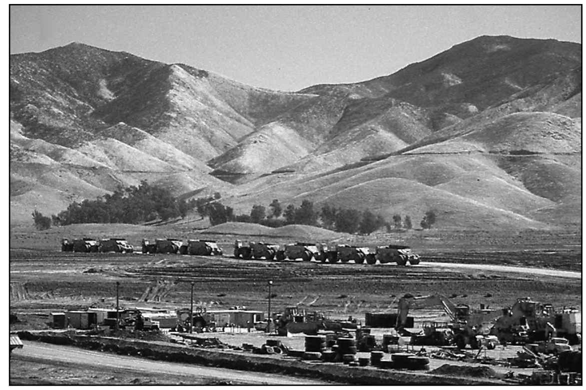
Urban Water Use in Las Vegas, Phoenix, and Los Angeles

The potential for water savings in the other major cities supplied in part by Colorado River water should be greater than in Tucson, because each has a substantially higher level of per-capita water use. Part of the explanation of these differences lies in the different types of commercial, industrial, and public activities in each city. It can be argued, however, that in water-scarce dry climates, economic activity will have to conform to water realities along with residential demands.

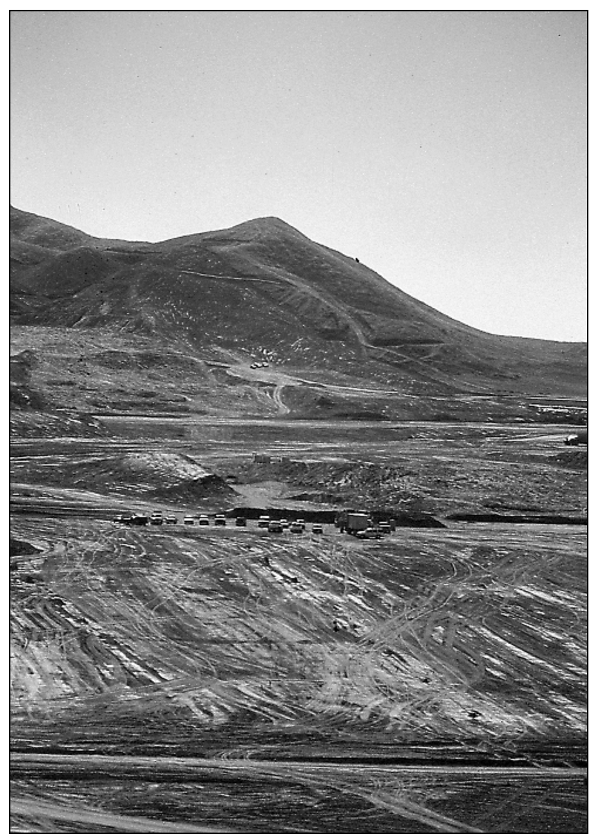
Las Vegas, which gets approximately 80 percent of its water supply from the Colorado River, has an extremely high per-capita use of 360 gpcd (Maddock and Hines 1995). This is in part attributable to the large tourist population, but also to extensive use of thirsty turf grass in residential and recreational landscaping and to heavy commercial use. The Las Vegas Valley Water District has estimated that water supplies could fall short of demands by 2010, even with a 10 percent reduction in per-capita demand through conservation. Their current conservation program, which includes a revised inverted water rate structure, promotion of xeriscaping, and low-flow plumbing ordinances for new development (which would be required by federal standards as well), is aimed at reducing per-capita demand up to 20 percent (Maddock and Hines 1995). Even if this goal is achieved, urban water use would average 288 gpcd, still a very high level. And with population in the Las Vegas area projected to increase by 115 percent by 2030, total urban water use would rise dramatically.

Water use in Phoenix is reported to be about 230 gpcd, although some researchers estimate it to be closer to 320 gpcd if water from the Salt River Project used for urban irrigation is included (Maddock and Hines 1995). In either case, it is considerably above the roughly 160 gpcd in Tucson. As in Las Vegas, extensive areas of turf grass — including numerous public golf courses — partially explains the high level. In light of Tucson's experience, Phoenix is evaluating the possibility of instituting a new water rate structure. The city is encouraging xeriscaping, the use of low-volume plumbing fixtures (which will be automatic in new construction as a result of the federal efficiency standards), and wastewater reuse. All new recreational lakes will be required to use treated wastewater. With such measures, per-capita demand for municipal water supplies is projected to fall from 320 gpcd to 260 gpcd — a 19 percent drop, but still a very high level.

While most of the Colorado river water received by California goes to irrigated agriculture in the southeastern part of the state, the Metropolitan Water District of Southern California (MWD) has priority rights to about 550,000 acre-feet per year. MWD has the physical capability of diverting a substantially larger amount from the Colorado, but actual diversions will depend on the hydrologic conditions in the



Earth-moving equipment on the floor of MWD's Eastside Reservoir Project. Consisting of three dams, the 800,000 acre-foot capacity storage facility is scheduled for completion in 1999 at a cost of $1.9 billion. (Photo by J. Morrison)



Construction equipment parked at the center of what will soon be the I .7-mile long West Dam of the Eastside Project. (Photo by J. Morrison) basin and the needs and rights of other users. MWD's service area had 15.7 million people in 1994 — about 50 percent of California's entire population. Total water use in 1990 was 4.0 million acre-feet, declining to 3.2 maf in 1994 because of recession, drought-induced efficiency improvements, and other factors. Of the 3.2 maf used in 1994, 91 percent went to meet municipal and industrial uses and the remainder went to local agricultural uses. Per-capita municipal and industrial water use in 1990 was 214 gpcd, dropping to 165 gpcd in 1994 (MWD 1995). The traditional projections of water demand estimate that municipal and industrial water use will increase 31 percent between 1994 and 2010 because of increases in population, household income, urbanization in hot, arid parts of the basin, higher industrial production, and decreasing household size.

A wide range of water conservation programs have been discussed, and many implemented, in the MWD service area. Official estimates of per-capita urban water use with anticipated conservation programs are about 190 gpcd for 2010. Without these conservation programs, MWD estimates urban water use would rise to over 225 gpcd (MWD 1995). Among the major components of their program are implementation of "Best Management Practices" — a set of urban conservation tools established at the state level, toilet retrofit programs, efficient showerhead distribution programs, industrial and commercial audit programs, and educational activities. Other efforts involve groundwater recharge and conjunctive use activities and a range of water reclamation projects to increase the proportion of water reused by all sectors. Some analysts believe that more aggressive programs for improving water efficiency and increasing water recycling and reuse could hold per-capita water use at well below official projections (Gleick et al. 1995).

Conclusion

Our illustrative scenarios for agriculture in Arizona and urban use in Tucson along with ongoing and possible programs in other lower basin regions suggest a range of strategies for achieving more sustainable patterns of water use in the lower Colorado. They rely on improvements in irrigation efficiency, changes in the crop mix, and the retiring of some irrigated farmland to eliminate groundwater overdraft and to free up water for delta restoration. They further attempt to hold total urban use constant, even in the face of population growth, by substantial water savings in the commercial and industrial sector and large reductions in per-capita residential water use. We base our estimates of potential water savings on reductions actually demonstrated with existing technologies and policies.

In the urban sector, we estimate that commercial/industrial demand could be reduced by 20-40 percent. In the residential sector, we considered the case of Tucson, Arizona, a city already widely recognized for its conservation achievements, and thus one in which the remaining conservation potential might be somewhat less than in other western cities. Virtually everywhere, including Tucson, indoor residential water use per capita will decline automatically because of the water efficiency standards now in force nationwide that require installation of water-efficient plumbing fixtures in all new construction and major remodeling. As long as the federal law remains intact, these savings will occur automatically, and water planners should take them into account in making their demand projections. Substantial additional savings are possible through native landscaping, greywater recycling, and more aggressive measures such as the directed use of rainwater through capture and storage in cisterns. All in all, these measures could reduce per-capita municipal water demand by 30-50 percent.

In our scenario, we attempt to achieve ecologically stable water use through adjustments in irrigated agriculture and a goal of no net growth in urban water use. This is only one of many possible scenarios. Likewise, the water-use reductions needed to achieve these goals will depend on factors specific to each region or city. Less severe cuts in per-capita urban use might be necessary, for example, if population growth were to slow or come to a halt sooner than expected.

D. STRATEGIES FOR STRETCHING THE RESOURCE: POLICY TOOLS FOR SUSTAINABLE WATER USE

The transition to sustainable water management will not occur overnight. It will take time to put into place the fora where dialog can begin and to negotiate and prioritize the competing values of water in a democratic way. Replacing wasteful technologies with efficient ones will occur incrementally but the process needs to be hastened. It is important to remember, however, that conservation and efficiency are not ends but means. They are means of achieving more sustainable patterns of water use, as well as ways to "buy time" until a societal consensus can be reached about which water uses should be met and what policies should be implemented.
Below we describe a set of strategies that can be combined to reach the sustainability goals described above and produce a sustainable water future.

1. Pricing Incentives

Central to the effort to revamp the way Colorado River stakeholders manage their water resources will be pricing policies that reflect the true costs of water to particular users at particular times of use. Historically, water prices have not reflected the full economic, social, and environment costs of providing it to users. Recent empirical research has repeatedly shown that rates influence demand for water (Curry 1994, Mitchell and Hanemann 1994, MWD 1995, Dziegielewski et al. 1991; Black and Veatch 1995). The measure of this relationship between the price of water and its use is called the *price elasticity* of demand, which gauges the expected response in demand given a change in price. The water utility industry has for a long time implicitly assumed that the price elasticity of demand for water by residential customers is zero, i.e., higher prices have no effect on quantities demanded. This philosophy has typically manifested itself in the form of uniform pricing (single block rates), which is still offered by a significant percentage of western state retail water agencies.

Pricing structures that promote water conservation, however, are becoming increasingly prevalent. With demand for urban water continuing to outpace supply, urban water agencies face a new reality where providing a reliable, affordable service will depend as much on how they manage demand as on how they manage supply. Innovative ways to price water services to encourage more efficient use, and adoption of cost-effective conservation, efficiency, reuse, and recycling measures will all be essential to sustainably meeting future needs.

Conservation and efficiency are not ends but means. They are means of achieving more sustainable patterns of water use, as well as ways to "buy time" until a societal consensus can be reached about which water uses should be met and what policies should be implemented.

Increasing Block Rate Structures

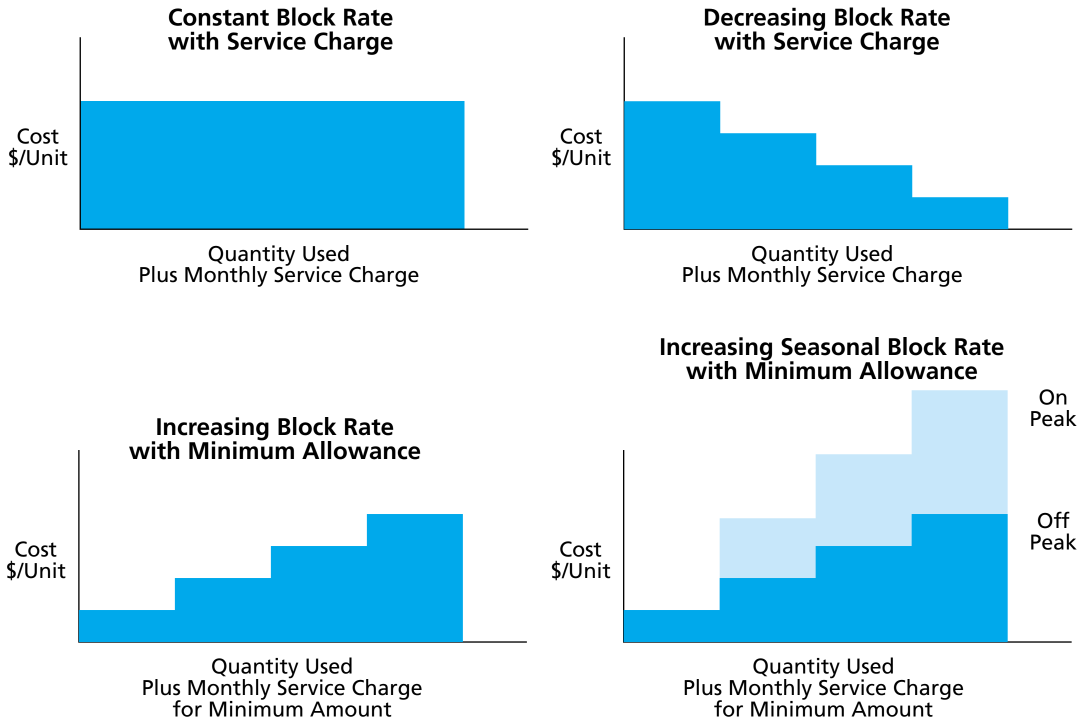
An increasingly popular choice with utilities, the increasing block rate structure establishes two or more rate blocks and then charges higher unit prices for each successively higher usage block. Thus, customers pay more per unit for higher levels of use (see Figure 8).

Tiered Pricing of Irrigation Water

Conservation pricing has also proven to be a successful tool in the agricultural sector. The experience of several districts on the west side of California's San Joaquin Valley shows the tremendous flexibility of agriculture to adapt to changing conditions. Through district-level conservation programs and tiered pricing, San Joaquin Valley west-side farmers increased irrigation efficiency and reduced drainage water in an effort to reduce some of the severe drainage problems there.

One west-side district that participated in this effort, the Broadview Water District, is a small district of just over 4,000 hectares (10,000 acres), which grows primarily cotton, melons, wheat, alfalfa seed, and tomatoes. The District was faced with the problem of having to reduce the volume of contaminated drainage water flowing into the San Joaquin River, and in 1988, implemented a tiered pricing rate structure. An increasing block rate for water use was seen as one way to help achieve drainage reductions and a program to implement such a structure was developed. The rate

Figure 8
Urban Water Rate Structures



Source: Modified from DWR 1994a.

was set at $16 per acre-foot for the first 90 percent of the 1986 to 1988 applied water average and $40 per acre-foot for any additional water. Accounting for water was fairly accurate because of careful monitoring.

By 1991, only seven of 47 fields exceeded the tier levels. The district average applied water decreased 19 percent, from 2.81 acre-feet/acre for 1986-88 to 2.27 acre-feet/acre in 1991. During this same period melons, wheat, and alfalfa seed crop production decreased, but there was an increase in tomatoes harvested (MacDougall et al. 1992). Drainage was both reduced substantially and smoothed out over the season. The drainage volume decreased from an average of 3,521 af per year over 1986-88 to 2,665 in 1990; salt discharges decreased from 26,000 tons to under 22,000; and boron decreased from 30.3 tons to 26.2 tons (Wichelns and Cone 1992).

While local experiences cannot easily be generalized to the entire Colorado River basin, these examples do point to promising areas for adapting to water cutbacks. The distinction between savings in applied water and savings in consumed water should be kept clear. Increased irrigation efficiency can lower applied water requirements, but actual water consumed may not change unless the crop evapotranspiration requirements change by either growing different crops or fallowing land.

Summer Surcharge Structures

The summer surcharge structure charges higher prices for water used in summer. These might be higher rates overall during the summer, or higher rates for the portion of water use that exceeds average winter water use. For example, in 1993, Tucson decided to convert from an increasing block rate structure to a summer surcharge rate structure. A study for Tucson had found that the summer surcharge plan was more effective than the inverted block structure in encouraging conservation, particularly in summer when the city faces its high and costly-to-meet peak water demand. The evaluation also found the summer surcharge structure to be more equitable, since it penalized heavy use of water outdoors for lawns and swimming pools, which is clearly discretionary, more than heavy use of water indoors due to large family size, which is less discretionary (Peart et al. 1993).

Thus a single family residence now has a $5.00 monthly charge, which includes use of 300 cubic feet (3 Ccf or 2,244 gallons) of water. The basic commodity charge for water used over this amount in single family and duplex-triplex residences is $1.55/Ccf ($2.07/1,000 gallons or $675/af). For all water used during the summer months (May-October) in excess of the average volume of water used during the winter period (November-April), a surcharge of $0.95 is added to the basic charge. A second tier surcharge of $0.25 is added on for any water use in summer that exceeds 150% of the average usage during the winter period. Thus, if a household's summer water use rises higher than 2.5 times its winter use, it will pay $2.75/Ccf ($3.68/1,000 gallons or $1,199/af) (Peart et al 1993).

One potential disadvantage of this type of rate structure is that some households may have a disincentive to conserve water indoors during the winter months, because their average winter use becomes the basis for determining what is excessive (and thus subject to the surcharges) in the summer. If implementation of this rate structure is accompanied by water-efficiency standards for indoor plumbing fixtures (as now required in new construction) and retrofitting of older fixtures, such a problem may not prove serious.

2. Low-Interest Loans and Rebates for Conservation Investments

Low-interest loans make it more attractive economically for water users to invest in conservation and more efficient technologies. The High Plains Water District of western Texas, where depletion of the Ogallala aquifer continues, offers irrigators low-interest loans for the purchase of equipment to improve irrigation efficiency, such as LEPA, surge valves, drip systems, and underground pipelines. As of October 1995, cumulative water savings from the program totalled nearly 156,000 af (Postel 1996).

In the urban sector, a growing number of utilities offer rebates to customers who install low-flush toilets. New York City, Santa Monica, and Denver are among the urban water providers that have offered rebates to customers purchasing low-volume toilet rebates. The Metropolitan Water District of Southern California (MWD) pays its member agencies $152 for each acre-foot of water they save, including through toilet replacement programs (M. Puffer, MWD, personal communication, 1992). As of mid-1995, MWD's rebate incentive programs resulted in the retrofit of 890,000 ultra low-flush toilets and over 3 million low-flow showerheads, representing annual water savings of more than 44,000 af/year (MWD 1995).

3. Water Depletion Taxes

One of many "green" taxes designed to raise government revenue while discouraging pollution and inefficient resource consumption, a water depletion tax might be particularly applicable to the overpumping of groundwater or to extractions from fossil aquifers. The Arizona Department of Water Resources (ADWR), for example, maintains the authority to impose fines on water users who overpump water supplies. In 1994, the ADWR fined a Pima County water purveyor for overdrafting groundwater but waived the fine after the company agreed to make improvements (Waterweek 1996). Currently, a Tucson-area water provider, the Rancho Vistoso Water Company, is being fined $25,000 by the ADWR for exceeding groundwater pumping limits (Waterweek 1996).

4. Linking Land Development to Water Supplies

Arizona's 1980 Groundwater Management Code included provisions prohibiting new urban development in areas of severe overdraft unless a long-term "assured water supply" could be demonstrated. Developers within overdrafted areas, known as Active Management Areas (AMAs), are required by the Code to demonstrate to ADWR that land for sale or lease has water of sufficient quantity and quality to sustain the proposed development for 100 years. In order to allow for continued economic growth in these regions without worsening the overdraft situation, a number of experimental institutions were created in the early 1990s. In 1991, the Arizona state legislature created a Groundwater Replenishment District in the Phoenix AMA to purchase and sell water rights in an attempt to obtain additional water supplies for urban areas. In this program, groundwater pumping credits could be purchased from the Replenishment District by a developer needing to prove a 100-year assured water supply. The Replenishment District, in turn, purchases water from outside the region, such as from the Central Arizona Project, recharging groundwater aquifers in the region.

5. Efficiency Standards and Regulations

Since the late 1980s, a number of local, state, and national governments have adopted water efficiency standards for household plumbing fixtures. In the United States, legislation passed in late 1992 requires manufacturers of residential toilets, faucets, and showerheads to meet specified standards of efficiency as of January 1994. As a result of these standards, the average U.S. resident's use of water from these fixtures will decline by more than 50 percent within 30 years—from an estimated 46 gpcd now to about 21 gpcd (Vickers 1993). Although efficiency standards have so far mainly been applied to household fixtures, they offer potential for water savings in agriculture, industry, and other municipal uses—including outdoor use— as well. The same 1992 law, the National Energy Policy Act, puts efficiency standards in place for commercial fixtures in 1997.

6. Water Transfers

Voluntary water transfers are another mechanism for moving water from low-valued uses to higher-valued uses. Within the last decade, numerous irrigation districts of the lower basin have entered into transfer agreements with urban areas within their state. Metropolitan Water District of Southern California (MWD), for example, has engaged in two significant water transfers with irrigation districts in its region. The Palo Verde Test Land Fallowing Program, implemented from 1992 to 1994, resulted in 185,000 acre-feet of water being conserved and stored in Lake Mead for use by MWD before the year 2000. In the Land Fallowing Program, 63 farmers agreed to fallow 8,100 hectares (20,000 acres) of irrigated farmland for two years in exchange for monetary compensation (MWD 1995, Loh and Steding 1996).

In a separate agreement in 1989, MWD entered into an agreement with the Imperial Irrigation District (IID), another agricultural water district located to the east of Los Angeles. In this agreement, MWD pledged to fund the direct and indirect costs of certain conservation projects within IID's boundaries, in exchange for the water that was "saved" through such measures. Measures pursued under the MWD/IID Water Conservation Program (Conservation Program) included lining existing canals with concrete, constructing local reservoirs and spill interceptor canals, installing nonleak gates and automation equipment, and instituting on-farm, water-use management practices (MWD 1995). In return, MWD was able to use an estimated 75,000 af of IID's Colorado River entitlement in 1995.

Water transfers in Arizona have mostly come in the form of "water farming," where rural land is purchased by cities solely for its attached water rights (a discussion of water farming is in section 1. Reducing Agricultural Water Use). Although not a true water transfer, urban water purveyors in southern Nevada have studied schemes where groundwater would be pumped and transported to cities from rural areas located to the north and west of the Las Vegas area. Due to severe opposition from rural communities and environmental groups in the region, and also due to high economic costs, the Southern Nevada Water Authority has opted to put the Cooperative Water Project, as it is known, on hold (SNWA 1996). While intrastate water transfers have been completed successfully in the last ten years, transfers between lower basin states have proven more problematic. A more in-depth discussion of interstate water transfers is included in the following chapter.

VI. Legal, Political, and Institutional Barriers to Sustainable River Basin Management

While strategies for more efficient water use will surely provide a means of buying time for the future, the transition to a sustainable river basin will entail a complete rethinking of how water in the basin is managed. As growing water demands on the lower Colorado basin approach the legal limits of the region, a scramble to protect rights for future use has ensued. The looming threat of regular water shortages for certain parties has spurred calls for substantial reforms in the way the river is managed. Many interests are beginning to recognize that current river management, the way in which water use is regulated, and the institutions that govern the basin are not adequate to meet the challenges of the future. There is a growing feeling that existing institutions will have to be reformed and new ones created in order to deal with the set of challenges confronting the river's water users. During this transition period, it is imperative that all the stakeholders of the river participate in the creation and modification of these institutions.

A. RIVER MANAGEMENT AND ENVIRONMENTAL VALUES

At its most fundamental level, a rethinking of the river's management is necessary not only because the river is grossly "over-apportioned" in terms of consumptive uses, but also because many values for water, such as fisheries protection and other ecological values, are not explicitly recognized in the current approach. River management has begun to move in this direction as evidenced by the relatively recent consideration of environmental values, long ignored during policy discussions and early decisions over water allocations. Environmental interest groups are now using powerful federal environmental legislation, such as the Endangered Species Act, as a tool to forestall development projects and to modify dam operations. River rafters and other recreational users such as sports fishermen have also applied pressure to have their interests represented. These new interests have become legitimate contenders for the use of the river's water, but hold no explicit, quantified rights to the waters of the Colorado under its current management regime.

Existing institutions will have to be reformed and new ones created in order to deal with the set of challenges confronting the river's water users. During this transition period, it is imperative that all the stakeholders of the river participate in the creation and modification of these institutions.

Laws such as the Endangered Species Act (ESA) and National Environmental Policy Act (NEPA) restrict and influence river operations, but only in a fragmented way. As a result, attempts to rescue imperiled species have been piecemeal. Only recently have agencies begun looking into comprehensive strategies for ecosystem recovery. The fact that the Lower Colorado River Ecoregion (LCRE) currently supports 24 federally-listed endangered and threatened species, one proposed for listing, four candidate species, and 67 species "at risk" of being listed (F&WS 1995a) shows that current and past river management have adversely affected ecosystem health. While minimum flow requirements currently exist for a handful of reaches in the upper Colorado basin, these are not sufficient to meet specific ecosystem needs. It is also apparent that the level of flows reaching the Colorado delta is insufficient to maintain a healthy environment there.

When the waters of the river were divided over 70 years ago, no water was explicitly dedicated to maintain healthy aquatic ecosystems — indeed, ensuring ecosystem health was not a concept given much consideration. One could argue that instream flows were accounted for by the 1922 Compact signatories when they apportioned only 15 maf of a river they

If the institutions that are being put in place now for the long-term management of the river do not address the issue of water for environmental values, it will be nearly impossible to do so in thirty years when scarcity will be a more intractable issue.

believed to have an annual average flow of 18 maf. Unfortunately, that 3 maf cushion was based on inaccurate assumptions about the long-term average flow of the river, as described earlier in Section 2. Despite the fact that the river's flows were grossly overestimated, subsequent laws and decrees have been based upon the original Compact apportionments.

Up until the present, any "minimum flow requirements" have been met with unused entitlements. In this sense, the environment is living off of "borrowed" water. As all the legally apportioned water for human uses is eventually utilized by basin states, there is great uncertainty as to what will happen to the ecosystems. Unless a mechanism can be established that provides water for the environment, water will surely be taken from the most junior water rights holders in order to meet ESA and NEPA requirements as they currently exist. Stakeholders on the lower basin such as MWD and CAWCD stand to be adversely affected by this scenario. Such a scenario could also adversely affect upper basin interests if instream flows mandated by ESA for the lower basin prohibit the upper basin from fully utilizing its basic entitlement.

There is still time to develop a strategy for freeing up water for aquatic ecosystems. Any environmentally sustainable regional solution will have to address the need for additional water to prevent species extinction and habitat protection. The first step to incorporating ecosystem values into a comprehensive management plan will be to reach consensus on what the river should look like in twenty or a hundred years, with specific information about the water requirements of particular environmental values. Decisions will have to be made about which portions of the basin can, or should, be restored and maintained at what economic and social cost. These decisions will have to be agreed upon by a reasonable majority of stakeholders in the basin. Once an agreed-upon "vision" is established and aquatic ecosystem needs quantified, the challenge will be to find ways of freeing up the water to meet those needs.

In an already over-apportioned system with continually increasing human demands, this will not be easy. However, if the institutions that are being put in place now for the long-term management of the river do not address the issue of water for environmental values, it will be nearly impossible to do so in thirty years when scarcity will be a more intractable issue. It will be a tremendous failure if the needs of aquatic ecosystems are not explicitly addressed in this transitory period in the river's management when institutions are being restructured to meet future challenges.

While a common "vision" of the river's environmental future is paramount for a transition to a sustainable basin, reaching consensus among basin interests is a major challenge. This is mainly due to a number of unresolved political, institutional, and legal controversies facing the basin. The threat of inadequate water supplies to meet growing needs has led to legal battles and political tension as states and water users work to secure an increasingly scarce resource. Taken together, the summation of conflicts represents a political, legal, and institutional quagmire that constrains progress toward sustainable river management. Since little water will be reallocated toward aquatic ecosystems until a regional solution is developed that ensures that the basic human and economic needs of each state will be met, a way around the "logjam" must be found. Below we discuss the major issues that must be addressed and resolved in order to move toward sustainable river management.

B. UNSETTLED INDIAN TRIBES WATER RIGHTS

A viable "regional solution" must include resolution of a host of Indian tribes water issues. While Indian tribes are currently in the process of having previously unrecognized water rights granted and quantified, one of the most significant problems for all of the stakeholders of the Colorado River is the complicated nature of the quantification process. While almost all parties agree that Indian tribes are entitled to some portion of the river's water, there has been considerable disagreement over both the quantity of water and the manner in which control should be balanced between the federal government and the Indian tribes themselves. Resolution of these issues will rely on both the future legal definition of Indian water entitlements and the rules that will be put in place that govern Indian water use once rights are established. Indian water issues must, therefore, be resolved as a fundamental part of any long-term management strategy for the Colorado River basin. Table 23 depicts the Indian tribes of the lower Colorado River basin.

To understand the water-related issues of the Indian tribes of the Colorado River basin, it is necessary to look at the historical relationship between Indian tribes and the federal government of the United States. Federal policy towards Indian tribes has shifted from treating tribes as foreign nations, to relocating, exterminating, and assimilating them, to the current policy of recognizing tribes as sovereign and encouraging tribal self-determination (Dongoske 1996). Throughout the various changes in policy, the concept of the federal government's "trust responsibility" for the Indian tribes has been an integral component of the relationship. The trust responsibility is the basis of much of today's Indian/federal arrangement and is rooted in the treaty-making era where the federal government promised to establish and protect permanent homelands in exchange for Indian land (Dongoske 1996).

Agencies within the Department of the Interior, such as the Bureau of Reclamation, now work to integrate Indian tribes' needs into long-term planning efforts. Among other things, this includes integrating Indian needs with state, local, and private interests in a region. The Bureau of Reclamation interprets its trust responsibility in terms of Indian tribe *trust assets* which are defined as: "[A]nything owned that has monetary value. The asset need not be owned outright, but could be some other type of property interest, such as a lease or a right to use something. Assets can be real property, physical assets, or intangible property rights" (USBR 1994 as cited in Dongoske 1996). The trust asset of paramount importance to Indian tribes in the Colorado River basin is their right to the river's water.

Table 23
Indian Tribes of the Lower Colorado River Basin

Native American Reservation	State
Las Vegas Colony	Nevada
Moapa	Nevada
Kaibab	Arizona
Hopi	Arizona
Navajo	Arizona
Hualapai	Arizona
Havasupai	Arizona
Colorado River	Arizona/California
Cocopa	Arizona
Tohono O'odham	Arizona
San Xavier	Arizona
Gila Bend	Arizona
Maricopa	Arizona
Gila River	Arizona
Yavapai	Arizona
Salt River	Arizona
Fort McDowell	Arizona
Papago	Arizona
Pascua Yaqui	Arizona
San Carlos	Arizona
Fort Apache	Arizona
Payson Community	Arizona
Camp Verde	Arizona
Zuni	New Mexico/Arizona
Fort Mohave	California
Chemehuevi	California
Fort Yuma	California

Source: Bureau of Indian Affairs 1989 as cited in Dongoske 1996.

Therefore, any Colorado River management plan developed with the Bureau's participation will have to address the water needs and rights of Indian tribes in the basin.

1. Water Rights

It is a federal policy objective to fulfill the promise of permanent tribal homelands by honoring and protecting the reserved water rights of Indian tribes. However, the unique relationship between the federal government and Indian tribes has clouded the definition of those water rights. At the heart of the issue is that there are two systems of law that govern water rights in the west — state and federal.

State water rights throughout the western U.S. have historically been based on the *prior appropriation doctrine,* which is predicated on the concept of "first in time, first in right." In essence, a senior and superior right is established once a user diverts and puts to beneficial use the water of a region. Once this occurs, an appropriation date is set giving that user more senior rights than the next person to utilize the water.

Indian water rights, on the other hand, have largely been established through the federal court system. They are largely based on federal courts' interpretations of historic treaties, Executive Orders, and other agreements between Indian tribes and federal agencies (Dongoske 1996). These types of federal reserved rights, known as *Winters* rights, are based upon the 1908 Supreme Court case *Winters v. United States*. This precedent setting case embodied the idea that sufficient water was implicitly reserved for the purposes of the reservation at the time that each reservation was established, and that this was a reserved right whether or not the water was actually put to use.

Winters rights are recognized as having priority dates coinciding with the date the reservations were established, thus providing a means to integrate federally reserved rights with appropriative rights recognized under state law (Checchio and Colby 1993). In most cases, these rights are senior to non-Indian rights because most reservations were established prior to extensive non-Indian settlement of the western states. Therefore, the increasing likelihood of these Indian rights being exercised in the near future lends uncertainty to most current stakeholder uses perfected under state law. By some calculations, unquantified Indian claims in Arizona alone could be as high as 3.1 million acre-feet per year — an amount exceeding the average annual surface flow of the state and almost half of the state's 1990 total water demand (Eden and Wallace 1992). Most of this water is currently being used in Arizona by non-Indian interests who will be forced to curtail use once Indian tribes begin utilizing the water.

If and when tribes are able to fully exercise their rights to Colorado River water, these new consumptive uses will come out of existing apportionments. It is for this reason that the settling of Indian water claims has been an issue of great interest and controversy throughout the Colorado basin. Given the lack of certainty of future rights for many non-Indian interests, long-term planning has been difficult. Furthermore, very few water rights holders will be willing to discuss water reallocations for environmental purposes until they are more certain of their future Colorado River water entitlements. The uncertainty associated with outstanding Indian water claims serves as an obstacle to long-term planning. All Indian claims, therefore, will have to be settled before any durable and comprehensive regional solution can be negotiated and implemented.

2. Water Settlements

That water is governed by two independent sets of law — state appropriative rights and federal reserved rights — has made settling Indian water claims difficult. While the Supreme Court's 1908 *Winters Decision* was a landmark legal interpretation of federal obligations to protect the water interests of Indian tribes, it did not make any attempt to quantify those rights. Due to the considerable economic and social repercussions of each settlement, the quantification process today has become extremely controversial, costly, and time-consuming.

Difficulty in reaching settlements is partially rooted in the 1963 Supreme Court *Arizona v. California* decision, where "practicably irrigable acreage" (PIA) was adopted by the Court as the criterion to be used when attempting to quantify Indian claims for five Indian tribes in the lower basin. While this method of quantification provided relatively generous settlements for these five Colorado River Indian tribes of the lower basin, more recent stricter interpretations of the PIA standard have curtailed the allowable amount of water for Indian tribes (Burton 1991). Beginning in the early 1980s, economic principles such as cost-benefit analyses were instituted to determine which lands were to be considered "practicably irrigable." Thus the PIA standard implicitly evolved to mean economically feasible using present technology. Applying the more liberal interpretation of the PIA standard used by the Court in 1963 to all remaining unsettled Indian water claims would most likely yield significantly larger water settlements for Indian tribes than they are likely to get today.

Some have questioned if it is in the best interests of the Indian tribes to quantify their claims by pursuing water rights settlements. This idea is based on the concept that, in legal terms, *Winters* rights include future needs and are not lost even if not exercised. Realistically, however, if tribes wait to quantify their rights, their ultimate apportionment will most likely get smaller. Courts will find it more and more difficult to reallocate water toward Indians tribes as non-Indian users become increasingly reliant on available water supplies. An example of this is already evident in the fact that tribes today are being held to different and more rigorous PIA standards than were applied when federal projects serving non-Indian agricultural water user were built decades ago (Checchio and Colby 1993).

3. Marketing Indian Tribes Water

Currently, only a small portion of already quantified tribal water rights is being utilized by Indian tribes. While it is clear that Indian tribes possess legal rights to considerably more water, a large percent has not been "developed" mostly for lack of financial resources. It is an open question as to what purposes this water will eventually serve. Some Indian tribes have expressed an interest in leasing a portion of their entitlements off-reservation to non-Indian water users. Until recently, it has generally been understood that federal laws have limited off-reservation water marketing (Water Strategist 1994). However, the Bureau of Reclamation in their 1994 Draft Regulations modified the federal position when it recognized the rights of Colorado River Indian tribes to market water off-reservation. The Bureau's preliminary conclusion was "that in the context of the lower basin, it is permissible, without additional authority from Congress, to allow for the use of Indian reserved right water off the reservations" (USBR 1994a).

However, there is a "Catch 22" associated with the issue of off-reservation marketing of Indian reserved water rights. Typically, under state law, water transfers have only been allowed for water that has a history of being put to beneficial use and then is conserved due to "extraordinary" measures (such as land fallowing, improvements in irrigation efficiency, concrete lining of canals, etc.). A significant percentage of Indian water rights has not yet been put to beneficial use largely due to a lack of capital to develop the supply. In fact, most recent water rights settlements have been packaged with funding — usually federal — for water development and distribution. If Indian tribes are restricted from marketing water that has not been historically used, then the only method to reap the economic benefits of the water is to develop their entitlements and irrigate more land. In some instances, this could have certain negative repercussions.

Most of the irrigable land on Indian reservations in the region is not suitable for growing high-value crops (McGuire et al. 1993). Therefore, a policy requiring historical use of water in order to enable marketing off-reservation will translate into removing water from an already over-allocated system for irrigation on marginal lands. It is questionable whether this is the most efficient use of water in a water-scarce region such as the Colorado River basin. Furthermore, even if they were attainable, large capital outlays to develop water supplies that are, in turn, marketed off-reservation are a questionable use of finances. With this in mind, it may be advantageous to allow the marketing of water that has no history of beneficial use. These issues should be considered when determining what is permissible in Indian water marketing.

In sum, one of the most complex and difficult management issues facing the Bureau of Reclamation is how to meet its trust responsibility of ensuring that Indian water rights are protected and fairly quantified while at the same time meeting other needs in an over-apportioned system. Given the potential to reshuffle the hierarchy of water rights in the basin, Indian water rights settlements are an important issue for all basin interests. Defining, quantifying, and integrating Indian water rights should be a top priority for the Bureau and other stakeholders as a first step toward a comprehensive management strategy for the basin. It is essential that Indian tribes be included early and participate continuously in such long-term planning efforts.

C. NEW RIVER MANAGEMENT STRATEGIES AND THE CURRENT POLITICAL STANDOFF

As mentioned earlier, a long-term management strategy for the river is contingent upon reaching agreement on what ecosystem functions and values are to be protected. Arriving at a consensus on this and other issues needs to be done democratically and with full involvement from all basin stakeholders. Realistically, however, freeing up water for environmental purposes will only be possible if it does not come at the expense of a particular stakeholder's needs. One goal of a "regional solution" will be to develop a consensus on innovative approaches to river management that will simultaneously allow for habitat recovery and health while also meeting existing and future human demands. What makes this task so complicated, however, is that the best interests and needs of the lower basin states are, in some cases, diametrically opposed. The roadblock presented by conflicting stakeholder needs must be addressed before water has a chance of being reallocated for environmental restoration and maintenance.

One goal of a "regional solution" will be to develop a consensus on innovative approaches to river management that will simultaneously allow for habitat recovery and health while also meeting existing and future human demands.

Faced with the problem of long-term demands potentially exceeding legally available supplies, water users and officials began rethinking management strategies for the river in the early 1990s. Particular attention was given to shifting water supplies toward more efficient and productive uses. The federal government, through the Bureau of Reclamation, began formally promoting conservation, improved management, and voluntary transfers of water as strategies to redistribute water towards its highest-utility use. Recognizing that the management practices of the river needed to be modified to more efficiently utilize the waters of the lower basin, the Bureau of Reclamation (Bureau) in 1994 released a draft document entitled *Regulations for Administering Entitlements to Colorado River Water in the Lower Colorado River Basin* (Draft Regulations), which provided a framework for new management strategies for the region. The Draft Regulations set into motion a series of stakeholder discussions — and eventually controversies — about how to revamp river management to best meet future needs.

Seen as overly ambitious by the states of the lower basin, time was requested to develop a lower basin consensus on a "regional solution" that would satisfy the water needs of each state. In mid-1994, it was agreed that a Lower Basin Technical Committee (Technical Committee) be established to discuss water issues pertaining to the lower basin. At the request of the Seven Colorado River Basin States and Ten Tribes Partnership (7/10 Partnership), the 11-member Technical Committee [9] was expanded to include the five Indian tribes of the lower Colorado basin. While considerable progress was made during eight months of negotiations, talks between the states dissolved when positions hardened on issues such as water banking and reservoir operations and Arizona dropped out of the discussions. Attempts to continue the negotiations failed shortly after and the dissolution of the Lower Basin Technical Committee now leaves the lower basin at a political standstill. While informal talks on matters of the Colorado have continued between certain lower basin principals, it is uncertain when official talks between the lower basin states will resume. In all likelihood, progress toward consensus will be slow given that the best interests of the three lower basin states are, in some cases, directly conflicting. The following discussion describes the major issues of contention.

[9] The following agencies were represented at the first meeting: Arizona Department of Water Resources (two representatives), Wellton Mohawk Irrigation District, Colorado River Board of California, Metropolitan Water District of Southern California, Imperial Irrigation District, Colorado River Commission of Nevada, Southern Nevada Water Authority, Bureau of Reclamation (2 representatives), Central Arizona Water Conservation District. No public interest groups or Indian tribes were present at the first meetings.

1. Re-operation of the Colorado River Reservoirs System

Some lower basin interests have argued that the Colorado River Reservoirs System (CRRS), the network of storage facilities on the mainstem of the Colorado, is not currently operated in the most efficient manner. More water can be utilized, it is argued, without any significant threat to water users in water-short years. Determinations for how the river is currently managed are based upon the *Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs* (Operating Criteria) issued in 1970. The Operating Criteria pursuant to the Colorado River Basin Project Act of 1968 requires the Department of the Interior to prepare an annual plan of operation for the CRRS. Included in the yearly plan are determinations as to how much water will be left in the reservoir system, the amount of water delivered to Mexico, the quantity of water to be delivered to lower basin users for consumptive beneficial uses (based on a declaration of the river's "normal," "surplus," or "shortage" condition), and the magnitude of lower basin users unused apportionments that may be used to satisfy the needs of other lower basin users. The Department of the Interior is directed by law to review the Operating Criteria for the CRRS every five years, but no changes have been made to them since they were written in 1970.

The criteria used by the Bureau in determining how much water to release from the Colorado River Reservoirs System are fairly straightforward. Historically, the Bureau has had a conservative approach to CRRS management, allowing in most years only the minimum water release of 8.23 maf from Lake Powell as required by the Operating Criteria. This 8.23 maf/year amount includes the average minimum flow required by the 1922 Compact and the 1944 treaty with Mexico, and is the quantity released unless greater releases are needed to avoid overflow spills (flows that bypass the hydroelectric turbines) during the spring runoff season. The monthly target releases are geared toward two primary objectives — having 2.4 maf of storage space for Glen Canyon Dam on January 1 for flood control, and being within 0.5 maf of full capacity (~27 maf for Lake Powell) by July 1 to achieve maximum storage for water supply and hydropower production during the summer.

Urban water purveyors in California and recently Nevada have been proponents of revamping the operation of Lake Mead to allow for increased beneficial use of the river's water. The states have argued that the Bureau's priority of ensuring certainty of supplying each state's basic apportionment has come at the expense of maximizing beneficial uses from the river system. Heavily affected by the Secretary's determination of "surplus" or "shortage" conditions,[10] California, in 1991, requested the establishment of "specific parameters" to help ensure that "determinations have a sound technical basis and that there is a balancing of the system wide benefits and risks" (State of California 1991). Partially due to pressure from the states, the Bureau is now in the process of developing new definitions of surplus and shortage.

The idea of drawing down reservoir levels to allow increased human use, however, is not without critics. Arizona has adamantly resisted the notion of cutting into emergency storage reserves, since the Central Arizona Project's (CAP) water entitlements are among the most junior water rights in the lower basin. Given CAP's low priority rights, the likelihood of having supplies reduced in drought years increases if the CRRS is consistently maintained at lower storage levels. From a water reliability standpoint, it benefits Arizona water users that rely on CAP supplies to have the reservoir system as full as possible.

Modifying CRRS operations to increase human uses has also been met with resistance from the environmental community. Aquatic ecosystems of the basin, with the exception of a few reaches in the state of Colorado, currently hold no rights to river water, and therefore, stand to lose the most during dry years. With this in mind, the potential negative environmental impacts of a sustained drought can be averted if reservoirs are kept at higher levels. Furthermore, as additional water is

[10] For the most part, a declaration of "surplus" condition has been determined only when the reservoirs begin encroaching on flood control space.

made available for urban and agricultural consumptive uses as a result of new reservoir operation procedures, it makes the task of reallocating water towards the river's ecosystems increasingly difficult. Until a mechanism is established that explicitly redirects a portion of the water toward stressed aquatic ecosystems, increased usage of stored Colorado River supplies does not represent a net environmental benefit. This is especially true if equivalent amounts of water can be made available merely by implementing urban and agricultural efficiency measures that are not currently being practiced.

The degree to which water is stored in case of drought versus utilized to meet current needs is determined by the size of the "safety cushion" desired by society. While, on one hand, it is not efficient to have the Colorado River Reservoirs System near capacity while users are forced to restrict uses, on the other, it is fundamentally shortsighted and risky to draw down the CRRS to a level where there is little protection in case of sustained drought. Until now, fear of a long-term drought similar to the one that is thought to have driven the Anasazi out of the basin has historically animated western water law and politics. States have tried to accommodate unlimited growth on a limited water budget by providing ample margins of safety against shortages (Ingram et al. 1991). Ultimately, stakeholders of the river and society as a whole should be allowed to decide how large the "comfort zone" should be. An overarching basin authority represented by all of the basin's stakeholders could be an appropriate forum to reach an equitable compromise that maximizes beneficial use while ensuring an adequate degree of reliability to meet water demands in times of drought. A detailed discussion of the establishment of an overarching basin authority is included in the chapter on Recommendations.

2. Water Banking

A related issue to the one of reforming dam operating procedures for additional water use is the concept of water banking. The two are linked due to the fact that as reservoirs are drawn down, more storage space is created for potential banking of conserved water. Many on the Colorado have seen water banking as a way to add flexibility in water management and also as a powerful potential incentive to foster conservation and more efficient use of water. Under a banking arrangement, water conserved by a lower basin user could be stored in Lake Mead or possibly Lake Powell for use during dry years. While the federal government and lower basin states have all agreed that the concept of water banking warrants further discussion, there is considerable disagreement about what should be allowed.

As with the increased water utilization schemes promoted by urban water purveyors in southern California, some Arizona water users look at CRRS water banking with reservation. An increase of "privately owned" water in the CRRS means less available supplies in times of drought for CAP water users who see CRRS banking as an unnecessary infringement on the future reliability of their entitlements. As an alternative, Arizona interests have promoted "off-river" banking in lower basin tributaries and groundwater aquifers. Adding to Arizona's concerns is the fact that Metropolitan Water District (MWD), one of the most vocal advocates of water banking, currently diverts unused lower basin entitlements, surpassing California's basic entitlement on an annual basis. The ability of MWD to bank water that is saved due to conservation efforts raises important questions about whether MWD even has title to the water it would bank.

3. Water Transfers and Exchanges

Water transfers are seen by many as a viable option for directing water toward its most valued use. The federal government, through the Bureau of Reclamation, endorsed the idea of voluntary water transfers in their 1994 Draft Regulations. While it is agreed that voluntary transfers of water will be a part of the lower basin's future, there is little consensus as to what the water markets will look like. It is still unclear whether transfers will be conducted between individual water users or if markets will be centralized and managed through state banks. Several Indian tribes of the lower basin have also expressed the desire to sell water but it is yet unknown if, or to what degree, they will be allowed to participate in the market.

Several recent events have begun to shape how the market for water transfers in the lower basin might develop. Intrastate transfers have already taken place without much controversy and were instigated and managed by the individual parties involved. Already, with the Bureau's approval, numerous irrigation districts of the lower basin have entered into transfer agreements with urban areas within their state, moving water from low-valued agricultural uses to higher-valued urban uses. With the exception of a successful groundwater banking program between Arizona and urban water purveyors in southern Nevada and southern California, interstate transfers and exchanges have proven more complicated and controversial.

At the state level, Nevada and California are the thirsty potential buyers while Arizona is the well-endowed water holder. Also, within each state there are individual interests, including those which are seeking water and those that are able to sell. However, water transfers between states will most likely take a few years to come to fruition for a number of reasons. First, due to a failed interstate transfer between urban water purveyors in California and Nevada, California has temporarily postponed negotiating any further transfers. An effort by Metropolitan Water District of Southern California (MWD) to include the Southern Nevada Water Authority (SNWA) in a previously arranged conservation program with a California irrigation district failed due to vast public outcry and eventual intervention by the California state government.[11]

Second, in 1995 Secretary of the Interior Bruce Babbitt made it clear that he will only look favorably upon, and therefore authorize, interstate transfers that have wide "political consensus" (Babbitt 1995). Given the current political climate regarding issues of the Colorado River, it is unlikely that an interstate transfer could take place without objections from some stakeholder in the lower basin. An example of this was Arizona's fierce condemnation of the MWD-SNWA partnership.

Third, interstate transfers may not occur for a period of time because the current structure of the Law of the River now allows lower basin states to use the unused entitlements of other lower basin states. California is the only U.S. state in the Colorado River basin currently using or exceeding its full basic entitlement. A formal water transfer between California and another party at this time would equate to California paying for something that it now receives free. Until Arizona and Nevada reach their full apportionments, there is little pressure for California to enter into a formal transfer agreement.

Since there appears to be some time before interstate water transfers become common, there is an opportunity to begin defining an ideal water market. Whether interstate water transfers will have a positive or negative affect on the river's mainstem ecosystems and delta has yet to be seen. While transfers to date have resulted in negligible environmental impacts, there is tremendous potential for water transfers to aid ecosystem restoration in the future. Like water banking schemes, if developed with environmental considerations in mind, water transfers and exchanges represent potential net benefits for aquatic ecosystems and could lead to a more sustainable patterns of water use. Future water transfers structured to include a surcharge or public trust fee could provide water or capital for environmental restoration and maintenance.

D. THE ABSENCE OF ENVIRONMENTAL CONSIDERATIONS IN INTERNATIONAL TREATIES

Almost no language in international treaties between the United States and Mexico explicitly deals with environmental considerations. This remains an obstacle to sustainable river management and, more specifically, restora-

[11] Environmental groups in California claimed that the MWD-SNWA "partnership," was not in the interests of the state as a whole, because of the risk of increased MWD reliance on water resources from the northern portion of the state, including the ecologically and politically sensitive Bay-Delta region. In the beginning of 1996, California's governor, Pete Wilson, asked MWD to postpone any interstate transfers until after California's Colorado River interests could reach a consensus position on issues pertaining to the Colorado River (Western Water 1996). With former federal judge Abraham Sofare serving as a facilitator, current closed-door discussions between the six California water users of Colorado River water and the Colorado River Board of California are in progress.

tion of the delta. Water users in the U.S. portion of the basin have voiced concern that any water reallocated for delta restoration and maintenance would never reach its intended use due to the high likelihood of it being diverted by agricultural interests once it crosses the border into Mexico. Unless there were assurances that reallocated environmental water was not going to be diverted for human uses, it is highly unlikely that basin states would agree to a delta restoration program.


The Cienega de Santa Clara now supports the largest wetland habitat remaining in the delta. (Courtesy of Dale Pontius)

Another problem is the fact that Mexico has legal entitlements to less than 10 percent of the river's average annual flow. This makes it both unrealistic and inequitable to assume that Mexico has sole responsibility for delta restoration. Given the current legal framework and distribution of water entitlements in the basin, any successful ecosystem restoration program for the delta will require a cooperative binational effort, and most likely a formal international agreement between the two countries.

A cooperative international project to augment water supplies to the delta stands to produce a host of recreational and economic benefits that should not be overlooked. Using California's San Francisco Bay–Sacramento/San Joaquin River delta estuary as a comparison, numerous recreational industries could flourish in the Colorado River delta region. Birdwatching, duck hunting, sport fishing, kayaking, and boating represent potential sources of income for local communities once the delta is restored. Given the variety of waterfowl and other wildlife endemic to the area, there is also great potential for ecotourism in the region. Increased fish populations such as those of the totoaba, which utilize delta areas as spawning grounds, could draw anglers from the urban areas of Los Angeles, Phoenix, Tucson, Tijuana, and San Diego. Also, commercial shrimping and fishing industries in the Upper Gulf that have reached their nadir in recent decades could possibly be reinvigorated with added inflows to the delta. Recovery of fish populations, however, will also depend on modified fishing practices in the Gulf and enforcement of fishing restrictions by Mexico.

Restoring the delta should not be seen as merely an altruistic endeavor. Interests on both sides of the border stand to gain from a healthy estuarine system.

For the above reasons, restoring the delta should not be seen as merely an altruistic endeavor. Interests on both sides of the border stand to gain from a healthy estuarine system. Since U.S. interests account for a majority of the river's water use and entitlements and also stand to benefit from a restored delta, assistance must be provided from north of the border. Given the current legal framework and distribution of water entitlements, a binational approach is the only viable alternative for delta restoration.

VII. Recommendations

The lower Colorado River basin is beset by a series of serious environmental, institutional, political, and social problems related to water allocation and use. In particular, unsustainable use of groundwater, overallocation and misallocation of total water resources, and substantial threats to significant ecological resources must all be resolved at a time when demands for the limited resources of the basin are increasing. This report has summarized the nature of the problems in the basin, described explicit criteria and goals for long-term sustainable water management and planning, and made some suggestions for policy tools, technologies, and strategies for reaching those goals. We summarize here the most important of those recommendations.

A. ALLOCATE WATER TO MEET BASIC ENVIRONMENTAL WATER NEEDS IN THE BASIN

The sustainability criteria defined earlier in this paper recommend that the basic water needs of ecosystems be met. While defining and quantifying these needs is difficult, failing to meet them will lead to continued degradation of the environmental health of the Colorado River basin. As a fundamental principle, therefore, all parties should acknowledge the need to both identify basic environmental needs in the basin and to allocate the water to meet them. There are many ways this can be done — through minimum flow requirements in rivers, through enforced water quality standards in sensitive areas, through explicit allocation of water to environmental purposes, and so on. In addition to identifying needs, however, there must be reasonable and acceptable ways of meeting those needs. Water can be conserved by current users and reallocated, legislation can alter current legal entitlements in favor of the environment, or environmental interests can purchase or lease water. Ultimately, the choice of policy will depend on a wide range of political, social, and economic factors. Below, we identify a few that we consider to be both high priorities and politically and socially equitable.

Negotiate an Environmental Component to the 1944 Colorado River Treaty

Any agreement to meet basic environmental needs, particularly in the lower reaches of the river and in the delta region, must involve international cooperation and agreement. Permitting additional releases of water for the delta will not benefit ecosystem health if that water is appropriated by other water users before it can reach the delta and upper Sea of Cortez. Changes in timing of flows and in water quality (including temperature and salinity) have far reaching consequences that require discussion, negotiation, and agreement, similar to that reached in Minute 242, when the problem of the quality of water delivered to Mexico was finally resolved. A comparable agreement is necessary to meet environmental water needs on both sides of the border.

As a fundamental principle, therefore, all parties should acknowledge the need to both identify basic environmental needs in the basin and to allocate the water to meet them.

Maintain Minimum Flows to the Cienega de Santa Clara

Although water flowing to the Cienega de Santa Clara consists almost entirely of agricultural return flows from the U.S., this water is vital to the survival of the largest remaining wetland in the region. Operation of the Yuma desalting plant or other actions that would cut these flows should not be permitted. In order to make deliveries to the Cienaga permanent, the language of the Salinity Control Act of 1974 will most likely have to be modified.

Restore Minimum Flows to the Colorado River Delta

Some minimum amount of water must be allocated and guaranteed to restore at least part of the formerly rich Colorado River delta. This paper has offered a variety of options for obtaining that water, including agricultural reforms, urban conservation, and explicit political guarantees.

B. END NON-RENEWABLE GROUNDWATER USE IN THE BASIN

Another fundamental criterion for sustainable water use is to maintain the renewability of the resource. The massive and long-term overpumping of groundwater resources in nearly every region in the lower basin is unsustainable and reduces options available to future generations. An explicit goal of water management in the Colorado basin as a whole should therefore be the elimination of long-term overdraft of groundwater. Annual groundwater overdraft can continue in regions that receive sufficient recharge in wet years to compensate, but long-term average overdraft should no longer be considered an acceptable form of water supply.

C. FILL WATER DATA AND INFORMATION GAPS IN THE REGION

While an enormous amount of information and research has been done on the shared water resources between the U.S. and Mexico, and on the Colorado River Basin in particular, considerable gaps in information, data, and knowledge remain. These gaps hinder the development of an acceptable and broad set of recommendations and solutions to current basin problems.

Among the most severe gaps is the lack of clear information on the amount, quality, and timing of water required to satisfy basic ecological needs in the basin. In particular, research is needed on the water needs of endangered and threatened species and on the water needs of the delta region and the marshes that are found at the mouth of the river.

Another major gap in knowledge is detailed data on water use, particularly in Mexico, but also in the United States. In order to plan for future water use and to identify opportunities for water efficiency improvements and reallocations, far more detailed information on current uses is needed.

Groundwater withdrawals and use are inadequately monitored and managed. Data on the quantity and quality of groundwater withdrawals is missing in many regions, making it difficult to know the extent and severity of non-sustainable water use.

D. RESTRUCTURE WATER INSTITUTIONS TO PROMOTE SUSTAINABLE WATER PLANNING AND USE

Improve the Participation of All Affected Parties in Colorado River Decision Making

One of the principles of sustainable water planning and use enunciated by the United Nations and other international water agencies and groups is the fundamental need for democratic participation in decision making. Because of the size of the Colorado basin and the large number of interest groups affected by any decision on the river, effective public participation is a real challenge. Nevertheless, without such participation, future effective management of the basin will be exceedingly difficult.

Form an Overarching International River Basin Commission

Time has proven that regionally, politically, and topically fragmented approaches to Colorado River management no longer work. A cooperative effort between the federal, state, and international agencies that manage and regulate water, as well as between the various basin interests (urban, agricultural, environmental) that depend on the resource is required to remedy the problems of the Colorado River. Such a collaborative effort could manifest itself in the form of a more effective and comprehensive river basin commission, with open and direct connections to the other institutions and organizations that play a role in decisionmaking and policy.

The general role of a river basin commission would be to develop a comprehensive, integrated, environmentally sustainable, long-term management plan for the Colorado River. By taking a comprehensive look at an entire river system, and by involving all affected stakeholders, it will be easier to solve both local and basin-wide problems. Specifically, the river basin commission can work to:

- develop a "vision" for what that river's aquatic ecosystems could or should look like in the future;
- find equitable and efficient ways of implementing some of the proposed solutions to basin problems, including water banking, water marketing, reservoir operations, and infrastructure changes; and
- create and oversee mechanisms that supply water for ecosystem restoration and maintenance for the Colorado River mainstem and the delta.

The structure of the commission could take many forms. One possible format could be one similar to California's San Francisco Bay/Sacramento-San Joaquin Delta Estuary CALFED process. In this process (described in detail in Appendix B), federal and state agencies as well as a range of private interests have been working to develop a consensus on a long-term management strategy for the Bay-Delta. A Colorado River basin commission could adopt a similar format to that of CALFED, drawing from its successes. While it is essential that all stakeholders are represented in the commission, the federal governments of the U.S. and Mexico are likely to continue to play a leading role in the river's management and, thus, also in the basin commission.

There are few alternatives to strong federal leadership, as basin states have consistently proven their inability to resolve differences without federal intervention. Historically, states have primarily worked to serve their own interests, which have typically been to maximize consumptive use of the river's water. At times when funding has been needed to build storage, flood control, and delivery systems along the river, they have worked together to secure it from the federal government, otherwise they have feuded amongst themselves. Left to their own devices, the states of the lower Colorado Basin have demonstrated little ability to work together to resolve differences efficiently or even peacefully.[12]

At the same time, the power of federal agencies must be complemented by far broader representation of non-governmental interests in the region, including federal and state watchdog groups, environmental and community interests, and research and academic organizations. Any long-term plan for managing the Colorado must be established through consensus, using input from the broad coalitions and communities that are part of the basin. The commission should provide a forum where all basin interests can be heard and where consensus can be reached through discussion rather than litigation.

E. APPLY OTHER TOOLS FOR REACHING A SUSTAINABLE VISION IN THE COLORADO BASIN

Once Basic Human and Ecological Needs are Met, Water Should be Considered an Economic Good

The prevailing notion that provision of water should be free or highly subsidized is no longer acceptable in an era when competition is increasing over scarce water resources. Where water is plentiful in relation to overall need and demand, there is little reason to focus on allocation or use efficiency. But in regions like the Colorado basin, allocating among competing uses requires incorporating economic considerations and values. Specific economic tools for efficient water use and allocations include:

- Properly designed pricing structures to promote water conservation and efficiency, and encourage reuse and recycling;
- Low-interest loans to make it more attractive for water users to invest in conservation

[12] Examples of this are Arizona's governor, B.B Moeur, calling out the Arizona National Guard in 1933 to stop the building of Parker Dam, the twelve years of litigation between California and Arizona and Nevada leading to the 1963 Supreme Court decision, and most recently, the disintegration of the Lower Basin Technical Committee.

and more efficient technologies;

- Water depletion taxes on groundwater overdraft to raise government revenue while discouraging inefficient resource consumption;
- Increased assessments instituted on all uses of Colorado River water to help pay for "public good" uses of the river such as ecosystem restoration and maintenance;
- Voluntary water transfers to move water from low-valued uses to higher-valued uses. Community participation in decisions to move water from a region should be a necessary condition of any transfer;
- Water surcharges on all voluntary water transfers of Colorado River water to provide funds for environmental restoration;
- A surcharge or fee on water conserved by a basin user and banked on the Colorado mainstem to provide water for environmental protection.

Improvements in the Efficiency of Water Use Should be a Higher Priority than Creating New Supply

The Colorado is one of the most heavily controlled rivers in the world. As a result, the construction of any new supply infrastructure in the Colorado River basin is likely to be opposed for environmental, economic, and social reasons. At the same time, improvements in the efficiency of agricultural, residential, and industrial water use, through application of existing technology, appear to be substantially less expensive than the marginal cost of new supply. These factors suggest that improvements in the efficiency of water use should be a higher priority — and in the end will be more productive — than projects to develop new supplies.

Improvements in the efficiency of water use should be a higher priority — and in the end will be more productive — than projects to develop new supplies.

Allocation Efficiency Should be Improved

When overall availability of water is less than the total demand for water, decisions about allocation must be made. For some uses, like maintaining certain environmental goods and services, water may be indispensable. For others, the value of the use varies enormously and must be considered in any allocation decisions. Where the "market" operates effectively, decisions can often be left to the market. But when market operations are hindered by subsidies, hidden values, unquantified benefits of water use, and so on, allocation decisions may be made inefficiently. This is particularly true in the agricultural sector, where allocations of water to low-valued, highly water intensive crops can disproportionately consume scarce resources. Reallocating water in the agricultural sector can reduce overall water demand while still sustaining a healthy agricultural community and industry.

Conclusions

A sustainable vision for the lower Colorado River basin can be identified, described, and, we believe, reached. Such a vision will include restoring and maintaining some of the unique environmental and ecological resources of the region, including the river delta and the endangered native fisheries, eliminating unsustainable use of the resource — particularly groundwater overdraft, and improving institutional structures to incorporate the viewpoints of the many diverse interests groups of the river. The answers do not lie in developing new technologies or finding new sources of supply, but in rethinking how to prioritize among the many competing uses, given the resources that are available and the values that need to be sustained. This approach has the best chance of reducing the risks of water conflicts and ecological collapse for the region as a whole and for moving forward into a sustainable 21st century.

VIII. Bibliography

Arizona Agricultural Statistics Service (AASS). 1994. "1994 Arizona Agricultural Statistics." Phoenix, Arizona.

Arizona Department of Water Resources (ADWR). 1996. "Concept Paper: A Program to Bank Additional Colorado River Water in Arizona." January 1996. Phoenix, Arizona.

Arizona Department of Water Resources (ADWR). 1994. "Arizona Water Resources Assessment." Volume I and II. Phoenix, Arizona.

Arizona Department of Water Resources (ADWR). 1991. "Second Management Plan 1990-2000: Pinal Active Management Area." Phoenix, Arizona.

Arizona Department of Water Resources (ADWR). 1987. "Overview of the Arizona Groundwater Management Code." Phoenix, Arizona.

Babbitt, B. 1995. Keynote Address to Colorado River Water Users Association's 50th Annual Convention. Las Vegas, Nevada. December 8, 1995.

Black & Veatch. 1995. "1995 California Water Charge Survey." Management Consulting Division. Irvine, California.

Burton, L. 1991. American Indian Water Rights and the Limits of the Law. University Press of Kansas.

Bates, S. F., D.H. Getches, L.J. MacDonnell, and C.F. Wilkinson. 1993. Searching out the Headwaters. Island Press. Washington, D.C.

Bertoldi, G.L. 1992. "Subsidence and consolidation in alluvial aquifer systems." In the Proceedings of the 18th Biennial Conference on Groundwater, U.S. Geological Survey. pp. 62-74.

California Department of Water Resources (CDWR). 1993. "California Water Plan Update." Draft Bulletin 160-93, November 1993, Sacramento, California.

California Department of Water Resources (CDWR). 1994. "California Water Plan Update." Final Bulletin 160-93. Sacramento, California.

California Department of Water Resources (CDWR). 1994a. "Urban Water Use in California." Final Bulletin 166-4. Sacramento, California.

Carothers S.W. and B.T. Brown. 1991. The Colorado River Through Grand Canyon. The University of Arizona Press. Tucson, Arizona.

Carrier, J. 1991. "The Colorado: A River Drained Dry," National Geographic, June 1991.

Checchio, E., and B.G. Colby. 1993. "Indian Water Rights: Negotiating the Future. " Water Resources Research Center. The University of Arizona College of Agriculture. Tucson, Arizona.

City of San Jose, Brown and Caldwell Consultants, and Department of Water Resources. 1990. "Case Studies of Industrial Water Conservation in the San Jose Area." Sacramento, California.

Coache, B. Nevada State Engineer's Office, personal communication, May 1996.

Colorado River Board of California (CRBC). 1996. "Water Issues Update: Maximizing Utilization of Colorado River Water for California." Testimony of Gerald Zimmerman, Executive Director, to the Assembly Committee on Water, Parks, and Wildlife. March 19, 1996.

Colorado River Basin Salinity Control Forum (CRBSCF). 1993. "Water Quality Standards for Salinity: Colorado River System." Final Report. October 1993.

Comición Nacional del Agua (CNDA). 1990. "Proyecto de Modernizacion de Areas de Riego Valles de Mexicali, B.C. y San Luis Río Colorado, Sonora."

Comición Nacional del Agua (CNDA). 1991. "Caracteristicas de los Distritos de Riego: Ano Agricola 1990." Volumen I. Regiones: Noroeste, Centro Norte y Noreste. Informe Estadistico Num. 5, Epoca 2. Noviembre de 1991.

Curry, F. 1994. Memorandum (with attachments) to The Commission, "Implementation of Ordering Paragraph No. 5 of Decision No. 94-06-033, closing Phase Two of the Water Risk Investigation." Public Utilities Commission, San Francisco, California. October 20, 1994.

Department of Finance (DOF). 1994. California Statistical Abstract. Compilation of U.S. Department of Commerce, Bureau of Economic Analysis data. Sacramento, California.

Dongoske, K.E. 1996. "Integrating Native American Economic and Cultural Interests into the Colorado River Basin." Paper prepared for the Colorado River Workshop, Phoenix, Arizona, February 1996.

Dziegielewski, B., E. Opitz, and G. Henfling. 1991. "Municipal and Industrial Water Use in the Metropolitan Water District Service Area: Interim Report No. 4." Planning and Management Consultants, Ltd., Report to the Metropolitan Water District of Southern California, Carbondale, Illinois.

Eden, S. and M.G. Wallace. 1992. "Arizona Water: Information and Issues." Water Resources Research Center. University of Arizona. Tucson, Arizona.

Erie, L.J., O.F. French, D.A. Bucks, and K. Harris. 1982. "Consumptive Use of Water by Major Crops in the Southwestern United States." Conservation Research Report No. 29, Agricultural Research Service. U.S. Department of Agriculture. Washington, D.C.

Federal Emergency Management Agency (FEMA). 1983. Flood Hazard Mitigation Report. FEMA-691-DR-AZ. pp.41. Washington, D.C.

Flug, M. and W.L. Jackson. 1993. "Emerging Role for Natural, Cultural, and Environmental Resource Issues: The Colorado River Experience." Water Resources Bulletin, June 1993, pp. 577-586.

Geraghty, J.J., D.W. Miller, F. Van Der Leeden, and F.L. Troise. 1973. Water Atlas of the United States. Water Information Center. Port Washington, New York.

Gleick, P.H. 1988. "The effects of future climatic changes on international water resources: the Colorado River, the United States, and Mexico." Policy Sciences Vol. 21, pp. 23-39.

Gleick, P.H. 1996. "Basic water requirements for human activities: Meeting basic needs." Water International, Vol. 21, pp. 83-92.

Gleick, P., P. Loh, S. Gomez, and J. Morrison. 1995. California Water 2020: A Sustainable Vision. Pacific Institute for Studies in Development, Environment, and Security. Oakland, California.

Glenn, E.P., C. Lee, R. Felger, and S. Zengel. 1996. "Water Management Impacts on the Wetlands of the Colorado River Delta, Mexico," Conservation Biology, in press.

Glenn, E. P., Environmental Research Laboratory, personal communication, May 1996.

Glenn, E.P., R.S. Felger, A. Burquez, and D.S. Turner. 1992. "Cienega de Santa Clara: Endangered Wetland in the Colorado River Delta, Sonora, Mexico, Natural Resources Journal, Vol. 32, Fall 1992, pp. 818-824.

Governor's Central Arizona Project Advisory Committee (GCAPAC). 1993. "Description of the Central Arizona Project." Prepared by Arizona Department of Water Resources. Phoenix, AZ.

Governor's Central Arizona Project Advisory Committee (GCAPAC). 1993a. "Final Report and Recommendations." Prepared by Arizona Department of Water Resources. Phoenix, AZ.

High Plains Underground Water Conservation District. 1995. The Cross Section, Vol. 41, No. 6., June 1995.

Howe, C. W. and W. A. Ahrens. 1988. “Water Resources of the Upper Colorado River Basin: Problems and Policy Alternatives, in M. T. El-Ashry and D. C. Gibbons, eds., Water and Arid Lands of the Western United States, World Resource Institute, Washington, D.C.

Holway, J., Arizona Department of Water Resources, personal communication, May 1996.

Ingram, H., A.D. Tarlock, and C.R. Oggins. 1991. “The Law and Politics of the Operation of Glen Canyon Dam,” in Committee to Review the Glen Canyon Environmental Studies. Water Science and Technology Board. Colorado River Ecology and Dam Management. National Academy Press. Washington, D.C.

Intergovernmental Panel on Climate Change (IPCC). 1995. Climate Change 1995: Impacts, Adaptations, and Mitigation. Working Group II Summary for Policymakers. World Meteorological Organization/United Nations Environment Programme.

International Boundary and Water Commission. 1992. “Flow of the Colorado River and Other Western Boundary Streams and Related Data.” Western Water Bulletin 1992.

Irrigation Journal, “1993 Irrigation Survey,” January-February 1994.

Jager, J. and H. L. Ferguson. 1991. Climate Change: Science, Impacts and Policy. Proceedings of the Second World Climate Conference Cambridge University Press, Cambridge.

Johnson, R.R. 1991. “Historic Changes in Vegetation Along the Colorado River in the Grand Canyon.” in Committee to Review the Glen Canyon Environmental Studies, Water Science and Technology Board. Colorado River Ecology and Dam Management. National Academy Press. Washington, D.C.

Karpiscak, M.M., K.E. Foster, and N. Schmidt. 1990. “Residential Water Conservation: Casa Del Agua.” Water Resources Bulletin, Vol. 26, No. 6. pp. 939-948.

Kneese, A.V., and G. Bonem. 1986. “Hypothetical Shocks to Water Allocation Institutions in the Colorado Basin.” In: New Courses for the Colorado River: Major Issues for the Next Century. G.D. Weatherford and F.L. Brown, (Editors). University of New Mexico Press. Albuquerque, New Mexico. pp. 87-108.

Kuranz, C.B. 1996. “Tucson’s Changing Landscape: A Response to State Conservation Requirements.” in Proceedings of Conserv’96: Responsible Water Stewardship, American Water Works Association, 1996.

León, M.V., T.R. McGuire, and H. Aubert. 1993. “Suggestions for a Sustainable Fishery.” in McGuire, T. R. and J. B. Greenberg, eds., Maritime Community and Biosphere Reserve: Crisis and Response in the Upper Gulf of California. Occasional Paper No. 2, Bureau of Applied Research in Anthropology. University of Arizona, Tucson, Arizona.

Leopold, Aldo. 1949. A Sand County Almanac, Oxford University Press, New York.

Loh, P. and A. Steding. 1996. The Palo Verde Test Land Fallowing Program: A Model for Future California Water Transfers? Pacific Institute for Studies in Development, Environment, and Security. Oakland, California.

MacDonnell, L. and B. Driver. 1996. “Rethinking Colorado River Governance.” Paper prepared for the Colorado River Workshop, Phoenix, Arizona, February 1996.

MacDougall, N.W., M. Hanemann, and D. Zilberman. 1992. “The Economics of Agricultural Drainage,” October 1992, submitted to Central Valley Regional Water Quality Control Board, Department of Agricultural and Resource Economics, U.C. Berkeley.

Maddock, T. S. and W.G. Hines. 1995. "Meeting Future Water Supply Needs: A Southwest Perspective." *Water Resources Bulletin*, Vol. 31, No. 2, April 1995.

Manzione, M., B. Jordan, and W.O. Maddus. 1991. "California Industries Cut Water Use," Journal of the AWWA, October 1991.

Massachusetts Water Resources Authority (MWRA). 1991. "MWRA Honors Spalding Sports Worldwide for Water Conservation." news release. Boston, Massachusetts. September 27, 1991.

McGuire, T.R., W.B. Lord, M.G. Wallace, editors. 1993. Indian Water in the New West. Tucson: The University of Arizona Press

Meko, D., C.W. Stockton, and W.R. Boggess. 1995. "The Tree-Ring Record of Severe Sustained Drought." Water Resources Bulletin. Volume 31, Number 5. October 1995.

Metropolitan Water District of Southern California (MWD). 1995. "The Regional Urban Water Management Plan." Los Angeles, California.

Milliman, J.D. and R.H. Meade. 1983. Worldwide Delivery of River Sediment to the Oceans." Journal of Geology. 91(1), pp. 1-21.

Minckley, W.L. 1991. "Native Fishes of the Grand Canyon Region: An Obituary?" in Committee to Review the Glen Canyon Environmental Studies, Water Science and Technology Board. *Colorado River Ecology and Dam Management*. National Academy Press. Washington, D.C.

Mitchell, D.L. and M. Hanemann. 1994. Report to the California Urban Water Conservation Council, "Setting Urban Water Rates for Efficiency and Conservation: A Discussion of Issues." M Cubed. Oakland, California.

Murphy, T. 1995. "Low Impact Agricultural Irrigation." Irrigation Journal. March 1995. pp. 8-12.

Nash, L. and P.H. Gleick. 1993. "The Colorado River Basin and Climatic Change: The Sensitivity of Streamflow and Water Supply to Variations in Temperature and Precipitation." U.S. Environmental Protection Agency, EPA230-R-93-009, Washington, D.C. 121 pp.

Nash, L.L. and P.H. Gleick. 1991. "The sensitivity of streamflow in the Colorado Basin to climatic changes." Journal of Hydrology. Vol. 125, pp. 221-241.

Nevada Colorado River Commission (NCRC). 1990. "Colorado River Water Budget." Las Vegas, Nevada

Nevada Department of Conservation and Natural Resources (NDCNR). 1995. "State Water Policy: Guiding Principles, Policies, and Issues." First Draft, revised March 1995. Division of Water Planning. Carson City, Nevada.

Nevada Department of Conservation and Natural Resources (NDCNR). 1992. "Nevada Water Facts." Division of Water Planning. Carson City, Nevada.

Peart, L.A., K.D. Warner, and Black & Veatch. 1993. "Tucson's Rate Structure Changes Designed to Strengthen Conservation Pricing Incentives," in American Water Works Association, *Proceedings of Conserv '93: The New Water Agenda*, Denver, Colorado.

Postel, S. 1985. *Conserving Water: The Untapped Alternative*, Worldwatch Paper 67, Worldwatch Institute, Washington, D.C.

Postel, S. 1992. Last Oasis: Facing Water Scarcity, W.W. Norton, New York.

Postel, S. 1995. "Where Have All the Rivers Gone?" *Worldwatch*. May-June 1995.

Postel, S. 1996. "Forging a Sustainable Water Strategy," in L.R. Brown et al., State of the World 1996, W.W. Norton, New York.

Puffer, M., Metropolitan Water District of Southern California, personal communication, June 1992.

Reich, P.L. , editor. 1984. “Statistical Abstract of the U.S.-Mexico Borderlands.” UCLA Latin American Center Publications. Los Angeles, California.

Ricci, H., Nevada State Engineer’s Office, personal communication, May 1996.

Robles, A., Conservation International, personal communication, February 1995.

San Diego Water Authority (SDWA). 1996. San Diego Water Authority press release. June 5, 1996.

Schumann, H.H., R.L. Laney, and L.S. Cripe. 1987. “Land Subsidence and Earth Fissures Caused by Groundwater Depletion in Southern Arizona.” *Regional Aquifer Systems of the United States: Southwest Alluvial Basins of Arizona*. American Water Resources Association Monograph Series No. 7. Bethesda, Maryland.

Smith, R.T. and R. J. Vaughn. 1994. “AZ DWR Releases Update on Indian Water Rights Settlement,” Water Intelligence Monthly, March 1994.

Southern Nevada Water Authority (SNWA). undated telefax. “Water Resources.”

Southern Nevada Water Authority (SNWA). 1996. “Water Resource Plan.” January, 1996.

State of California. 1991. “Conceptual Approach for Reaching Basin States Agreement on Interim Operation of Colorado River System Reservoirs, California’s Use of Colorado River Water Above Its Basic Apportionment, and Implementation of an Interstate Water Bank.” Prepared for the Colorado River Basin States Meeting in Denver, Colorado August 28, 1991.

Stockton, C.W., and G.C. Jacoby. 1976. “Long-Term Surface Water Supply and Streamflow Levels in the Upper Colorado River Basin.” Lake Powell Research Project. Bulletin No. 18. Institute of Geophysics and Planetary Physics. University of California Los Angeles. California.

Sunding, D., D. Zilberman, R. Howitt, A. Dinar, and N. MacDougall. 1994. “The Costs of Reallocating Water from Agriculture.” University of California, Berkeley.

Sweetman, W., Spalding Sports Worldwide, personal communication, March 1992.

Tucson Water. 1984. “Energy Innovation Through Applied Technology.” Tucson, Arizona.

Tucson Water. undated. “Conservation Programs,” Tucson, Arizona.

United Nations. 1992. “Earth Summit Agenda 21: The United Nations Programme of Action from Rio.” New York. Chapter 18 of Agenda 21 is devoted to freshwater resources.

UNLV Center for Business and Economic Research. 1994 telefax.

United States. 1944. *Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande*. Treaty Between the United States and Mexico. Treaty Series 994.

U.S. Bureau of Indian Affairs. 1989. Handbook of North American Indians. Volumes 9 and 10. Smithsonian. Washington D.C.

U.S. Bureau of Reclamation. undated. “Managing the Lower Colorado River to Meet Contemporary Needs”(Fact Sheet), Boulder City, Nevada.

U.S. Bureau of Reclamation. 1995 telefax. “Estimate of 1995 Colorado River Water Use.” May 16, 1995. Boulder City, Nevada.

U.S. Bureau of Reclamation. 1994. “Indian Trust Asset Policy and NEPA Implementing Procedures: Questions and Answers About the Policy and Procedures.” Draft March 1994.

U.S. Bureau of Reclamation. 1994a. “Draft Regulations for Administering Entitlements to Colorado River Water in the Lower Colorado River Basin.” May 1994. Boulder City, Nevada.

U.S. Fish and Wildlife Service (USFWS). 1995. "Recovery Program for the Endangered Fishes of the Upper Colorado River." Winter 1995. Denver, Colorado.

U.S. Fish and Wildlife Service (USFWS). 1995a. "Lower Colorado River Ecoregion Plan." November 1995.

U.S. Geological Survey. 1994. "Summary of Ground-Water Conditions in Arizona, 1987-90." by D.W. Anning and N.R. Duet. Open File Report 94-476. Tucson, Arizona.

Vickers, A. 1991. "The Emerging Demand-Side Era in Water Management." Journal AWWA. October 1991.

Vickers, A. 1993. "The Energy Policy Act: Assessing its Impact on Utilities." Journal AWWA: Vol. 85, No. 8, August 1993. pp. 56-62.

Wade, W.W., J.A. Hewitt, and M.T. Nussbaum. 1991. "Cost of Industrial Water Shortages." prepared by Spectrum Economics, Inc. for the California Urban Water Agencies. San Francisco, California.

Waggoner, P.E. (ed.) 1990. Climate Change and U.S. Water Resources. John Wiley and Sons, Inc., New York.

Wahl, R. W. 1989. "Markets for Federal Water: Subsidies, Property Rights, and the Bureau of Reclamation." Resources for the Future. Washington, D.C.

Waller, T.S. 1993. "The Politics of Agricultural Water Conservation in the Border Region of the Californias." UMI Dissertation Services. Ann Arbor Michigan.

Water Strategist. 1994. "Indian Water Marketing: A Realizable Vision?" Vol. 8, No. 3, October 1994.

Waterweek. 1996. "Arizona water company fined for overpumping." Waterweek Vol. 5, No. 12, p.4.

Weatherford, G.D. and G.C. Jacoby. 1975. "Impact of Energy Development on the Law of the River." Natural Resources Journal. Vol. 13.

Western Water. 1996. "Colorado River Controversies." March/April 1996. Publication of the Water Education Foundation. Sacramento, California.

Wichelns, D. and D. Cone. 1992. "Tiered pricing motivates Californians to conserve water." Journal of Soil and Water Conservation. March/April 1992. vol. 47. no. 2. pp. 139-144.

Wigington, R. and D. Pontius. 1996. "Toward Range-Wide Integration of recovery Programs for the Big, Native Fishes of the Colorado River," Draft Paper prepared for the Colorado River Workshop, Phoenix, Arizona, February 1996.

Williams, A.A. 1983. "Cocopa." In Alfonso Ortiz, ed. Handbook of North American Indians. vol. 10. Smithsonian. Washington D.C.

Wilson, F. 1994. "A Fish Out of Water: A Proposal for International Instream Flow Rights in the Lower Colorado River," Colorado Journal of International Environmental Law and Policy. Vol. 5. pp. 249.

Wilson, P., H. Ayer, and G. Snider. 1984. Drip Irrigation for Cotton: Implications for Farm Profits, U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 517, Washington, D.C.

World Commission on Environment and Development (WCED). 1987. Our Common Future. Oxford University Press. New York.

Appendix A: List of Federally-Listed Endangered, Threatened, Candidate, and Species at Risk which may occur in the Lower Colorado River Ecosystem (Source: USFWS 1995a)

ENDANGERED

Mammals:

Hualapai Mexican vole
(Microtus mexicanus hualpaiensis)

Birds:

American peregrine falcon
(Falco peregrinus anatum)
California condor (Gymnogyps californianus)
Brown pelican (Pelecanus occidentalis)
Yuma clapper rail
(Rallus longirostris yumanensis)
Southwestern willow flycatcher
(Empidonax traillii extimus)

Fish:

Gila topminnow
(Poeciliopsis occidentalis occidentalis)
Razorback sucker (Xyrauchen texanus)
Colorado squawfish (Ptychocheilus lucius)
Desert pupfish (Cypzinodon macularius)
Bonytail chub (Gila elegans)
Humpback chub (Gila cypha)
Virgin River chub (Gila seminuda)
Woundfin (Plagopterus argentissimus)

Invertebrates:

Kanab ambersnail
(Oxyloma haydeni kanabensis)

Plants:

Arizona cliffrose (Purshia subintegra)
Brady pincushion cactus (Pediocactus bradyi)
Sentry milk vetch (Astragalus cremnophylax var. cremnophylax)

THREATENED

Birds:

Bald eagle (Haliaeetus leucocephalus)
Mexican spotted owl (Strix occidentalis lucida)

Reptiles:

Desert tortoise (Mohave population)
(Gopherus agassizii)
Coachella Valley fringe-toed lizard
(Uma inortata)

Plants:

Siler pincushion cactus (Pediocactus sileri)

PROPOSED ENDANGERED/THREATENED

Reptiles:

Flat-tailed horned lizard (Phrynosoma mcallii)

CANDIDATE CATEGORY I

Birds:

California black rail
(Laterallus jamaicensis coturniculus)

Plants:

Paradox milk vetch
(Astragalus hoj-mgreniorum)
Fickeisen pincushion cactus (Pediocactus peeblesianus var. fickeiseniae)
Kaibab plains cactus (Pediocactus paradinei)

SPECIES AT RISK

Mammals:

California leaf-nosed bat
(Macrotus californicus)
Spotted bat (Euderma maculatum)
Greater western mastiff-bat
(Eumops perotis californicus)
Navaho Mountain Mexican vole
(Idicrotus mexicanus navaho)

Hualapai southern pocket gopher
(Thomomys umbrinus hua lensis)
Searchlight southern pocket gopher
(Thomomys umbrinus suboles)
Yuma hispid cotton rat
(Sigmodon hispidus eremicus)
Colorado River cotton rat
(Sigmodon arizonae plenus)
Marble Canyon kangaroo rat
(Dipodomys microps leucotis)
Yavapai Arizona pocket mouse
(Perognathus amplus amplus)
Yuma puma (Fells concolor brovni)

Birds:

Loggerhead shrike (Lanius ludoricianus)
Ferruginous hawk (Buteo regalis)
Northern goshawk (Accipiter gentilis)
Western least bittern
(Ixobrychus exilis hesperis)
White-faced ibis (Great Basin population)
(Plegadis chihi)
Western snowy plover
(Charadrius alexandrinus nivosus)
Mountain plover (Charadrius Montanus)
Large-billed savannah sparrow
(Passerculus sandvichensis rostratus)

Reptiles & Amphibians:

Arizona toad
(Bufo microscaphus microscaphus)
Chuckwalla (Sauromalus obesus)
Desert tortoise (Sonoran population)
(Gopherus agassizii)
Rosy boa (Lichanura trivirgata)
Cowles fringe-toed lizard
(Uma notata rufopunctata)
Lowland leopard frog (Rana yavapaiensis)

Fish:

Roundtail chub (Gila robusta)
Longfin dace (Agosia chrysogaster)
Speckled dace (Rhinichthys osculus)
Sonora sucker (Catostomus insignis)
Desert sucker (Catostomus clarki)
Flannelmouth sucker (Catostomus latipinnis)
Virgin spinedace (Lepidomeda mollispinis
mollispinis)

Invertebrates:

Cheese-weed owlfly (Oliarces clara)
Grand Canyon cave psuedoscorpion
(Archeolarca cavicola)
Grand Wash springsnail (Pyrgu-lopsis bacchus)
Kingman springsnail (Pyrgulopsis conicus)
MacNeill sooty wing skipper
(Hesperopsis gracielae)
California floater (Anodonta californiensis)

Plants:

Dune sunflower (Helianthus niveus
ssp. tephrodes)
Sand food (Pholisma sonorae)
Virgin thistle (Cirsium virginensis)
Pima Indian-mallow (Abutilon parishii)
Yellow-flowered desert poppy
(Arctomecon californica)
Gumbo milk vetch (Astragalus ampullarius)
Cliff milk vetch (Astragalus cremnophylax
var. myriorraphis)
Beaver Dam milk vetch (Astragalus geyeri
var. triquetrus)
Freckled milk vetch (Astragalus lentiginosus
var. ambiguus)
Sheep Range milk vetch (Astragalus
musimonum)
Camissonia confertiflora
Camissonia exilis
Camissonia gouldii
Camissonia speculcola ssp. hesperia
Tusayan rabbithrush
(Chrysothamnus molestus)
Cryptantha cinerea var. arenicola
Ripley wild buckwheat (Eriogonum ripleyi)
Atwood wild buckwheat (Eriogonum
thompsonae var. atvoodii)
Kaibab bladderpod (Lesquerella kaibabensis)
Giant Spanish.needles
(Palafoxia gigantea var. arida)
Beaver Dam breadroot
(Pediomelum castoreum)
Kane breadroot (Pediomelum epipsilum)
Penstemon albomarginatus
Cerbat beardtongue
(Penstemon bicolor ssp. roseus)
Mt. Trumbull beardtongue (Penstemon distans)
North Rim primrose (Primula hunneyellii)
Grand Canyon rose (Rosa stellata ssp. abyssa)
Grand Canyon catchfly (Silene rectiramea)

Appendix B: The CALFED Bay-Delta Process as a Model

In the early 1990s, California embarked on an innovative collaborative federal-state-civic process in an attempt to resolve the long-standing problems pertaining to the San Francisco Bay/Sacramento-San Joquin River Delta Estuary (Bay-Delta). This waterway sees the outflow of 47 percent of the state's total surface water runoff and provides freshwater to over 20 million of the state's residents (CDWR 1994). After years of conflict between federal and state agencies trying to regulate and manage the Bay-Delta, a framework agreement was signed in June 1994, which formalized a cooperative effort called the CALFED Bay-Delta Program (CALFED). The broad goals of the CALFED Bay-Delta process were to formulate water quality standards, coordinate water project diversions with regulatory requirements,[1] and find long-terms solutions to problems in the Bay-Delta Estuary.

To assist the ten federal and state agencies involved in CALFED, a 30-member public advisory committee, representing urban, agricultural, environmental, business, and fishing interests was assembled. This Bay-Delta Advisory Committee (BDAC) played an instrumental role in the negotiating and signing of the December 1994, Bay-Delta Accord. This monumental agreement established interim water quality standards for the Bay-Delta until future research provides the basis for permanent standards. The Delta Accord marked a radical departure from the legal confrontations of the past, representing the first time in California water history that environmental, agricultural, and urban interests were able to reach a consensus on such major issues.

Underlying the success of the Bay-Delta Accord was the fact that all stakeholders were present at the bargaining table. Had any of the stakeholders been left out of the negotiation process, any agreement reached by the remaining interests would have been legally challenged by the excluded party, delaying action and ultimately solutions into the indefinite future. The creation of the Bay-Delta Advisory Committee has already and will continue to foster more environmentally sound and socially equitable solutions for the Bay-Delta Estuary. Through its on-going role of advising and monitoring the CALFED program as it attempts to develop a comprehensive plan for the Bay-Delta, the BDAC has helped ensure more balanced long-term solutions.

The lessons learned and framework established in the CALFED process can be of vital interest to governmental agencies and stakeholders of the Colorado River. More headway was made during two years of the CALFED process than over the previous twenty years of conflict surrounding the Bay-Delta. While there are certainly shortcomings with the current CALFED process as it struggles toward a long-term management strategy for the Bay-Delta Estuary, the benefits are noteworthy. Drawing from its successes, officials of the Colorado River basin can use the CALFED process as a template when attempting to develop a river basin commission for the Colorado River.

[1] The Central Valley Project and the State Water Project, two of the largest water distribution systems of the state, now divert almost 20 percent of the normal inflow to the Delta in an average water year and a substantially larger fraction in dry years.