An Examination of Arizona Water Law and Policy from the Perspective of Climate Impacts

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Abstract

Any assessment of climate impacts on water resources must take into account the legal and institutional structure within which decision making is framed. This document provides a summary of international, federal, state, and local laws and policies that may facilitate or constrain decision making within the context of climate impacts. The evaluation concludes that Arizona has a reasonably well-developed structure for governing water management in the more stringently managed areas of the state. This structure provides a basis for balancing climatic and ecological factors with human stresses, especially rapid population growth, on the state's environment and natural resource base. However, there is a need to take climate more fully into account in policy making and implementation. Among the greatest needs is to develop a comprehensive drought contingency plan that recognizes the possibility of droughts at least of the magnitude of the decadal-scale drought of the 1950s. The plan should be statewide, but should also take care to address issues of local vulnerability and equity. A sharper emphasis also needs to be placed on public education about not only water management issues, but also about the nature of climate variability in the region and the kinds of impacts on water supply and demand that residents should take into consideration when making and carrying out their plans. Pressures on water management structures and processes are likely to escalate in the future; these pressures will certainly be exacerbated under conditions of climatic stress, particularly deep, extended drought. Climate information, if effectively disseminated and used, has the potential to contribute to effective management decisions.

1. Introduction

The Climate Assessment for the Southwest (CLIMAS) project is an interdisciplinary study drawing upon the expertise of hydrologists, climatologists and social scientists to examine the impacts of climatic variability upon water users in the Southwestern United States. Funded by a grant from the National Oceanic and Atmospheric Administration (NOAA), the project seeks to provide decision-makers and stakeholders with better access to and understanding of climate forecasting products, and also to provide those who produce climate predictions with insight into what kinds of information may be most useful.

This paper reflects work carried out under the Urban Water Study component of the CLIMAS project. The Urban Water Study, to date, has encompassed the Phoenix, Tucson and Santa Cruz Active Management Areas[1], as well as the Benson and Sierra Vista subwatersheds (Figure 1). Studies of these areas have included a sensitivity analysis of the potential impacts of severe sustained drought on selected urban communities in Arizona, an assessment of potential vulnerability of urban water providers in Arizona to climate impacts, and an institutional analysis that focuses on the capacity of existing laws, regulations, and decision-making practices to respond effectively to climatic stresses.

This paper is one of a series of publications addressing climate impacts on water resources in the U.S. Southwest. The aim of this working paper is to provide an overview of the climate implications associated with selected international, national, and state legal arrangements that strongly influence water management options in Arizona's urban centers. The topic is particularly salient today, with urban populations and economic development increasing rapidly throughout the region at the same time that local and regional capacity to develop additional water resources is becoming ever more

Figure 1. Active Management Areas and San Pedro River Subwatersheds
Source: Arizona Department of Water Resources, 1999

challenging. Concurrent advances in understanding past climatic conditions and patterns, as well as in climate forecasting at seasonal, annual, decadal and longer time scales, present opportunities for development of a more integrated knowledge base to be used in decision making. Yet efforts to operationalize new knowledge are seldom straightforward, due to constraints posed by existing value systems, economic and political structures, and institutional frameworks. The following narrative highlights some of the pivotal points where existing institutional arrangements may facilitate or impede such efforts.

2. Water in the Southwest—The Context

The semiarid Southwest lacks abundant surface water sources, and groundwater resources are unevenly distributed, with some areas having large volumes of groundwater and some having very little. Rights to surface water are fully allocated, and in urban areas such as Phoenix and Tucson, groundwater withdrawals are closely regulated. Arizona water withdrawals top 7 million acrefeet (maf) a year and consumptive use is in the range of 5 maf; by comparison New Mexico's withdrawals are in the neighborhood of 4 maf per year, with more than 2.4 maf classified as consumptive use.

In fast-growing areas such as Albuquerque and Santa Fe, New Mexico, and Flagstaff, Sierra Vista, Prescott, Phoenix, and Tucson, Arizona, population growth and related increases in water demand have drawn attention to the need to reprioritize water use to more effectively reflect highest and best uses. How to prioritize among competing uses remains contested, however, especially with regard to establishing an acceptable relative value for agricultural water use and for in-stream and ecosystem support. In the Tucson and Phoenix areas, urban growth poses a serious challenge to agricultural activity, with residential subdivisions and other urban land uses replacing cotton, citrus, and other crops. Yet, as will be discussed in more detail below, groundwater law in Arizona continues to emphasize agricultural water rights in important ways. Likewise, existing and potential institutional arrangements that allocate substantial water supplies to adjacent Indian reservation lands present challenges to sustainable water management in both cities. Certain kinds of climate impacts such as extended drought, when combined with high growth rates and these sorts of institutional arrangements, hold the potential to seriously challenge "business-as-usual" water management in Arizona.

At the same time, although substantial information about the utility of various management mechanisms already exists, little work has been done in the region on the nature and probable severity of climate impacts on water management, or on how to incorporate information about climate variability and change into institutional structures and management practices. Prolonged and/or severe climatic stress, especially drought, will require state and local water management entities to identify effective ways to meet higher water demands in the face of decreased water supplies. This must be done in a matter that is politically acceptable to municipal, industrial, commercial, residential, and agricultural users as well as to environmental interests concerned about protecting in-stream flows and ecosystem vitality. This analysis is a preliminary effort to fill a specific gap in the literature on climate change impacts: how federal, state and local policies and institutions may buffer or exacerbate the effects of climatic variability on urban water supply, demand and quality in Arizona.

In arid regions such as the Southwestern United States, conflicts over scarce water resources have a long history. In order to efficiently utilize this precious resource in a sustainable manner, a complex set of water physical structures—including dams, reservoirs, and interconnected groundwater pumping and delivery systems—have been built. Likewise, over the years, an increasingly complex institutional structure has emerged at scales from the international to the local to mediate competition over water allocation and use. To a great extent, the response of an individual water system to increased climate variability is shaped by factors such as the types of water available (e.g., surface water, renewable groundwater, fossil groundwater, reclaimed water), the hydrological and geological characteristics of the source area, the area's population and economic profiles, and existing water management policies.

As the Arizona Department of Water Resources (ADWR) notes in its Third Management Plan for the Phoenix Active Management Area, "The key to effective water management is to anticipate change and to develop systems flexible enough to respond to conditions unlike those experienced today" (ADWR 1999a: 12-10). However, the primary "change" referred to by the Department of Water Resources is population growth; the "conditions unlike those experienced today" principally involve more water users exerting greater pressure on existing water resources. In the Southwest, rapid population growth is a key factor that must be incorporated into any serious consideration of the utility of current water management policies in coping with climate impacts. Projections by the Arizona Department of Economic Security indicate that both the Phoenix and Tucson metropolitan areas will grow by about 40 percent by 2025 (ADES 1999). The vast majority of the state's population is already urbanized, and expectations are that most additional population growth will occur in municipalities.

The analysis that follows begins with a key underlying doctrine of western water law, that of prior appropriation. The focus is then trained on laws and policies related to management of the Colorado River, the primary source of water for millions of water users in a substantial portion of the western United States.[2] Federal regulations, including federal reserve rights and the Endangered Species Act, are explored, followed by a more in-depth examination of key Arizona institutions, including the Central Arizona Project and the Groundwater Management Act. The analysis concludes with examples of climate-related water management issues important to the Phoenix and Tucson areas, and a summary of outstanding issues that, if addressed, could enhance institutional capacity to cope with the impacts of climate variability on Arizona's water resources.

3. The Doctrine of Prior Appropriation

The Right of Prior Appropriation underpins Arizona (and most Western) water law (Sax et al. 1991: 10). In the western United States, long-standing water rights were typically established to apply to the entire amount of water a user can put to "beneficial use;" however, to achieve beneficial use it is usually only necessary to divert the water from its source, regardless of the economic or social value to which it is then applied. A corollary to this rule is "use it or lose it," meaning that any water not put to beneficial use (diverted) for an extended period of time may be claimed by another appropriator (Sax et al. 1991: 137).

Under prior appropriation, senior rights holders are entitled to the full amount of water that is legally theirs, before junior rights holders receive even a portion of their allocations; hence the phrase "first in time, first in right" (Sax et al. 1991: 138). In times of extreme heat and dryness, there is less return flow from crops due to higher evaporation and higher plant use of water. This can have disastrous effects on junior rights holders (Tarlock 1991). Reduced return flows can also cause downstream municipal estimates of water availability to be inaccurate by a large percentage. Many large irrigators have extra storage and other means of cushioning themselves against drought. Municipal users, in recent years, have been able to acquire access to other water sources. Thus, when water deliveries are reduced or stopped according to a priority schedule, the users most negatively affected tend to be small farmers, Indian tribes, and fish and wildlife.

Prior appropriation may prove to be an untenable basis for the type of highly flexible water policy system that would be required to best address the risks posed by climate variability. As Tarlock notes with regard to the potential implications of global climate change, "The issue that prior appropriation poses for global warming adjustment strategies is how flexible the system will be in shifting water to areas of greatest need and in promoting maximum access to a scarce resource" (1991: 243). The same may be said for the challenges posed by natural climate variability.

The beneficial use doctrine does not require economic considerations; rights and the risks of shortages are allocated *only* on the basis of the date that the water right was acquired. Often, the highest priority water users are agricultural interests who may represent a small proportion of total economic or social value, and who employ far fewer people than industrial or municipal interests. The result is that under prior appropriation in some cases, a great deal of water may be used to grow surplus or low-value crops (Glennon 1990). Historically, considerable amounts of water used for irrigation have been wasted through inefficient delivery technologies and excessive application of water; today, however, new techniques are improving efficiency both in terms of delivery and amount used (Daniel 1995).

Agricultural water users have greater flexibility to curtail their water use than do "demand hardened" municipal and industrial users. By contrast, industrial and municipal users are generally deemed to be putting water to higher-value uses. These entities are more likely to have resources at their disposal to pay the cost of pursuing additional water rights and expanding or improving their infrastructure. The saved water could, with proper institutional arrangements, be made available to the municipal and industrial sectors to cover shortages.

Under Arizona law, water rights holders often do not have the flexibility to lease or trade their water rights to municipal or industrial sectors, a potentially serious barrier in times of climatic stress. The "use it or lose it" premise of prior appropriation doctrine is based on the requirement to continue demonstrating beneficial use of the allocated water. This, understandably, prompts serious concern among rights holders that, if they make the water available to other higher-value users even during severe drought situations, they may lose their right to that water in the future. The conundrum introduces a high level of uncertainty into the practice of managing water under conditions of climatic stress. Yet any structural change in prior appropriation doctrine is likely to meet with stiff resistance and/or hard bargaining on the part of rights holders. A significant level of political will would be required to effect changes; however, a severe drought of 10 years' or longer duration might provide the necessary context for modifying prior appropriation law.

Economists have long criticized western water law because it ignores higher, alternative values of water (Glennon 1990; Graff and Yardas 1998). Tarlock (1991) suggests that water marketing could become the cornerstone of a more adaptive water management strategy, which would allow greater efficiency and flexibility in managing water resources, as would likely become necessary in coping with the impacts of climatic variability and change. Miller (1997) recommends expanding the ability to temporarily transfer small blocks of water between individual and municipal users as a way of coping with severe drought. However, prior appropriation appears to be a stumbling block to the further development of water marketing and water transfers. Modifications to this doctrine would be necessary to remove the obstacles that stand in the way of improving efficiency in allocating water resources and facilitating water transfers, both under normal and drought conditions (Sax et al. 1991: 213; Frederick 1991).

Many of the obstacles to more economically efficient allocation of water resources are non-economic, and thus must be valued using alternative criteria. A 1989 study by Oggins and Ingram of 317 community leaders in 12 regions of Arizona, New Mexico and West Texas, including Arizona communities of Phoenix, Tucson, as well as La Paz County and Marana/Avra Valley, illustrates this point. Nearly all of the communities surveyed agreed that rural areas face losses from water transfers that cannot be monetarily compensated. These perceived losses include loss of control over the region's future; reduced economic opportunity; losses to wildlife, natural areas and recreational amenities; losses to security; losses to the local tax base; and losses from the effects of retiring farmland for its water rights (Oggins and Ingram 1990). As noted above, reconciling potential contests is likely to require careful consideration of prior appropriation rules, in the contexts of equity and the value of water to the competing users.

4. Regulation and Management of the Colorado River System

As one of the Lower Basin states, Arizona has a strong vested interest in the management of the Colorado River. The following narrative highlights some of the legal arrangements that must be taken into account when considering the relationship between climate and water management in Arizona.

4.1. Accords Between the United States and Mexico

There are two specific accords between the United States and Mexico that have significant implications for managing water resources under conditions of climate variability. The first is the Mexican Water Treaty; the second is Minute 242 of the International Boundary and Water Commission (IBWC).

4.1.1 The Mexican Water Treaty

Mexico was allotted 1.5 maf of Colorado River water under the Mexican Water Treaty, which was ratified in 1944. This treaty also deals with issues relating to the Rio Grande (called the Rio Bravo in Mexico) and Tijuana Rivers (Sax et al. 1991: 793). Under the treaty, during severe droughts, the United States may reduce its allotment to Mexico "in the same proportion as consumptive uses in the United States are reduced"[3] (section III, art.10, para. B). However, drought conditions have never triggered this provision. It is unclear whether, in the event of a severe sustained drought, obligations under the Mexican Treaty would take precedence over allocation to priority rights holders in the United States. On the one hand, these parties have present perfected rights to their allocations; on the other hand, the federal government would be under intense pressure to meet its obligations under the international treaty. Under this treaty, fulfilling the delivery requirement to Mexico would take precedence over meeting Arizona's fourth-level priority for its Central Arizona Project (CAP) allocation of Colorado River water. As discussed later in this working paper, loss of CAP water, combined with extended severe drought conditions would pose serious challenges to management of water supplies, particularly in the Phoenix and Tucson areas.

Ultimately, all decision-making power regarding Colorado River allotments lies with the Secretary of the Interior, who must balance the river's importance in generating electricity with water rights issues. One set of studies has suggested that, in a severe sustained drought involving extremely high temperatures, the demand for electricity could increase such that releasing water from Glen Canyon dam would become a higher priority. This would in turn exacerbate pressure on Upper Basin states to provide adequate flows. Once these potentially greater-than-normal amounts of water have passed through Glen Canyon, they would be available to Lower Basin states, and possibly Mexico. Under such conditions, the impacts on Mexico and the Lower Basin could potentially be much smaller than those felt in the Upper Basin (Harding et al. 1995).

4.1.2. Minute 242

The Mexican Water Treaty stipulates that Mexico may receive an additional 0.2 maf of Colorado River water in years when a surplus is available (1944 Treaty, section III, article 10). When the treaty was ratified, however, there was no stipulation that the water had to be of usable quality. This omission resulted in delivery of highly saline and polluted water, derived from return flows generated by agricultural operations that fed into the Wellton Mohawk Canal in southwestern Arizona (Gantz 1972). Not surprisingly, Mexico objected strenuously, eventually resulting in a 1973 international agreement formalized in Minute 242 of the International Boundary and Water Commission (IBWC) and its Mexican counterpart, the Comisión Internacional de Límites y Agua (CILA). The Minute obligates the United States to deliver Colorado River water at a stipulated minimal quality level to Mexico. Agribusiness in the Mexicali Valley and other areas of Baja California now utilizes approximately 1.1 maf of Mexico's allotment. As a result, very little of the river's flow normally reaches the Colorado River delta and the Gulf of California; in dry years no water reaches the delta at all (see, e.g., Postel et al. 1998).

Overall availability of surplus flows to Mexico is likely to become a rarer occurrence in the coming years as population growth in the Upper and Lower Basins leads to consumption of a greater proportion of the total river flow. At the same time, high levels of precipitation, often but not always associated with El Niño conditions, have resulted in as much as 10 maf being discharged into the Gulf of California. Although recent high-flow events have restored some of its vegetation, the Delta's once rich estuarine ecosystem continues to be heavily affected by salt and pollution residues deposited before Minute 242 was enacted, and even now continues to be polluted by pesticides and fertilizers applied to fields within the Mexican portion of the watershed. Rising salinity has decimated the estuarine nurseries of many species of economic importance to fishermen (Furnish and Ladman 1975). Severe sustained droughts such as the 20-year drought of the late 1500s and the 10-year drought of the 1950s would likely exacerbate these problems. Likewise, any change toward increases in the frequency or magnitudes of flood events could have potentially serious ramifications for the area. Environmental groups have called for action to restore the Colorado's flow through the Delta, and a biosphere preserve has been established in the Upper Gulf. Better access to and use of a broader range of climate information as well as of seasonal and longer-scale climate forecasts could contribute significantly to achieving the goal of preserving the Delta and its ecosystems.

4.2. The Law of the River

The shortcomings of prior appropriation are evident on a regional scale in the rules governing the use of Colorado River water. More than 17 million people and more than one million acres of farmland in Arizona, California and Nevada receive water from the Colorado River (ADWR 1999b). Arizona's largest municipal areas, Phoenix and Tucson, as well as dozens of Indian tribes and countless other direct users, depend on the Colorado River for at least part of their water supply. The Law of the River dictates each state's allotment and level of priority to the Colorado River water. It is a composite of state and federal laws and regulations, court decisions, and international treaties, the most pertinent of which are discussed below.

4.2.1. The Colorado River Compact

The Colorado River Compact was signed in 1922 to apportion water between the Upper Basin states (Wyoming, Colorado, Utah and New Mexico) and the Lower Basin states (Arizona, Nevada and California) of the Colorado River Basin (Figure 2). Each basin was to get 7.5 maf per year, with Lower Basin states receiving 1 maf more when the water supply was sufficient (Sax et al. 1991: 703). The Colorado River was drastically overallotted in the original Colorado River Compact. The 16.4 maf flow at Lees Ferry that the Colorado Compact allocations were based upon was later found to be the highest flow in the past 500 years (MacDonnell et al. 1995). Tree-ring records indicate that flows vary from 4.4 maf to over 22 maf, with the average being about 13.5 maf (Meko, et al. 1995; Tarboton 1995). Such high levels of past hydrologic variability strongly suggest that decision making should rely on a broader range of climatic extremes. Assessments of potential future impacts of climate variability and change on the Colorado River Basin (Nash and Gleick 1993, Gleick and Chelecki 1999) provide a further argument for integrating climate information and forecasts at all scales from monthly to centennial into long-range planning.

Figure 2. Colorado River Basin
Source: U.S. Bureau of Reclamation

4.2.2. The Boulder Canyon Project Act and Arizona v. California

The Boulder Canyon Project Act, enacted in 1928, further divided the Lower Basin's allotment, with 4.4 maf going to California, 2.8 to Arizona, and 0.3 maf to Nevada, with Arizona and California agreeing to split any excess equally. California, Arizona and Nevada were to equally share in any shortage. The Act also authorized construction of Hoover Dam and the All-American Canal (Sax et al. 1991). In 1963, the system of priority rights to Colorado River water in times of shortage was clarified and water was apportioned to the Central Arizona Project (discussed in more detail later in this working paper).

Tensions in the Lower Basin over access to Colorado River water led to litigation, and issuance of the rulings published under *Arizona v. California* (373 U.S. 546, 1964). The rulings specify the quantity of water to which each of the Lower Basin states is entitled, and gives specifics for how water is to be divided under conditions of shortage. The ruling also sets the operational priorities to be followed in managing the river as follows: (1) regulation of the river, improvement of navigation, and flood control; (2) irrigation and domestic uses, which include satisfaction of present perfected rights; and (3) power generation.

Laws and rulings notwithstanding, California has continued to exceed its 4.4 maf allotment of Colorado River water in recent years by as much as 1.1 maf. California has been able to regularly exceed its right to Colorado River water in large part because the Upper Basin states have not yet seen their water demand rise to levels that require full diversion of their entire allocations; thus more water has remained in the river for downstream use. Recently, however, California, Nevada, and Arizona have negotiated an agreement whereby California's over-appropriation will cease in future years, in order to free up water needed to meet the legal allocations of the other two Lower Basin states (these issues are discussed in a later section). Nevada, for example, expects its water demand to exceed available supplies by 2015, and expects to not only appropriate its full Colorado allotment but also to develop new water supplies (Yozwiak 1997). Arizona only began using its full 2.8 maf apportionment in 2000, largely through newly institutionalized water banking arrangements (see the Water Banking section of this working paper).

The 7.5 maf annually of water that the Upper Basin provides to the Lower Basin is based on a 10-year rolling average. In other words, in dry years, the Upper Basin does not have to meet its entire obligation, as long as the amount is made up over the 10-year period. Section 301(b) of the Colorado River Basin Project Act dictates that the Secretary of the Interior ensure that non-CAP Arizona, California and Nevada receive their full allocations first; other rights holders in California are next in line. Contract holders and federal reservations in Arizona and Nevada have third priority for meeting their allocations. It is only after all of these obligations are met in full that Arizona receives its CAP allocation (MacDonnell et al. 1995).

Miller (1997) identifies the negotiation of agreements based on inadequate information (such as the Colorado River Compact) as a serious problem in coping with future uncertainty. The large volume of storage capacity on the Colorado River (discussed in a later section of this working paper) provides a substantial buffer against the impacts of water shortage on the Lower Basin states, including Arizona. However, as modeling of the potential impacts of the 20-year severe sustained drought of the late 1500s revealed,

> Lake Powell and other major Upper Basin reservoirs would be emptied, and Lake Mead nearly so, after two decades of severely reduced runoffs. Water deliveries for consumptive uses in the Upper Basin would fall to about half of normal levels, *albeit* for only a few years. Consumptive uses in the Lower Basin would be largely unaffected, save for those served by the Central Arizona Project (Lord et al. 1995, p. 490; emphasis in original).

According to model results by Harding et al. (1995), while Lake Powell would be essentially drained, Lake Mead would continue to store nearly 7.5 maf of water that would be available for use in the Lower Basin states. Importantly, the Lower Basin states would only see a 3 percent shortfall in their allotments during the worst drought year. However, the cumulative impacts of reduced deliveries would certainly trigger actions such as implementation of stricter conservation measures and water rate hikes. In addition, if political pressure for supply augmentation—particularly from powerful urban interests—were to arise, pursuit of new interbasin water transfers might be anticipated (a discussion of interbasin transfers in Arizona is provided in a later section).

Exploration of alternative interstate institutional rules,[4] as well as changes in water allocation and management rules within the individual states suggested that allowing more water to be stored high in the Upper Basin, where evaporation losses are less, and engaging intrastate and interstate water banking and water marketing were particularly effective strategies. Water banking and marketing strategies were determined to be particularly useful for enabling Arizona to better manage its CAP allocation (Henderson and Lord 1995). Interestingly, the research indicated that "Changes in intrastate water allocation and management were more effective in mitigating drought damages than were … changes in the Law of the River…" (Lord et al. 1995, p. 941). The authors note,

> Our studies suggest that institutions which possess (1) sufficiently broad responsibility and authority to deal with all interrelated problems, (2) provide for appropriate representation and participation of all major affected interests, (3) generate and distribute objective and technically sound information, and (4) facilitate communication and bargaining between states are most likely to adopt and implement operating rules which resolve conflict and achieve efficient and equitable resource allocation. The single federal administrator model which is predominant in the complex of existing collective choice institutions in the Colorado River Basin largely fails to meet these criteria (Lord et al. 1995, p. 941).

The authors of the study conclude that non-consumptive uses, including hydropower, of waters of the Colorado River system are highly vulnerable to drought under existing institutional arrangements. This is particularly true for the Lower Basin. By contrast, consumptive water uses in the Lower Basin States are generally well protected from drought impacts, although chronic water shortages would likely be experienced (Lord et al. 1995). These findings reinforce the need to improve water management institutions in order to increase adaptive capacity and overall resilience to climate impacts on non-consumptive as well as consumptive uses.

4.3. The Colorado River Reservoir System

The Colorado River reservoir system is structured around a series of dams on the mainstem and tributaries of the river in both the Upper and Lower Basin. Accounting for Colorado River flows and reservoir storage is complicated by the fact that designation of normal, shortage or flood conditions is determined by not just how much water is in the Colorado River, but the water levels in Lake Mead, projected inflow into the reservoir, status of the 10-year rolling average of deliveries from the Upper Basin to the Lower Basin at Lake Powell, and current demand (AWBA Commission 1998; MacDonnell et al. 1995). Thus the sequence of wet and dry years can be as important in determining the state's water status as the actual amount of rain that has fallen.

The large amount of reservoir space allows Arizona greater latitude in coping with climate impacts on its

Colorado River water supplies (see Miller 1997). A change in frequency, over relatively short terms, of extreme climatic conditions and related fluctuations in river flows would be unlikely to adversely affect Arizona's share of Colorado River water supplies. However, a longer-term trend towards warmer and drier conditions throughout the Upper and Lower Basins could have significant impacts. For example, in an average year, approximately 1.5 maf of the Colorado's flow evaporates from Lakes Powell and Mead, an amount that would certainly increase under conditions of higher temperatures, as would likely occur in an extended drought. Further, as noted by Frederick (1991), the rate of construction of new reservoirs has not kept pace with population growth; nor is it likely to in the future, for several reasons. For one, the most feasible reservoir sites have already been developed. Investing the funds necessary to expand storage capacity only increases the probability of being able to supply water at a diminishing rate of returns. Furthermore, in addition to rising construction costs, the opportunity costs of storing and diverting water also have also risen considerably as more members of society place higher values on in-stream flows. This appears to be a problem not only for water providers relying on water stored in large reservoirs, but also for providers who rely on smaller storage systems that cannot easily or economically be expanded to meet the demands of a growing population coupled with more variable climatic conditions. This issue will be further explored in the sections on issues within specific AMAs.

4.3.1. Policies and Operating Criteria—Upper and Lower Colorado Basins

The actual amount of water to be made available to Arizona and the other Compact states each year lies within the purview of the Secretary of the Interior, and that of the U.S. Department of Interior's Bureau of Reclamation (see Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado River Basin Project Act of September 30, 1968). The Secretary transmits the Annual Operating Plan, which stipulates how the Colorado River System will be managed over that year, to the Governors of the Basin States, as stipulated in the Colorado River Basin Project Act (43 U.S.C. § 1552(b).

In essence, the amount of water that flows down the river in any given year from Glen Canyon Dam and Hoover Dam is based on the amount of water already in storage, anticipated releases for various uses such as hydroelectric power generation, and the need to equalize storage behind the two dams. When the amount of water available exceeds the total of all quantified Lower Basin rights, and there is no need for flood control measures, the Secretary, in his/her role as Watermaster, may declare a "surplus" on the river. Under these conditions, each of the Lower Basin states may increase their demand by the following maximum percentages: California, 50 percent; Arizona, 46 percent; Nevada, 4 percent. Any excess beyond these proportions flows as surplus to Mexico. Since Mexico has the capacity to use only 0.2 maf above their allotted 1.5 maf today, excess water above 1.7 maf flows into the Gulf of Mexico (see Pagano et al. 1999).

The agency responsible for operating the river's infrastructure to meet the above rules is the Lower Colorado Bureau of Reclamation (LC-BOR). This agency operates the eight dams on the Lower Colorado River, including Hoover Dam. Lake Mead, behind Hoover Dam, has by far the greatest storage capacity of the eight dams (approximately 27.3 maf). The Upper Colorado BOR operates Glen Canyon Dam, in addition to other reservoirs higher up in the basin. Lake Powell, behind Glen Canyon Dam, has a capacity of some 24.3 maf. Together, Lakes Mead, Mohave, Havasu (all Lower-Basin reservoirs), and Powell can store more than 4.5 years of average inflow. As noted by Pagano et al. (1999), "This ratio is exceptionally high when compared to other basins within the United States" (p. 122).

Pagano et al. also noted that the management of the Lower Basin is distinctly different from that of the Upper Basin. The Lower Basin is managed according to a philosophy of strict adherence to inflexible rules, in no small part due to continuing tensions among the three Lower Basin States and because portions of the river below Lake Mead are relatively heavily populated. The Upper Basin agency, by contrast, has formally adopted an adaptive management approach that emphasizes monitoring the effects of management actions on the environment, followed by adjustments to reflect the findings of such monitoring. In the Upper Basin, human habitation is far less dense. Further, unlike Lake Mead management practices, Lake Powell management includes scheduling of high releases of water *before* the snow melt season, low releases *during* the melt season, then a return to high releases *after* the melt season. According to Pagano et al., "The Upper Bureau estimates that it can adjust for inaccuracies in [climate] forecasts on the order of 1.5 maf per month. This adjustment of the timing of releases is one part of a sophisticated method of risk management..." (p. 124).

Both bureaus use annual operating plans that predict reservoir levels and monthly releases two years in advance. These plans are based on recent stream-flow data, flood control criteria, hydrologic forecasts (water supply outlooks issued by the NOAA River Forecasting Center), equilibration of Lakes Mead and Powell, and other factors such as need for system maintenance. The operating plans are revised monthly as new water supply outlooks are issued (Pagano et al. 1999). Skilled climate forecasts have high potential for improving the water supply outlooks used to determine management of the river and, by extension, the capacity of water providers and regulators to manage water supply and demand more efficiently.

Climate variability clearly affects the operation of the river system, but only recently have the system's managers begun to take climate information and forecasts into account in their decision process. The effects of the strong El Niño of 1983 on Glen Canyon Dam may be credited with beginning the process of thinking more broadly about climate impacts, for intense precipitation and consequent runoff brought Lake Powell to within a few feet of the top of the dam. Emergency actions, including opening all release valves and the two diversion tunnels, averted disaster. By the time 1993 El Niño forecasting began, Upper Basin dam managers were prepared to take the kinds of proactive measures needed to ensure that the reservoir did not over-fill. Intensive, ongoing interactions between climate researchers and river managers, currently underway, provide an opportunity for integrating use of climate information into management of the Colorado River system.

The Upper Basin management style, with its greater latitude for flexible response to stresses such as those posed by climate variability, has significant implications for Arizona and the other Lower Basin states. If the forecasts used by river managers consistently fail to reflect higher probabilities of exceptionally wet or dry conditions over multiple years, water managers in the Lower Basin States, including Arizona, may be misled about the amount of water available. Given that CAP allotments have junior priority, this situation should be a matter of significant concern to water managers who rely heavily on CAP supplies to meet customer demand.

5. Federal Regulations

Numerous federal regulations have implications for management of water resources in Arizona. The laws that are especially pertinent within the context of climate impacts are reviewed in this section.

5.1. Federal Reserved Water Rights on Native American Land

Indian water rights claims pose a significant challenge to long-term water management, nowhere more so than in Arizona. Federal reserved water rights on Native American land were recognized after the 1908 Supreme Court case *Winters v. United States*. The Court held that in setting aside reservations, Congress had also intended to set aside sufficient water to satisfy Indians' present and future needs (Sax et al. 1991: 809). This was later interpreted in *Arizona v. California* to mean that reservations where agriculture is a primary activity are entitled to an amount of water sufficient to irrigate all of the practicably irrigable acreage on a reservation, regardless of how much water a tribe was actually using (Sax et al. 1991: 859). For five tribes along the Colorado, their water needs were to be met through the Lower Basin states' apportionment. These tribes are presently using 80 to 90 percent of their entitlement. However, many other tribes have not yet had their claims adjudicated. Resolution of these potentially very large claims could have major impacts on water supplies in the West. For example, the Navajo Nation has not yet claimed its Colorado River rights, but could, theoretically, eventually claim up to 5 maf. Glennon and Maddock (1994) discuss an example of the large potential impact of Native American water rights, related to adjudication of the waters of the Gila River, a tributary of the Colorado River and traditionally a major water source for some of the local tribes. Adjudication began in 1974, and has since been expanded to cover not only the Gila itself, but also all tributaries and the river's source area. Claims have been filed by 24,000 parties; to date, the adjudication has cost approximately $52 million, and matters are still unresolved.

Federal reserve rights for Native American claims were identified in a 1993 Office of Technology Assessment report as having the potential to cause future conflicts with other water users, if stream flows diminish. Many tribes are currently in the process of adjudicating their water rights. This is an essential step in making it possible to reallocate water rights in times of severe drought (Miller 1997; Tarlock 1991). Also subject to debate is the question of whether their allotment could be sold out of state and, if so, what restrictions would apply. The Bureau of Reclamation has proposed regulations to address how Indians may lease their entitlements for off-reservation purposes, with the idea that, "Allowing these transactions also promotes tribal economic and governmental self-sufficiency on the part of Indian tribes" (Garner and Ouellette 1995: 487).

Native American water rights issues are pertinent to analysis of climate impacts on water resources in Arizona for several reasons, including the fact that making water available to settle Indian rights claims was part of the impetus behind both the CAP canal and the Arizona Water Banking Authority (Glennon 1995). Determination of these rights could affect CAP allocations and the amount of water available to be banked. The origins of some of the Salt River Project water, which Phoenix relies on for nearly 40 percent of its supply (based on 1995 figures), are located on Indian land and could be subject to prior appropriation. In addition, Phoenix may eventually have to seek Gila Indian water supplies to meet its growing water demands while at the same time staying in compliance with the Arizona Groundwater Management Act (discussed later in this working paper).

The Phoenix AMA's Third Management Plan notes that the largest Indian water rights claims affecting water supplies within the AMA remain unsettled. This means that many important water supply and demand questions cannot yet be fully answered. The Plan also notes the need for better coordination of water management across reservation boundaries and cites groundwater pumping just outside of reservation boundaries as having caused a drop in the water table level within reservation boundaries. (ADWR 1999a: 12-3). Decisions in these cases are likely to have significant impacts on some municipal water providers. Thus, the lack of resolution of Native American claims creates difficulties for urban planners trying to pinpoint what water supplies will be available from which sources, and at what cost, in the future.

5.2. Federal Reserved Rights in Protected Areas

As public values increasingly turn towards the preservation of wildlife habitat, in-stream water uses are likely to become increasingly important in the state. In-stream flow rights are often particularly vulnerable during periods of water shortage because they are generally junior rights. Conflict already exists between municipal and agricultural users and advocates of the preservation of riparian habitats in several areas of Arizona, for example along the San Pedro River in southeastern Arizona (see San Pedro Expert Study Team 1998). The San Pedro River originates in northern Mexico and flows toward the north. A tributary of the Gila River, which is, in turn, a tributary of the Colorado River, the San Pedro is one of the few remaining perennial streams remaining in southeastern Arizona. Stream flow in the San Pedro is composed of base flow and flood flows, generated by summer monsoon, winter frontal, and tropical storm activities in the area.

In some stretches of the river, flows are perennial and a high degree of stream-aquifer interaction occurs. The hydrology of the river is complex, with some stretches gaining water and others losing. In April 1999, American Rivers, an environmental organization, listed the San Pedro as the fourth most endangered river in the United States (American Rivers 1999).[5] Concern revolves around water use by the nearby City of Sierra Vista and Fort Huachuca Army Base, which lies adjacent to the city. Over-pumping by Sierra Vista and Fort Huachuca of the regional aquifer was cited by American Rivers as the primary threat to the San Pedro River. The organization went on to predict that, at current pumping rates, reaches of the San Pedro that currently have perennial flows will be dry for at least part of the year by 2008. Climate variability poses further challenges for management of this and other protected areas in the Southwest, because research and decision making are typically based on mean climate figures, or at best on a limited range of climatic variability that fails to recognize the full extent of potential climate impacts. Inclusion of data reflecting periods ranging from seasonal to multi-century is needed to fully assess the potential range of impacts on such protected areas.

5.2.1. Surface Water-Groundwater Conjunctive Management

The San Pedro River provides a good example of one of the thorniest problems associated with managing for in-stream flows and riparian ecosystems. Congress designated the San Pedro Riparian National Conservation Area (SPRNCA) in 1988 (Tellman et al. 1997), a designation that makes the area subject to federal reserve water rights. Similar to the rules that govern Indian water rights claims on reservations that were set aside by the federal government, this designation indicates that Congress also intended to set aside water rights sufficient to fulfill the purpose of the land. However, the exact implications are subject to judicial interpretation. Conflicts already exist in the vicinity of the San Pedro River and in other areas of the Southwest between human uses and maintaining an aquifer at a level high enough to continue feeding connected surface water and riparian areas.

The issue is particularly difficult in Arizona, because it is one of only a few Western states that still have separate groundwater and surface flow appropriations laws. As Glennon and Maddock (1994) note, most states now base their laws on contemporary scientific knowledge of hydrological connections, a trend that Arizona law has thus far been unwilling to acknowledge. Arizona's more arcane water law also fails to consider the fact that the technology commonly used for groundwater pumping has also changed significantly since the laws were written. More powerful pumps have a greater impact on groundwater levels, resulting in more overdraft. The legal framework for water management, even today in Arizona, remains based on an Arizona Supreme Court decision that rejected landowners' rights of ownership of the groundwater under their land, prior to its withdrawal from the aquifer (see *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source*, Interlocutory Review, Issue No. 2, 175 Ariz. 382, 857 P.2d 1236, 1993; see also Glennon and Maddock 1994). This issue could have significant bearing in times of extreme drought, for under current law pumping of groundwater feeding streams and adjacent riparian areas could be legally continued or increased to the point of depleting any flows that might otherwise have supported the instream and riparian areas, thus threatening any existing federal reserved rights.

5.3. The Endangered Species Act

Water management may also be affected by environmental law, particularly the Endangered Species Act (ESA). An Office of Technology Assessment report (1993) noted that the ESA could be used to restrict the future use and development of water supplies, and would likely be affected by climate change. The ESA requires federal departments and agencies to cooperate with state and local agencies to identify and conserve endangered species and their habitats. Habitat preservation, as discussed in the San Pedro example above, often requires reductions or modifications in water use. It is conceivable that the viable habitat of many species could be reduced to a fraction of their previous range by more extreme climatic conditions. For example, Snyder et al. (1997) examined what would happen to the San Pedro if increased groundwater pumping caused the water table to decline. The researchers found that a three-foot drop in the water table would eliminate marshy species, while a six-foot drop would prevent cottonwood and willow seedlings from sprouting, meaning that most cottonwood and willows would eventually loose out to mesquite and sacaton grass. Even under existing climate conditions, if pumping proceeds at the rate projected for the Sierra Vista area, losses within the next 10 to 20 years could include 52 percent of the marsh vegetation, 42 percent of cotton and willow seedlings, and 17 percent of the mature cottonwood forest (Tellman et al. 1997). Such a decline in vegetation could more easily cause the remaining riparian areas to be declared critical habitat areas under the ESA. A requirement to do whatever is required to preserve those areas, regardless of the economic impact, could follow such a designation. Glennon and Maddock (1994) describe a similar situation wherein a preliminary injunction was awarded to the Sierra Club in a case involving over-pumping of the Edwards Aquifer in central Texas; however, the injunction was later vacated.

The ESA also has bearing on the use of Colorado River water, as well as on Indian rights claims (Hansen 1995). When the Colorado River compact was created, environmental impacts were not among the factors considered. The results have been devastating to native fish species, and four species have been listed as endangered. The massive dams that segment the Colorado block fish passage, reduce spring flows, trap silt, and alter water temperatures. Inner canyon beaches that fish need to spawn have also been destroyed, and exotic fish have been introduced. Pending lawsuits seeking to enforce compliance with the ESA could have serious impacts on the use of Colorado River water. The implications of climate variability for management under ESA rules could be significant, for quantification of water needs typically does not reflect the potential for severe sustained drought, nor does it take into account shifts in the distribution of climatic norms and extremes.

Indian tribes who have not yet been able to use their entire allocations hold many of the water rights to the remaining undiverted in-stream flow in the West. These rights constitute many of the best sources for the water needed to maintain instream flows. Thus, it is not surprising that conflict has arisen between tribes requesting federal funding for the diversion projects necessary for irrigation projects, and environmental interests who wish to see in-stream flows preserved. Unfortunately, consideration of the impacts of climate variability, including floods as well as sustained droughts, has not been effectively incorporated into decision processes associated with these kinds of contests.

Miller (1997) suggested that managing in-stream water rights would be easier in times of climatic stress if public agencies were allowed to represent in-stream interests in a market system, with a budget that would allow them to buy or rent water rights for environmental purposes. The Office of Technology Assessment report (1993) suggests that, instead of a single minimum flow standard, a range of environmentally desirable flow levels should be included in assessments of current and projected water supplies. The lower of these various flow levels would serve as a trigger point to tell water authorities when to purchase water rights or implement restrictions of existing rights. Higher level flows could trigger the establishment of new rights for use in times of surplus.

5.4. Water Quality Provisions

The interaction between climatic variability, water supply, and water quality is an important influence on the nature of water demand and volume of water available.

5.4.1. Clean Water Act

The Clean Water Act (CWA) was enacted by Congress in 1972 to eliminate, by 1985, the discharge into the nation's waterways of pollutants, as well as to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The Act allows enforcement by citizen suits, provides for monitoring and record keeping, and subjects violators to criminal penalties and the loss of governmental funding. Under the Act, however, administration of water quality standards is left to the states, which are free to impose stricter controls than required by federal effluent limitations. The Third Management Plan for Phoenix (ADWR 1999a: 12-3) cites the need for closer coordination between Arizona Department of Environmental Quality (ADEQ) and ADWR, particularly regarding effluent reuse regulations, remedial action projects for polluted or poor-quality groundwater, and ADEQ conservation requirement exemptions of 65,000 af state-wide.

The most pertinent section of the CWA for climate impacts analysis is Section 208, which provides for the development of area-wide wastewater management plans in areas that have been designated as having waste treatment problems. Water quality issues are certain to come to the fore as enhanced use of effluent supplies and increased utilization of municipal graywater (non-sewage wastewater from homes and businesses) become more prevalent. Generally drier conditions would add additional incentives to the development of these alternative water sources. Water quality issues also link to flood events, which can lead to contamination of water supplies through damage to water and sewage mains, additional run-off to surface water supplies, or flood-water penetration of wells. Increases in flood frequency or intensity due to changing climatic conditions may hold serious implications for sustaining water quality at regulatory levels.

5.4.2. Safe Drinking Water Act

The Safe Drinking Water Act (SDWA), passed in 1986, has implications for management under conditions of climatic variability as well. The SDWA sets out water quality regulations for water providers. In Arizona, responsibility for enforcement of the SDWA lies with the Arizona Corporation Commission.

It has been argued that Congress was wrong in passing this legislation without taking into account the costs of compliance for small water providers (80% of regulated water systems in Arizona are categorized as "small"). Indeed, most of the water providers that have difficulties complying with the SDWA are small companies that lack adequate funds to maintain properly monitored distribution facilities. Further, in some border areas, such as Nogales, Arizona, flood waters from Nogales, Sonora (in Mexico) sometimes carry chemical contaminants and sewage into Arizona, threatening local water supplies. An increase in flood frequency and/or intensity could pose serious challenges to continued compliance with the SDWA, as well as to the capacity to fund necessary treatment of contaminated drinking water sources.[6]

6. Arizona State Water Policies

Many provisions of the water management laws and policies of the State of Arizona have potential implications for managing supply and demand under conditions of climatic stress. An overview of some of the key features of water supply and demand management are discussed below.

6.1. The Central Arizona Project

The Central Arizona Project (CAP) (Figure 3) is a 335-mile long canal and series of pumping stations and reservoirs that took nearly $4 billion and about 25 years to build (Glennon 1995). The canal begins in Lake Havasu and proceeds southeast across Arizona, eventually ending in Tucson. As previously discussed, the canal is allotted 1.5 maf of Arizona's 2.8 maf total apportionment of Colorado River water, but is classified as fourth in line to Lower Basin allocations of wa-

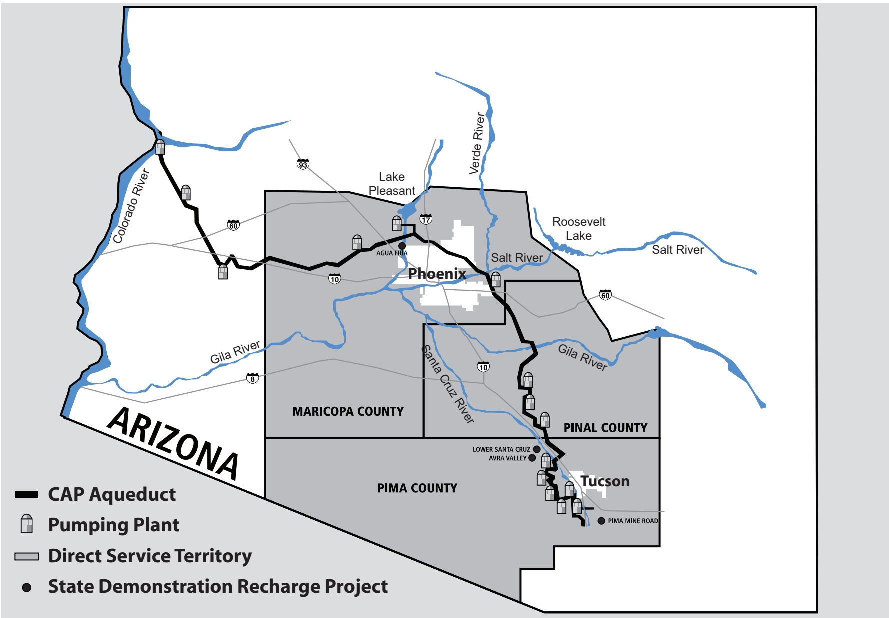

Figure 3. Map of the Central Arizona Project
Source: Central Arizona Project

Ironically, the larger problem, to date, for Arizona has not been too little CAP water, but rather too much of it. Part of the purpose of constructing the canal was to enable Arizona to use a greater proportion of its Colorado River allotment, rather than risk losing it to the water-short states of California and Nevada. However, declines in the agricultural economy and Tucson's rejection of CAP water in January 1995 constrained the state from appropriating its full allotment until the past year (2000). The Arizona Water Banking Authority (discussed in more detail in the following section) estimates that Arizona will not have sufficient population and infrastructure to effectively *use* its entire allotment until 2030; currently, much of the unused portion is being stored as a buffer against future need. This is in sharp contrast to California's historical pattern of using some 1.1 maf more than its 4.4 maf allotment. (Recently enacted Interim Surplus Guidelines, discussed in Section 6.2.2, aim to reduce California's reliance on volumes in excess of its allotted share).

In addition, due in large part to Las Vegas' explosive growth, southern Nevada's water needs will exceed the state's apportionment by 2015. Given these projections, the risk of diversion of unused portions of Arizona's allotment to other Lower Basin states may again arise, particularly under conditions of severe climatic stress. If this were to occur, there is no assurance that the Supreme Court would once again favor Arizona (Glennon 1995).

ter from the river. Under section 301(b) of the legislation authorizing the CAP system (Colorado River Basin Project Act, 43 U.S.C. §§ 1501-56, 1988), in times of shortage the CAP will receive its 1.5 maf allotment only after obligations to California, Nevada and non-CAP Arizona are met (Sax 1991: 710; Glennon 1995). As noted above, this makes the CAP allotment among the most vulnerable of the Colorado River allocations during times of drought. Due in part to this vulnerability, both Phoenix and Tucson must maintain the infrastructure to allow them to switch to groundwater if the situation requires it.

The over-allotment of the Colorado River clearly contributes to the tenuous nature of CAP supplies. The Arizona Department of Water Resources notes in its Third Management Plan for Phoenix that shortages are to be expected on the Colorado River, on average, 30 percent of the time over the next 100 years, and 50 percent of the time by 2050 (ADWR 1999a: 12-6). The Lower Basin has not been confronted with a severe water shortage since the canal was built. However, dependence on CAP supplies is anticipated to increase substantially in the near future: Arizona's Groundwater Management Act (which will be discussed in greater detail in a later section) mandates the greater use of renewable supplies such as CAP water and less dependence on groundwater. Coupled with rapid population growth throughout the Lower Basin, increased water demand will likely put the CAP allocation in jeopardy, at least some of the time.

6.2. Water Banking, Surplus Water, and Transfers

The State of Arizona recognizes in its water laws and policies the possibility that the availability of water will vary from time to time, and, in particular, that serious water shortages may occur. Such water shortages might be caused by climatic conditions, or by interruptions in deliveries due to system malfunctions or other uncontrollable events. Further, the State has expressed a strong interest in assuring that it retains control of all water rights it has been accorded under the Law of the River. To these ends, the State has implemented the Arizona Water Banking Authority, established a framework for allocating water supplies over a 15-year period during which California is expected to reduce its appropriation of Colorado River water to its allotted 4.4 maf, and set in place the conditions under which water transfers may and may not be undertaken.

6.2.1. Arizona Water Banking Authority

The Arizona Water Banking Authority (AWBA) was created in 1996 amidst concern about Arizona's inability to fully utilize its entire allotment of Colorado River water. The AWBA estimated that before the state reached levels of population and industrial growth commensurate with utilizing Arizona's full CAP allotment (not projected to occur until 2030), about 14 maf of Colorado River water would have to be forfeited (AWBA Commission 1997; see also A.R.S. Chapter 14, Arizona Water Banking Authority). Although California, Nevada and the Bureau of Reclamation each proposed a different version of a plan involving water transfers, Arizona remained suspicious of any arrangement involving selling or leasing its water rights to California or Nevada, out of concern that its entitlement would be permanently reduced. This concern was a major factor behind creation of the AWBA and a subsequent effort to assure that California would not continue its pattern of taking more than its 4.4 maf allotment each year.

AWBA has the authority to accumulate water rights from underground water storage credits under Arizona's various replenishment statutes, Colorado River water available through voluntary land fallowing, and short-term contracts with the Central Arizona Water Conservation District (CAWCD, the administrative arm of the CAP system) for unused CAP water for underground water storage.

The main idea of the Bank is to store unused (i.e., "excess") CAP water in underground storage facilities until it is needed. In addition to the political motivation of enabling Arizona to hold on to its Colorado River allocation, AWBA stores water for municipal and industrial users in Arizona as insurance against any potential future water shortages, such as those produced by drought or other causes. Officials also intend, through AWBA, to facilitate leasing of a portion of Arizona's Colorado River water to Nevada and California during times of water stress; during these periods Arizona would instead rely on water stored through the Bank (AWBA Commission 1998).

Under A.R.S. 45-2401 and 45-2423, the AWBA may administer and oversee water banking for individual entities within Arizona through centralized banking services. Long-term storage credits are distributed to depositors by AWBA, as provided in A.R.S. 45-2457. Further, Arizona entities may borrow long-term storage credits in return for reasonable compensation to AWBA. AWBA is permitted to store additional CAP water, and effluent as well, once all available "excess" CAP water has been stored or when "excess" CAP water is not available to AWBA. In addition, AWBA can contract with similar authorities in California and Nevada to bank the two states' unused Colorado River water, provided that the contracting state is willing to pay for the service. In return, the depositing state would be allowed to draw a similar amount directly from the Colorado River at a future time. Notably, the program explicitly does not involve sale of any future rights to water, but only the specified quantity of unused water.

As indicated above, AWBA holds potential to expand Arizona's capacity to deal with hydrological stresses through water transfers, as Miller (1997) recommends. However, the Bank's effectiveness has been challenged on the grounds that it is merely an accounting device through which "paper water" may be shuffled, with little relation to the amount of "wet water" (actual water) being stored (La Bianca 1998). While the intent is certainly to store water underground in order to assure firm supplies in the event of drought conditions, issues remain with regard to the amount of water actually being recharged, the availability of infrastructure to move the stored water to the locations where it is needed, and the effectiveness of institutional arrangements for moving the water from storage to provider pipelines. Thus, to date, water "banking" continues to be most effective in facilitating the exchange of water storage credits for permission to maintain existing water management practices. Another potential problem, as stated by Miller (1997), is that, at present, most water transfers involve permanent transfers of large blocks of water, and indeed, Arizona Water Bank transactions are based on transfers at the state level for multi-year periods of time. Little consideration is given to potential climatic fluctuations in these transfers, even though climatic stress could prompt decisions to shift quantities of water, especially from senior to junior users, during periods of low flows. It is unclear whether AWBA could exhibit enough flexibility to allow for these types of more limited and specific transfers.

6.2.2. Interim Surplus Guidelines: Colorado River Water

In Spring 2001, the Arizona State Legislature ratified, and the Governor signed, a proposal of the governors of the Colorado River Basin states that calls for the Secretary of the Interior to adopt interim surplus guidelines designed to wean California from its use of Colorado River water in excess of its 4.4 maf allotment (SJR 1001, First Regular Session of the Arizona State Legislature, 2001; for the governors' Basin States Proposal, see *Federal Register,* August 8, 2000, Vol. 65, No. 153, pp. 48531-48538). This resolution, which is quite complex, has significant ties with the AWBA, for it sets the framework for allocating and banking the surplus water that Metropolitan Water District and others in Southern California have been using for many years. The resolution also has significant implications for incorporation of climate information and forecasts into water planning and management, as discussed below.

The Resolution covers the period January 1, 2002 through December 31, 2016, and includes support for a program adopted by contractors of Colorado River water in California to reduce their dependence on that water over the 15-year period. Further, the resolution acknowledges that the program implementing interim surplus guidelines adopted by the Secretary of the Interior is dependent on Arizona's foregoing delivery of some of the surplus water that would otherwise be legally available based on the *Arizona v. California* decision. In exchange, California is expected to reduce its orders for water and to provide insurance to Arizona that California's use of surplus water during the 15-year period will not cause a shortage of Colorado River water within Arizona either during or after that period. If a shortage occurs during or after this period, the Metropolitan District of Southern California agrees to reduce its use of Colorado River water by up to a total of 1 million acre feet and to direct that water to Arizona.

The Resolution articulates specific definitions for surpluses and shortages, each of which triggers different rules with regard to how much surplus water California can appropriate during the interim period. According to the Resolution, a "normal year" is defined by the Secretary of the Interior as one in which "no more than 7.5 maf of Colorado River water shall be delivered for consumptive use" in the Lower Basin states (SRJ 1001, Article 1.1.20). A shortage year is defined as "Any year when the Secretary determines, under Article II(B)(3) of the Decree in *Arizona v. California*, and the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado River Basin Project Act of September 30, 1968, that insufficient water is available for release to satisfy annual consumptive use of 7,500,000 af in the states of California, Nevada and Arizona collectively" (SJR 1001, Article 1.1.25).

During a normal year, the elevation of Lake Mead storage is projected to be at 1,125 feet. A partial domestic surplus year is defined occurring when Lake Mead storage is between 1,125 and 1,145 feet in elevation (Article 4, 4.2 and 4.3). Full domestic surplus years occur when Lake Mead is projected to have an elevation greater than 1,145 feet, but less than the amount that would initiate a "surplus" determination. Quantified surpluses are established by the Secretary of the Interior according to the 50% (California), 46% (Arizona) and 4% (Nevada) rule included in the Law of the River. However, the Resolution stipulates how the surpluses are to be used. They are specifically to be used by California and Nevada to meet basic demand. Conversely, Arizona's share is expected to be allocated to surplus demands, including "Off-stream Banking and interstate banking demands" (SJR 1001 Article 4.5.3). Any remaining water is to continue to be stored in Lake Mead (SJR 1001, Article 4.5.6).

If a Flood Control Surplus Year is declared, "MWD [Metropolitan Water District of California] and the State of Arizona agree that releases may be made to satisfy all beneficial uses within California and Arizona, including unlimited off-stream banking and section 215 deliveries qualifying under the Reclamation Reform Act of 1982 (95 Stat. 1263). MWD and Arizona contractors may make their orders for Colorado River water to the Secretary without any limitation under this agreement. Thereafter, the Secretary may notify the United States Section of the International Boundary and Water Commission that there may be a surplus of water as provided in Article 10 of the *Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Treaty Between the United States of America and Mexico*, signed February 3, 1944 ('Mexican Water Treaty of 1944')" (Article 4.6). Skilled climate forecast and related river supply outlook information in advance would be very useful to decision makers and water managers in the Lower Basin and in Mexico, under this type of situation

Not surprisingly, the Joint Resolution goes into some detail regarding the obligations of the MWD during years of shortage, during and after the 15-year interim period, or if there is a suspension in the interim surplus guidelines. In effect, if the Secretary declares a shortage, MWD is barred from ordering water in excess of the allotted 4.4 maf. Furthermore, if the Secretary releases water to MWD under either a Partial or Full Domestic Surplus condition during the 15-year interim period, and subsequently declares a Shortage Year during the Interim Period—and if the declaration causes deliveries to Arizona to be reduced—MWD must compensate Arizona for the impacts of the shortage. In this situation, MWD is to reduce its order for Colorado River Water for the shortage year by enough to ensure that total consumptive use of that water in California remains less than 4.4 maf.[7] The water foregone is intended exclusively for consumptive use in Arizona (Article 5.2, and 5.2.1). Both Arizona and California would benefit from the kind of forewarning that skilled climate and water supply forecasting could potentially supply in this situation.

Under the Resolution, MWD and Arizona Department of Water Resources may agree to share the impact of shortages. As noted above, use of skilled forecasts would be of significant benefit, for the two entities must confer to assess the relative impact of the shortage on the states. If the shortage appears likely to last more than one year, ADWR may (after consulting with Colorado River contractors in Arizona) consent to allow MWD to spread the shortage reparation over more than one year. If this type of agreement is made, MWD is to reduce its water order for the next two or more years (Section 5.2.2). Interestingly, even if the years following the Shortage Year are not also declared to be such, MWD is still obligated to forego use of Colorado River water and to return the water owing to Arizona in subsequent years. In this event, MWD must acknowledge that Arizona may not need the water for direct use; if this is the case, MWD agrees to pay the actual cost to store the forgone water in Arizona through the Arizona Water Banking Authority (Section 5.2.2.1).

Implementation of Article 5.2.3 of the Joint Resolution also suggests the importance of incorporating climate forecasts into decision making, for it stipulates that MWD can enter into interstate banking arrangements with the Arizona Water Banking Authority. The arrangement includes allowing MWD to call on credits held by AWBA to replace MWD water that would otherwise have to be forborne under the provisions outlined above.

According to Articles 5.3, 5.3.1., and 5.3.2, if the Secretary releases water to MWD under either Partial or Full Domestic Surplus during the interim period, then declares a year after the Interim Period to be a Shortage Year, MWD agrees to compensate Arizona for the impacts of the shortage. This involves reducing its order for Colorado River water by an amount equal to that by which the Secretary limits consumptive use of river water, by Arizona, to less than 2.8 maf.[8] MWD must notify Arizona, within 60 days of receipt of notice of a Shortage Year (via the Annual Operating Plan), how it will fulfill its obligations. In turn, Arizona has 15 days from receipt of the notice to lodge an objection and MWD has a subsequent 15 days to respond. Other provisions apply if the Interim Surplus Guidelines are suspended. Access to long-term forecasts could enable Arizona to better anticipate notification in advance of the 60-day requirement.

Under the Joint Resolution, Arizona contractors are limited in how they can use surplus water during the Interim Period. In a Partial or Full Domestic Surplus Year, the state agrees to partially waive its contractual rights to surplus Colorado River water; in other words, consumption will remain within the state's basic apportionment of 2.8 maf. In a Quantified Surplus Year (i.e., when the Secretary determines that water should be released for use to reduce the risk of potential spills from the reservoirs), the Secretary is expected to allocate the surplus sequentially according to the 50-46-4 percent formula stipulated in the Law of the River rules. Arizona's share of the surplus is expected to be allocated first to meet basic demands, then to any remaining direct-delivery domestic uses and off-stream banking. This latter includes interstate banking as well as off-stream banking demand. Any water left over is to remain in storage in Lake Mead.

Article 10 makes some stipulations to the Resolution that have potentially significant implications for management, under unusual stresses ("force majeure") affecting the Colorado River over the 15-years of the interim period. In essence, if the obligations stipulated in the Resolution are hindered, interrupted or prevented by "wars, strikes, lockouts, fire, acts of God or by other acts of military authority, or by any other cause beyond the control of the respective parties," the obligations are to be extended to the extent and for the period of time that performance is affected by the event. Obligations resume when the stress is no longer an issue (Articles 9.1, 9.2). Notably, the Resolution also explicitly states that it is not to be "construed as a conveyance, abandonment, or waiver of any water right, or the right to use the water, nor shall it be construed as conferring any right whatsoever upon any person, firm, corporation or other public or private entity not a party to this agreement" (Article 10.3). These two provisions have significance under conditions of severe climatic stress (which could be interpreted as an act of God or a cause beyond the control of the parties to the Resolution), for it reinforces prior institutional arrangements governing water allocation in the Lower Basin. Thus, climate impacts would be dealt with through the longer-standing rules under the Law of the River.

6.3. The Groundwater Management Act

The primary water management entity in Arizona is the Department of Water Resources (ADWR), which was established under the Groundwater Management Act of 1980. In addition to overseeing water supply and demand in all areas of the state, ADWR has designated five Active Management Areas (AMAs) where stricter regulatory mechanisms are in effect. The basic concept behind the groundwater use regulations in the AMAs is *safe-yield.*

6.3.1. Safe-Yield

Safe-yield is defined in the Groundwater Code (A.R.S. 45 §561.12) as "a groundwater management goal which attempts to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in an active management area and the amount of natural and artificial recharge in the active management area." This goal is one of the foremost factors driving the development of ADWR policies and management plans within the AMAs.

As stipulated in the Code (A.R.S. 45.562.4) "The management goal of the Tucson, Phoenix and Prescott active management areas is safe-yield by January 1, 2025, or such earlier date as may be determined by the director." For the Santa Cruz AMA, the goal is "to maintain a safe-yield condition... and to prevent local water tables from experiencing long-term declines." The Pinal AMA, being primarily agricultural, has as its goal allowing development of non-irrigation uses as provided in the Groundwater Code, and to "preserve existing agricultural economies ... for as long as feasible, consistent with the necessity to preserve future water supplies for non-irrigation uses." The wording of the provisions appears to assume relatively stable climate conditions; certainly long-term, significant changes in the climate regime are not expressly reflected. Yet, unless suitably designed conservation measures are instituted in a timely manner, achieving and sustaining safe-yield may be facilitated or constrained by climatic conditions, particularly Colorado Basin-wide severe sustained drought. Significantly, even without consideration of potential climatic stresses, a review of the Arizona Department of Water Resources conducted by the Arizona Auditor General in 1999 found that the Phoenix and Tucson AMAs are unlikely to meet their safe-yield goals by 2025, as specified in the Groundwater Code (Norton 1999).

6.3.2. Groundwater Recharge

Although often addressed in water accounting as a constant, recharge rates in fact vary widely according to climatic conditions. The relationship between precipitation and recharge is complex. Factors such as seasonality and duration of rainfall, temperature, hydrologic structure and the amount of time between the precipitation event and when the water actually reaches the aquifer must all be taken into account, as must the speed and direction of water movement into, through, and out of the aquifer. Climatic variability, particularly extended periods of deep drought, would have significant impact on the sustainable management of groundwater supplies. At the same time, scientific understanding of recharge processes remains very imprecise, which means that even with the best climate information, more research is needed to determine the impacts of climate variability on aquifer recharge rates and, by extension, recharge of surface water bodies by subflows from aquifers.

6.3.3. Assured Water Supply Rules, Grandfathered Rights, and Exempt Wells

One aspect of the Groundwater Management Act that is particularly salient to this analysis is the Assured Water Supply (AWS) rules. The AWS program was originally established in Arizona in 1973 to preserve groundwater resources and to promote long-term water supply planning. The program also serves to protect consumers by requiring developers to demonstrate that sufficient water supplies are available to support new subdivisions, prior to sale (ADWR 1997). The original 1973 Water Adequacy law still governs areas outside the AMAs and unsubdivided land within the AMAs.

The AWS program was modified by the Groundwater Management Act of 1980 to emphasize more strongly actual achievement of safe-yield. The new provisions went beyond the 1973 law to prohibit the sale or lease of subdivided land in an AMA without demonstration of an assured water supply (that is, a sufficient quantity of water of adequate quality to last at least 100 years), consistency with the AMA management goals, and financial ability to construct delivery systems and related features. The AWS rules were again modified in 1995. Chief among the amendments was a rule requiring that AWS be demonstrated using predominantly *renewable* supplies, for example CAP water and/or effluent.

Today, under the Groundwater Code, a water provider or developer must demonstrate that water of sufficient quantity and quality is available to sustain use for 100 years; that the proposed use is consistent with the AMA management plan and goals; and that the water provider possesses the financial capability required to build the necessary water delivery and treatment systems (see ADWR 1997). AWS rules stipulate that anyone who offers subdivided *or* unsubdivided land for sale or lease must demonstrate to ADWR, *before* the land is marketed, that an assured supply of water exists for that land. Developers can satisfy these rules in two ways, either through obtaining their own certificate of assured supply or through providing written proof that a water provider who possesses a designation of assured supply has agreed to supply water to that development (see ADWR 1997). AWS rules required all existing water providers to have provided demonstration of an assured supply by 2001.

The AWS rule requiring continuous physical and legal availability of water for 100 years is the most salient with regard to the impacts of climate variability on water supply in the AMAs. Satisfying the rule, particularly when the emphasis is on demonstration of sufficient renewable water, becomes much more challenging when the potential of severe sustained drought is considered. The AWS determination is based on hydrologic analysis of potential water supply and demand, which in turn is typically based either on a determination of mean annual climate for a designated period of the historical record or on a relatively conservative distribution of climate variance. However, such assumptions fail to consider the potential impacts of deeper and more sustained drought conditions, such as those that occurred during the 1950s. Backup resources are required where primary reliance is on groundwater, yet stresses could be exacerbated by growth in demand, potentially leading to conflicts among water users. The assumptions also fail to take into account long-term shifts in climatic means and extremes.[9]

While groundwater pumping is thus restricted, existing providers and some new subdivisions (depending on the depth to the water table at their location) are given an allowable groundwater allocation. The groundwater allocation is comprised of a basic allocation of acceptable overdraft, an incidental recharge factor, and extinguishment credits. In the Phoenix, Tucson, and Prescott AMAs, the basic allocation rules for *physical availability* of water (as opposed to the volume of groundwater allocated) are designed to assure that the water table does not drop to more than 1,000 feet below the land surface. Again, extended severe drought could challenge the ability of providers to adhere to this rule.

The incidental recharge factor is the portion of allowable groundwater pumping most likely to be affected by climate change. Incidental recharge is the amount of water used outdoors for purposes such as irrigation of turf and landscapes that is expected to trickle down and return to the aquifer. At present, the incidental recharge allocation in the water budgets of the AMAs is set at 4 percent of the demand in the previous year. However, this factor is likely to be reduced in times of elevated evapotranspiration rates, which typically occur during droughts, when extended periods of sunny weather prevail. Demand is likely to be highest under these conditions, and higher than normal rates of incidental recharge would be registered. However, a greater percentage of the water used could be lost to evaporation. Incidental recharge amounts would also be compromised in situations where severe drought and water shortages led to restrictions on outdoor water use, but other types of demand remained higher than normal. Thus an across-the-board incidental recharge factor may not accurately reflect conditions in a changing climate.

6.3.4. Extinguishment Credits

The third component of the groundwater allocation, extinguishment credits, is designed to facilitate reductions in certain kinds of water use, for example, grandfathered water rights for agricultural irrigation (see A.R.S. §§ 45-462 through 45-465). The credits are intended to serve as an incentive to these right holders to permanently retire their rights. In some cases, rights to the amount of groundwater thus retired and credited may be purchased for use away from that parcel of land by water providers attempting to prove an assured water supply. The extinguishment credits provision ends in 2025; however, and thus does not really provide a long-term resolution to the issue of water rights reallocation. Further, within all of the AMAs, the amount of groundwater tied up in grandfathered rights exceeds the amount that is actually being recharged; thus there is more “paper water” in existence than what is legally available for withdrawal and use.

The Phoenix Third Management Plan notes that the total of all "residual pumping" legal exemptions, including those for grandfathered right holders, water providers and permit holders, amounts to 238,000 af per year (ADWR 1999a: 12-5). In an effort to close this loophole, AWS rules require that the physical availability of the water be proven, regardless of the amount of paper water an applicant for AWS certification may have accrued.

Arizona surface water law specifies the relative value of uses of water in situations where "conflicting applications for the use of water from a given water supply, when the capacity of the supply is not sufficient for all applications...." The priority specified in A.R.S. 45-157 is as follows:

1. Domestic and municipal uses, including gardens not exceeding one-half acre per family
2. Irrigation and stock watering
3. Power and mining uses
4. Recreation and wildlife, including fish
5. Nonrecoverable water storage (pursuant to A.R.S. 45-833.01)

The prioritization of the relative value of water constitutes a potentially powerful tool for coping with severe extended drought, particularly if CAP supplies are significantly reduced or even eliminated. To date, this provision has not been tested in areas where increased groundwater pumping may not be a sufficient—or viable—option.

6.3.5. Assured Water Supply and Climate Variability
Some features of the AWS rules may make these regulations useful for monitoring and coping with climate impacts. Designated water providers must file annual reports on water demand and supply, and can ask that a certificate be amended if they secure new water supplies. AWS designations and certificates are reviewed at least every 15 years, and can be amended or revoked by ADWR if a designated provider is out of compliance with the management plan or goal of their AMA, does not construct necessary treatment or storage facilities, or fails to meet its replenishment obligation. This is clearly preferable to a system where a provider could acquire the 100-year assured water supply designation at a single point in time, and then (if no growth occurs) not be subject to review of its water supply and demand for a century, during which time supply and demand characteristics, as well as other factors, could have changed significantly.

AWS regulations should be fairly easy to enforce with regard new subdivisions, since without an AWS certificate the Arizona Department of Real Estate will not authorize the sale of homes in a subdivision. However, there is a limitation to the flexibility of AWS rules: a certificate of AWS cannot be revoked once any of the residential lots within the subdivision have been sold. This means that, under a Certificate of AWS, a permanent change in the water supply that occurs during a possibly long development period will not constitute grounds for stopping the development. There are reports of unscrupulous developers who have attempted to skirt the AWS rules by staying outside of the legal definition of a subdivision, which is defined in real estate law as land divided into six or more parcels with at least one parcel having an area of less than 36 acres. If, however, the developer has proven in writing that water is being provided by a water provider holding an ADWR-issued Designation of Assured Supply, ADWR has greater flexibility to intercede in resolving the issue through working with that provider (for more information, refer to ADWR 1999a and 199b).

There are also concerns about the number of domestic wells that rely on groundwater exclusively. The amount withdrawn by individual exempt wells must be 35 gallons per minute or less; however, the urban sprawl and more dense well spacing seen in each study area indicates that the combined impact of unregulated wells could be significant (Glennon and Maddock 1994). This phenomenon is thought to be a major factor behind the drop in the water table in the Sierra Vista area, and is probably affecting other areas as well. Since wells of this nature are generally shallow and therefore more closely connected with surface water conditions than deeper wells, they are far more likely to suffer shortages during severe sustained droughts. Adding to their vulnerability is the fact that unlike municipal water providers, domestic wells are unlikely to have back-up systems or extensive water storage facilities.

6.4. Groundwater Management Within versus Outside the AMAs
Issues surrounding the extent of groundwater contributions to surface flow in the San Pedro River, and the effects of groundwater pumping on stream recharge in the Sierra Vista area illustrate an overarching limitation of the GWMA: it constitutes a strong regulatory policy in the designated AMAs, but it does not effectively address issues surrounding surface water-groundwater connectivity.[10] Glennon and Maddock (1994) note that this is-

sue is based on outdated and incomplete understanding of hydrological processes.

There is widespread agreement that the failure to consider the integration of groundwater and surface water policy has caused serious problems in water management. It is highly likely that, under conditions of climatic stress, this weakness in existing water policy would pose challenges to effective and equitable water management. Already, the lack of conjunctive management of water resources has led to the fragmentation of water management in the Phoenix AMA, where surface water, CAP water, and effluent are subject to different regulations, and owned or controlled by different jurisdictions (ADWR 1999a: 12-3). Riparian habitat, instream flows, and water quality issues complicate the issue further, for these elements are also not managed by the ADWR at the AMA level.

6.5. Water Transfers into the AMAs

Water transfers proved to be a highly contentious issue in Arizona in the mid-to late 1980s, when cities such as Scottsdale, adjacent to Phoenix, began buying properties in remote parts of the state to gain access to the water rights appurtenant to those lands. The idea was to retire the land, and ship the water, via interbasin transfer, to the right holder. Rural counties protested, noting that such interbasin transfers deprived them of not only water, but also of the direct and indirect income generated by agricultural activities. In response to strong political opposition, the Arizona Legislature, in 1991, enacted the Groundwater Transportation Act, which severely constrains the ability of municipal water providers to transfer groundwater from rural basins to urban areas. However, the Act does provide a legal framework allowing for certain interbasin groundwater transfers that assist in efforts to demonstrate an assured water supply (see A.R.S. 45-544 and Article 45-551). This latter exception to the ban in interbasin transfers may prove to be important in the event of a severe sustained drought of 10 years or more.

6.6. Regulation of Water Providers – Municipal and Private

All providers in the AMAs must comply with the rules and regulations issued by the Arizona Department of Water Resources. In addition, municipal water providers in Arizona are regulated by the governing body of the municipality in which the operation is located. In the Tucson AMA, for example, Tucson Water, the municipal provider for the City of Tucson, is regulated by the City Council; the City Manager's office is also involved in overseeing the utility and its director. By contrast, non-municipal service operations are governed by the Arizona Corporation Commission (ACC), as provided in the Arizona State Constitution (A.R.S. 40). The ACC has as its first priority regulating the rates charged by these providers. As detailed in A.R.S. 40-370, the ACC "shall authorize water utilities to recover increases in specific operating costs by means of a surcharge on water sales and to reduce rates when those specific operating costs decrease. The operating costs that may be considered in this procedure are limited to specific, readily identifiable costs that are subject to the control of another person, including the cost of purchasing electricity or gas, the cost of purchasing water from another utility, municipality or district...." Notably, passing the costs of conservation on to customers in the form of increased water rates under conditions of drought stress is not included in the statute. This omission has significant implications for providers' ability to manage supplies effectively under conditions of water scarcity, such as those posed by drought. While some providers, especially those with large groundwater reserves and proportionally low levels of demand, could probably weather even a severe sustained drought, others are already stressed even under "normal" climate conditions. Inability to enforce conservation measures among their customers, including raising rates to cover conservation activities, could seriously constrain the capacity of these providers to meet demand. This situation exemplifies a potential scale problem in managing water resources, and in assessing vulnerability to climate: assessments made at the AMA scale may miss important potential impacts at finer scales of resolution.

7. Issues and Implications in the AMAs

Each urban area in Arizona faces unique hydrological and climatological challenges. However, it is also important to note that the areas share important similarities. For example, the two largest metropolitan areas in Arizona, encompassed by the Tucson and Phoenix AMAs are characterized by large numbers of water companies (147 providers in the Phoenix AMA and 151 in the Tucson AMA), most of which—especially small providers—rely entirely on groundwater.

All the AMAs share important climate characteristics, including a general bimodal distribution of precipitation in winter and summer; spring and fall tend to be relatively dry. Particularly notable in terms of water management is the fact that the late 1980s and early 1990s were some of the wettest on record in Arizona; 15 of the past 20 years have seen above-average precipitation (Western Regional Climate Center 1999). These were decades of pronounced urban growth, and related growth in water demand. Although fairly severe droughts have occurred over the short term during this time frame, their effects have been offset by the occurrence of several unusually wet El Niño years. While the climate record reveals the occurrence of significant droughts, such as that of the 1950s, and local accounts illustrate that people coped rather effectively with these kinds of climatic stresses, the consequences of a recurrence of such conditions at current and projected urban population levels could be far more severe.

7.1. Revisiting the Groundwater Code: Safe-Yield Task Force

Assessing the impacts of such stresses requires analysis of the social, political and economic characteristics that determine water supply and demand in each specific urban area. Insights into the issues and concerns of the urban AMAs emerged recently through a recent review of ADWR, conducted by the State Auditor General's Office (Norton 1999). In response to the review, which stressed that achievement of safe-yield was highly unlikely to occur by the legislatively specified year 2025, a "Safe-Yield Task Force" process was initiated in the AMAs. The purpose of the task force process, still underway, has been to examine, at the AMA and the state levels, barriers to achieving safe-yield, and to raise the identified issues (with recommendations for resolution) to the state level. At the state level, the Governor of Arizona appointed a Water Commission responsible for recommending legislative changes to state water law. The Commission is made up of prominent individuals representing a range of interests. In the Pinal, Prescott and Santa Cruz AMAs, the local Groundwater Users Advisory Council (GUAC) assumed responsibility for the process. By contrast, in the Phoenix and Tucson AMAs, a broader process involving an extensive open meeting process was adopted. In these two AMAs, the process has included participation by private and municipal water managers and providers, agricultural interests, mining representatives and other industrial interests, and members of general public.

Due to the large number of issues to be covered, subcommittees focusing on designated issue subsets were formed in the Tucson and Phoenix AMAs. Each of the groups formulated a series of issue papers, identifying specific problems and recommending possible solution(s); the issue papers were approved by formally designated task force members, then forwarded to the state-level Governor's Water Commission, and its Technical Advisory Committee, for further consideration. The state-level group then assembled the issues into "families" of issues. Evaluation of the issue families and formulating recommendations for legislative changes is currently underway.

7.2. Potential Climate Impacts on Institutions – Phoenix Active Management Area

The Phoenix metropolitan area is one of the fastest growing areas in the nation; the population of Maricopa County, where most of the Phoenix metropolitan area is located, is expected to increase from 2,721,761 in 1997 to 4,948,423 by 2025 (ADES 1999). Projections of the impact of such growth on water supplies indicate that, while population is expected to increase by 45 percent, water supplies are projected to increase by 20 percent, resulting in an increase in groundwater overdraft in the AMA from 365,707 af in 1995 (ADWR 1999a: 11-21) to 412,467 af by 2025. Thus, even under assumptions of climate stationarity, and continuation of generally the above-average precipitation levels experienced in the past decade (Western Regional Climate Center 1999), attainment of safe-yield is looking increasingly unlikely. Indeed, according to the recently released Third Management Plan for the Phoenix AMA,

> …based on current projections of water demand and supply, the Phoenix AMA will not be at safe-yield in 2025. Although safe-yield is an attainable goal, it is apparent that sufficient progress has not been made toward this goal, nor have the statutory and institutional structures necessary to succeed been fully established…The AMA also lacks the understanding and support by the community for a full range of water management initiatives. (ADWR 1999a: 12-1)

The Phoenix AMA is somewhat unique among the AMAs in that it has significant surface water resources, as well as groundwater reserves and access to CAP water. However, as the AMA's Third Management Plan notes, "Renewable supply reliability is almost exclusively dependent on weather patterns in the watershed which can limit the amount and timing of renewable supplies." (ADWR 1999a: 3-1). Further, multiple sources of water are available only to portions of the

AMA; other areas rely entirely on groundwater, and some of these latter areas already have concerns about adequate supply even under normal climate conditions.

A climate sensitivity analysis conducted by CLIMAS (Carter et al. 2000) sought to explore the potential impacts of drought on water supply and demand by the municipal, agricultural, industrial and riparian sectors of water use. In the study, the AMA's water budget for 2025 was adjusted based on percentage decrease in renewable supply that might be generated by a recurrence of the most intense historic droughts of one-, five-, and 10-year durations. Some of the key findings for the Phoenix AMA are summarized below.

7.2.1. Potential Implications of a One-Year Severe Drought – Phoenix AMA

If a severely dry winter similar to that of 1903-1904 (the driest winter on record) were to recur under the population and demand pressures projected for 2025, a 44 percent decrease in supply and a 6 percent increase in demand would be likely to occur in the Phoenix AMA. The AMA, as has occurred under similar conditions in the recent past, would most likely cope with the situation by drawing down reservoir levels and increasing groundwater pumping. Indeed, the two-year drought of 1998 to 2000 resulted in depletion of one of the primary surface water sources for the AMA, the Salt River Project's Roosevelt Lake Reservoir. By the beginning of winter 2000, the reservoir was at only 17 percent capacity (Central Arizona Project, 2000). Higher energy costs associated with increased pumping and conveyance would likely occur. It is unlikely that, under similar drought conditions, the full cost of coping with reduced supplies would be immediately or directly passed on to consumers. It is also unlikely that stricter conservation measures (such as limiting outdoor watering, car washing, etc.) would be invoked. The Third Management Plan for the Phoenix AMA (ADWR 1999a: 12-6) notes that there is a waning commitment to voluntary conservation on the part of water users, due to users' assumptions that the greater emphasis on the use of renewable supplies decreases the need to conserve. The plan observes that, in this type of context, "Conservation goals need to be reinforced through pricing structures, ordinances, incentives, informed governmental decisions, and public information about the serious long-term nature of water supply limitations in the area." (ADWR 1999a: 12-6). Motivating consumers through the proper combinations of incentives and regulation is pivotal to changing existing water use behavior.

7.2.2. Potential Implications of a Five- or 10-Year Severe Drought – Phoenix AMA

The cumulative impacts of the most severe five- and 10-year droughts recorded in the climate reporting division that encompasses the Phoenix AMA (1900-1904, and 1946-1955, respectively) would likely have significant consequences for water providers and managers in the Phoenix AMA, including water table declines and subsidence. A recurrence of the worst five-year drought in the historical record, combined with demand conditions projected for 2025, would place considerable stress on the AMA's water system. The CLIMAS sensitivity analysis suggests that the shortfall in renewable supplies for meeting business-as-usual demand might range from 47 percent to 67 percent of normal renewable supply levels, averaged over the five-year period. The lower figure reflects continued full delivery of CAP water while the higher figure reflects a total cutoff in CAP supplies for the duration of the drought. A recurrence of the worst 10-year drought in the historical record, combined with 2025 demand projections, could produce shortfalls in renewable supplies ranging from 39 percent to 58 percent, averaged over the 10-year period. Again, the lower percentage reflects continued full availability of CAP water while the higher percentage reflects a complete cutoff of CAP water throughout the drought. While these percentages are somewhat lower than those for the five-year scenario, they are still significant and would likely lead to changes in water management policy and practices. Some of these changes would likely be temporary, such as stringent controls on water consumption. Others might be permanent, such as enhanced infrastructure and increased interlinkage among provider systems.

Particularly in the context of an extended severe drought, the policies most likely to be examined would be existing restrictions on water transfers among right holders and from outside the AMA boundaries, the safe-yield provisions of the Groundwater Code, water availability and delivery policies associated with the Arizona Water Bank and various other recharge projects, and the assured water supply rules. In the recent two-year drought, for example, the Salt River Project, a major provider of water to Phoenix, negotiated a one-time purchase of water from the Central Arizona Water Conservation District (CAWCD) to augment its seriously dwindling supplies (Central Arizona Project 2000). It is worth noting, however, that the principals involved in the negotiation explicitly restricted the arrangement to that single transaction. Also likely to be scrutinized would be the rules of the Arizona Corporation Commission, particularly with regard to current restrictions prohibiting private water companies from passing costs of conservation programs on to customers.

New developments might find it more difficult to obtain a certificate of Assured Water Supply, and those wishing to drill new "exempt" wells might be more tightly regulated, though it is unlikely that ADWR could (or would) completely deny such activity. New incentives would likely be formulated to facilitate the transfer of water from agricultural water right holders to higher-value urban uses, and provisional agreements might be sought with local Indian Tribes to purchase water for the duration of the drought. Conservation measures would likely include increasing incentives for low-water use landscaping and appliances, restructuring and raising of water rates, and bans on certain kinds of non-essential water use. These would be significant changes, for, as noted in the Phoenix AMA's Third Management Plan,

> The undervalued cost of water in most instances, as well as the cost differential between certain renewable sources of water and groundwater, provides little incentive to maximize efficiency or reduce groundwater use. The cost of using groundwater should be commensurate with the value placed on it and should reflect the cost of overdrafting groundwater. (ADWR 1999a: 12-5).

Managers of "turf" facilities such as parks and golf courses would likely face substantially higher water costs, and possibly conservation measures restricting the amount of turf they could irrigate. Likewise, residential areas featuring lush expanses of turf and artificial lakes and streams might be hard pressed to sustain their landscapes and, more importantly, their real estate values. In these cases an extended drought could be expected to prompt efforts to reprioritize water uses. Building codes might be revised to encourage greater water conservation and less emphasis on water-intensive landscapes. It is also likely that riparian areas would come under greater stress due to strong competition for scarce water.

At the individual level, rising water prices and stricter rules might diminish the panache of owning swimming pools and having tropical style landscaping, and result in a greater number homeowners adopting desert landscaping and water-conserving behaviors. In the agricultural arena, severe sustained drought (lasting 10 years or longer) might lead policy makers to institute subsidization programs that would encourage farmers to fallow their fields for the duration of the drought. Mechanisms for municipal water providers to lease or purchase agricultural water rights would likely be pursued as a longer-term strategy to buffer against future drought.

While urban growth has increasingly replaced agriculture in terms of land use within the Phoenix AMA, water experts expect large water settlements involving local Indian tribal lands to be used for agricultural purposes; thus, the AMA does not anticipate that agriculture will completely disappear. It is, however, likely that inordinately dry conditions lasting 10 years or longer would generate substantial changes in the extent and types of farming carried out on tribal and non-tribal agricultural lands within the AMA. Notably, the water sensitivity analysis conducted by the CLIMAS Urban Water team indicates that, even if all agricultural water use were instead dedicated toward meeting municipal and industrial needs, substantial deficits would remain.

The issue of agricultural-to-urban land-use transformation is particularly salient in the Phoenix AMA, for agricultural demand currently comprises 75 percent of total water demand, and is expected to decrease only to 60 percent of total demand by 2025. Although thousands of acres of former farmland are converted to urban uses every year, overall agricultural water use remains relatively steady (ADWR 1999a: 12-1). The impact that urbanization of former agricultural lands will have on water demand is likely to depend not only on the availability of water that is no longer used by crops, but also on the zoning density of new municipal areas. The issue becomes more complex when other and often more immediately salient issues such as commodity prices and government subsidy policies are considered. The question of whether new development should take place on converted farm land, where one existing water use is replaced by another, or on virgin desert land, where new water demands are generated, must also be taken into account (ADWR 1999a: 12-5).

As noted above, the extent that agricultural water allotments could be switched to municipal uses is limited, since agriculture in the AMA is increasingly taking place on Indian lands, and Indian water allotment settlements have typically included explicit restrictions on use and exchange of the water resources involved in the individual settlements. (Checcio and Colby 1993). Adjudication of rights to surface water on the Gila River and its tributaries has been in process since 1979, and several Colorado River tribes are currently litigating for additional water rights to Colorado River water (Hansen 1995). The decisions rendered in these cases are sure to have major impacts on water management in the state, and are likely to be felt strongly in the Phoenix AMA.

Actions are currently being taken to better protect the Phoenix AMA from water shortages in times of drought. As mentioned above, the Arizona Water Banking Authority (AWBA Commission 1998) plans to store as much water as possible over the next 20 years as insurance against drought. Further, the Third Management Plan for the Phoenix AMA reports that 22 full-scale underground storage and groundwater savings recharge facilities have been issued permits in the AMA during the last 10 years. During that time, 564,000 af of water has been stored. Permits have been issued for nearly 700,000 af of additional annual storage capacity, and for 11 pilot recharge facilities (ADWR 1999a: 12-2). Preliminary results of a survey of reservoir capacity indicate that many large water providers intend to expand their reservoir space. It is also possible that existing storage capacity could be expanded through raising dam heights. The heights of Roosevelt and San Carlos Dams have been recently raised for exactly this reason.

As noted earlier, the eight reservoirs serving the Lower Basin (including Lake Powell) have the capacity to store approximately four and a half years of the river's flow, thus providing a considerable buffer against drought. However, since Arizona's CAP allotment has only fourth priority under the Law of the River, the CAP-dependent water systems remain vulnerable to potentially deep, sustained drought. A commonly held view among water managers is that it is highly unlikely that a severe drought would simultaneously affect both the Salt-Verde system and the Colorado watershed. However, the Severe Sustained Drought project demonstrated that just such a severe and widespread drought occurred in the 16th century (Meko et al. 1995). Patterns in the paleo record, dating back 1,000 years, as well as the historical record suggest that it is prudent to bear in mind the possibility of similar climatic shifts in the future.

If such a severe regional drought were to occur under existing and anticipated demand patterns, including the patterns of more senior right holders such as California and Nevada, water linked to Arizona's more junior CAP allocation could diminish or completely cease to flow through the canal. The loss of CAP water availability would certainly challenge water management in the Phoenix AMA, for much of the agriculture in the AMA depends on heavily subsidized CAP water. Suspension of this supply, or loss of subsidies, would drive agricultural water users to shift to groundwater, or to seek other sources.

A large shift to groundwater use under drought stresses would have significant implications for water management as well, for a substantial number of agricultural right holders have water rights that were grandfathered in when the Groundwater Code was enacted in 1980. In addition, substantial groundwater impacts would likely be generated by agriculturalists who have engaged in "in lieu" water transactions whereby they accrue groundwater credits by agreeing to use CAP water instead. If they began to call in their credits, the imbalance between renewable supply and demand would increase substantially, pushing the AMA ever farther from the possibility of achieving safe-yield.

Some tribal allotments would also suffer, in cases where the new water rights have involved CAP water. At the same time, retirement of agricultural lands, even if just for the duration of the drought, would create its own problems: unsightly landscapes, greater air pollution, loss of top soil through increased wind and water erosion, and other impacts. While some of these lands might be transformed into housing or industrial/commercial developments, this would not occur on all retired lands. Large parcels of Indian agricultural lands within and adjacent to the AMA, for example, would probably not be transformed to such uses.

Severe sustained drought such as that experienced in the 1950s, not to mention the even more widespread and intense drought of the 1500s, could be expected to exacerbate subsidence problems in areas where cones of depression deepen and widen. This would likely occur, though to a lesser degree, even with intensified conservation programs. Further, water table declines would undoubtedly necessitate increased electricity demand for pumping water at greater depths, at precisely the same time that electrical generation was intensifying in other sectors, such as commercial and residential cooling. The recent power issues in California provide a glimpse of what a worst-case scenario might be in the greater Phoenix metropolitan area. Pressures to import water, via the CAP canal or other means, to the AMA would intensify, and the rural-urban contests of the 1980s over whether the cities have a right to destroy rural community viability by diverting water supplies (Oggins and Ingram 1990), would be replayed at an even higher pitch.

7.3. Potential Climate Impacts on Institutions – Tucson Active Management Area

In contrast to the multitude of water sources utilized within the Phoenix AMA, water providers in the Tucson AMA have, until this year, been dependent on groundwater as their source of a reliable water supply. In fact, Tucson was, for a number of years, the largest city in the nation to rely exclusively on groundwater.

Before the completion of the CAP canal to Tucson in 1992, the specter of severe sustained drought hovered over the AMA's already unsustainable water use patterns. With the addition of CAP supplies and some easing of Tucson voters' resistance to receiving CAP water in their homes, the AMA will no longer rely solely on groundwater to meet its demand. Recently, Tucson Water began phasing in delivery of a "blend" of recharged CAP water and local groundwater to the 78 percent of Tucson AMA residents who constitute its customer base. Recharging CAP water into the ground remains the primary management tool in the Tucson AMA, even though water managers concur that few acceptable recharge sites exist that are capable of accommodating the large allotment of CAP water the AMA contracts for each year (the Tucson AMA's annual CAP allotment is 215,333 af).

The 1995 population of the AMA was some 768,000; by 2025, ADWR projections indicate that the population will increase to some 1,266,500 people (ADWR 1999b). Even at existing population levels, groundwater reserves are being used at approximately twice the rate at which they are replaced through natural and incidental recharge (ADWR 1999b: 12-1). Groundwater levels have fallen as much as 200 feet in the AMA since 1940. This has resulted in the loss of most surface water flow (never large to begin with) and riparian habitat in the AMA. The Tucson AMA office of the Department of Water Resources estimates that approximately 12 maf of groundwater exist at or above the 1,000-foot water table level. This is the lowest level of water-table decline allowed under assured water supply provisions. At current depletion rates, this amount could be consumed within approximately 50 years. If the present rate of population growth continues as expected until 2025, water demands are projected to increase by 29 percent. Based on anticipated levels of groundwater depletion, it is expected that lands overlying the Tucson Central Well Field will experience subsidence of up to 12 feet by 2024.

As in the Phoenix AMA, assuming continued exclusive use of groundwater, intensified groundwater overdraft would lead to diminished well yields, increased pumping costs, and possible deterioration of water quality. The Tucson AMA's calculations, and the CLIMAS sensitivity analysis (Carter et al. 2000), suggest that the impacts of increased demand would be significantly buffered by supplanting much of the fossil groundwater pumping with delivery of CAP water.

7.3.1. Potential Implications of a One-Year Drought – Tucson AMA

If the driest winter on record, from 1903-04, were to be repeated under 2025 demand conditions in the Tucson AMA, the projected deficit in renewable water resources would double from 15 percent (calculated using average annual rainfall), to 34 percent. This figure reflects the combination of a 29 percent decrease in renewable supplies and a 3 percent increase in demand. Unlike the Phoenix AMA, Tucson does not have large reservoir capacity; in fact, supply problems tend to occur regularly, in spring, just before the monsoon season begins (see, e.g., Arizona Daily Star 1999). As has already been demonstrated in recent pre-monsoon contexts, severe drought would heavily tax pumping and storage capacity, resulting in lower water pressure and perhaps even disruptions of service. Tucson Water is among the providers having contingency plans that include enforceable water conservation rules; however, overall the Tucson AMA may have less short-term conservation potential than Phoenix, in part due to the fact that the AMA has already been successful in reducing daily water use rates. The Tucson AMA estimates usage to be in the neighborhood of 155,500 af per year, based on 1995 calculations. This is an increase of approximately 17 percent from 1990, reflecting a decline in the rate of demand growth relative to the rate of population growth. The decline is most notable in the municipal sector, where reductions in outdoor water use have made a substantial impact. For example, new developments are subject to restrictions on the amount of water-intensive landscaping that may be installed, and public landscapes, such as municipal golf courses, parks, and roadway plantings, have already been modified to reduce water use. Thus, while outdoor watering would certainly be restricted or perhaps banned, fewer readily available means to reduce overall demand exist in the Tucson AMA than in the Phoenix AMA.

7.3.2. Potential Implications of a Severe Five- or 10-Year Drought –Tucson AMA

If a repeat of the driest five-year period, which lasted from 1900-1904, were to recur at 2025 population levels, the cumulative impact would be an additional 241,993 af of groundwater pumping; non-renewable water supplies would be required to meet 28 percent of total demand, rather than the 15 percent projected in the Tucson AMA's Third Management Plan (ADWR 1999b). The same types of conservation initiatives as suggested for Phoenix could—and probably would—be enacted in the Tucson AMA. However, overall, the Tucson AMA might actually experience less of an impact from a drought of this duration, once the short-term pumping capacity problem is resolved, since groundwater supplies are sufficient to meet increased demand within this time frame.

A drought beginning in 2025 that extended for a 10-year period and included conditions similar to the deepest 10-year drought in the historical record for the local area, which occurred from 1947 through 1956, would result in 380,687 af of additional groundwater pumping. While the aquifer could support such conditions for a time, it is highly likely that land subsidence and reduced well production would result in some areas of the AMA. The Tucson AMA may also have less potential to shift water consumption away from agricultural uses and toward meeting municipal demands, since the role of agriculture in the AMA has already been steadily decreasing, a trend which is expected to continue into the future: in 1995, agriculture accounted for 42 percent of total water demand; by 2025, this proportion is expected to fall to 21 percent (ADWR 1999b: 11-21).

As in the Phoenix AMA, severe sustained drought of 10 years or more duration would likely encourage providers to negotiate with farmers on leasing water. The amount of potentially available water would be considerable, especially if grandfathered and in-lieu supplies were taken into account. Such arrangements would entail construction of new infrastructure to get the water from source to destination. Also, as in the case of the Phoenix AMA, it is likely that local providers would attempt to change the policy structure to facilitate inter-basin water transfers. This water could be "wheeled" down the CAP canal, and delivered to end users through the systems of the providers linked to the canal. Those providers not linked either to one of these systems, or to the CAP canal itself, would not benefit from these arrangements, and would likely have little option except to intensify pumping and encourage greater conservation among their customers. Given current ACC restrictions against passing the cost of conservation programs on to customers through rate changes, it is unclear how the scenarios for these providers would play out over the long run. In extreme cases, emergency deliveries of water via tanker truck could be initiated, although these measures could only be sustained under emergency conditions.

Ever since the CAP canal reached Tucson in 1992, the pressure to utilize alternative renewable supplies has been intense within the AMA. At the same time, a turbulent history of resistance to direct use has unfolded. In November 1992 the city's largest water provider, Tucson Water, began delivering CAP water to about half of its customers. However, the different chemical composition of the water proved to be incompatible with the pipes of many older homes in the delivery area. Customers were confronted with brown, foul-smelling water that in some cases caused extensive damage, including burst pipes and corroded appliances. After nearly two years, the city council voted to terminate CAP delivery and return to strictly using groundwater. In 1995 city voters passed an initiative that prohibited the city from delivering CAP water directly to homes. The initiative was strengthened by voters in a subsequent election. However, in November 1999, voters defeated an initiative that would have strengthened the initiative's provisions even further. In the wake of this election, the City of Tucson has unrolled plans, including the delivery of blended water noted above, to fully utilize its 138,920 af allotment (ADWR 1999b: 12-5). These steps will go a long way to assuring that the total allotment of 215,333 af will begin being used in ways that, over the long term, will benefit the AMA. It remains to be seen, however, how the new recharge/recovery and delivery policies and procedures will buffer the impacts of severe sustained drought across the AMA. Given current infrastructural and institutional limitations, it is likely that outlying areas of the AMA that are rapidly growing and far from the CAP canal would be most affected by drought stresses.

As discussed with regard to the Phoenix AMA, the water systems in the Tucson AMA are very sensitive to loss of CAP supplies, including reductions or cutoffs prompted by severe sustained drought conditions. Since today the Tucson AMA does not depend, to any significant extent, on non-CAP surface water to meet demand, the effects of drought on groundwater supplies are less visible; however, the long-term consequences of decreased winter precipitation for maintaining safe-yield are considerable. While preliminary results of a survey carried out by the CLIMAS Urban Water team indicate that water providers see themselves as fairly insulated from climate impacts, severe sustained drought could pose significant challenges in terms of increased energy costs, the need to find ways to impel or persuade customers to decrease their water use, and risk of land subsidence.

Interestingly, under normal (i.e., non-drought) climatic conditions, overdraft could be eliminated if all available CAP water and effluent were used efficiently, instead of groundwater (ADWR 1999b: 12-1). The Tucson AMA water budget for 2025 includes usage of 177,900 af of Tucson's allotment of CAP water, thus reducing reliance on mined groundwater from 70 percent (in 1995) to 15 percent. By contrast, as noted earlier in this working paper, the Phoenix AMA water budget for 2025 shows a continued rise in overdraft. Other measures, such as greater recharge of effluent, are now becoming more widely used in both AMAs, and also contribute to reducing overdraft conditions.

The shift to CAP water is expected to double the renewable water supply in the Tucson AMA during the next 25 years. Over the same time period, the population of the Tucson AMA is projected to increase by 40 percent. This rate of population growth is similar to Phoenix's 43 percent growth rate, although the actual additional numbers are much smaller: 498,500 additional people in Tucson AMA, as opposed to 1,932,947 more residents in Phoenix.

Under normal conditions, as noted above, the Tucson AMA's increased reliance on CAP supplies will clearly ease the overdraft situation. However, a long-term, widespread drought would have impacts similar to those detailed above for the Phoenix AMA. The most readily available strategy, apart from increasing the stringency of conservation rules, would be to develop policies and pricing mechanisms that would encourage, or perhaps even require, the transfer of agricultural water and/or water rights to urban water providers and users.

Many of the same mechanisms available to the Phoenix AMA for coping with severe sustained droughts, under conditions of a significantly higher demand, would be similar for the Tucson AMA. However, a few unique characteristics of the Tucson AMA could have bearing on community acceptance of policy changes. Water users in the Tucson AMA have a rather long history of controversy over water issues. Distrust of professional water managers and providers remains high, and an extended severe drought would surely bring longstanding issues back into the foreground. Longtime local residents recall events such as the ouster of the mayor and council in the 1970s in response to an attempted water rate hike. Further, the controversy over direct delivery of CAP water led to the formation of several citizens' groups focusing on water supply and demand issues. While public discourse on these issues is currently muted, direct delivery of CAP water remains a point of contention. Much of this latent resistance may be attributed to the fact that Tucson has a particularly visible activist community that is concerned with long-term sustainability issues, including greater water conservation through use of residential gray water and effluent and low water use landscaping. Through their efforts, as well as through the influence of early adoption of desert landscapes by homeowners in some of the wealthier areas of the city, xeriscaping is now common throughout the community.

Tucson residents, representing a range of environmental and political positions, regularly question the wisdom of relying on CAP supplies. Arguments center on one or both of two issues: there is no guarantee that CAP supplies are secure; and use of Colorado River water has already severely damaged the once-thriving Colorado River Delta and Gulf of California ecosystems. Although generalizing about community attitudes is risky at the best of times, analysis of events and discourses suggests that broadly based efforts to resolve the community's concerns in a manner that fairly distributes the costs and benefits of water use among the various sectors, including ecosystem demands, could go a long way toward averting the worst impacts of severe sustained drought.

Such efforts, however, cannot be restricted solely to a single AMA. Among the issues that must also be addressed are interjurisdictional barriers, including lack of a comprehensive vision and of trust between individual water interest groups. This was cited as a significant problem in the Tucson AMA's Third Management Plan, for example (ADWR 1999b). The lack of strong regulation over either surface or groundwater outside AMA boundaries can pose problems as well, particularly given the current growth trends in areas adjacent but external to the AMA boundaries. Likewise, numerous questions remain with regard to how water would be moved from where it exists as "wet water" to where it is needed. In some cases, the issues are institutional in nature; for example, it is unclear what rules would be involved (or required) to wheel non-CAP water down the CAP canal. Related to this is the question of what sorts of conditions would be considered sufficiently dire to effect a lifting of the restriction on interbasin water transfers. Further, in some situations, lack of infrastructure continues to pose a considerable barrier to moving water from one place to another. In this case, the unanswered question revolves around what sorts of measures would be required to address this shortcoming. Whose needs could be satisfied through expensive infrastructure development, and whose would be addressed (perhaps through trucked-in water) only during extreme emergency? The lack of a state-level drought contingency plan contributes to the high level of uncertainty about how drought impacts would—or should—be managed.

Lack of effective communication to the public regarding the nature of the state's water-related issues constitutes a further problem. Visible threats to water supplies, such as a severe, long-term drought, would likely spur the public into being more receptive toward conservation measures. However, even the worst decadal drought in the historical record, that of the 1950s, included years when precipitation was relatively close to normal. Maintaining public commitment to stringent conservation measures would surely be difficult during those times when short-term weather conditions contradict longer-term drought assessments. An additional challenge to sustaining conservation behavior arises with regard to the lag time between the onset and conclusion of drought conditions and the environmental impacts of the drought, for drought impacts typically lag behind onset of a climatological drought, and persist after the climatological drought has abated. Convincing water users that they must severely curtail water use when precipitation is communicated as being at (or above) normal is certain to become increasingly difficult. The challenge for water regulators and for the climate forecasting community is to develop effective, persuasive narratives about the relationships between long-term and short-term conditions and processes to stakeholders and the general public.

8. Conclusions

Arizona has a reasonably well developed structure of policies and institutions for governing water management within the central portion of the state. Overall, this web of regulations provides a basis for balancing natural systems of climate and ecology with human factors of rapid population growth and increasing water demand. However, the institutional foundation in the state is based on a relatively narrow conceptualization of climate variability, and thus is a source of potentially serious constraint to effective water management in times of climatic stress. Some of the existing institutions and policies, especially those addressing water rights, water storage and recovery, interstate and intrastate water marketing, water transfer, and consumer pricing, need to be broadened in scope and authority to manage water resources effectively under conditions of severe stress.

The state needs to develop a comprehensive drought contingency plan, one that recognizes the potential for deep, sustained drought of at least the magnitude of the 1950s decade-long dry period. This plan should be statewide, and should place a special emphasis on balancing "business as usual" demands in receiving regions with equity issues in the source regions from which supplemental water would be acquired. Also needed is a focused public education effort to bring consumers as well as water managers up to speed on the implications of climate variability. Greater communication with the public is likewise needed with regard to existing and potential weaknesses in water institutions and physical systems with regard to coping with the impacts of multiple stresses (climate, demand growth, depletion of supplies, disparities between where water is available and where it is needed, and other such stressors).

The existing institutional framework for water management in the AMAs has to date succeeded reasonably well in buffering residents from the vicissitudes of climate and hydrology. For the future, however, competition over water is very likely to escalate, brought on by increased demand associated with rapid urban growth. Pressures to allocate water, for example, to instream and ecosystem uses, Native American water rights, and federal reserved water rights must also be considered. A comprehensive review of policy and decision making processes, one which takes climate variability into account, is essential to planning for and responding to stresses on water resources. Development of mechanisms to assure effective dissemination and use of climate forecasts and other types of climate information, including efforts currently underway within CLIMAS and within NOAA more generally hold promise for contributing to decision making processes. A subsequent CLIMAS analysis will address in more detail potential changes to institutional arrangements, together with more comprehensive use of climate information and forecasts, that could enhance resilience and coping capacity among water managers and decision makers.

Endnotes

[1] Active Management Areas (AMAs) were designated by the Arizona Department of Water Resources in 1980 as part of the Groundwater Management Act to regulate groundwater withdrawals in areas of the state experiencing rapid declines in water table levels.

[2] Due to the Colorado River's potential as a flash point for interstate conflicts, several in-depth analyses have been conducted on this highly developed source of water (see, e.g., The Powell Consortium 1995; Pontius 1997; Arizona Water Banking Authority 1998).

[3] Feb. 3, 1944, 59 Stat. 1219, T.S. No. 994, 3 U.N.T.S. 313 (effective Nov. 8, 1945)

[4] Institutional changes included (a) adoption of a "reverse equalization rule" that would maintain similar water levels in both Lake Mead and Lake Powell (current rules call for more water to be stored in Mead, even if at the expense of Powell); (b) temporarily ignoring the delivery obligation of the Upper Basin to the Lower basin, so as to equalize the burden of the drought; (c) revising reservoir operating rules to allow storage of water in headwater reservoirs for as long as possible, thus minimizing losses from evaporation; and (d) allowing interstate water banking and marketing to the extent that no harm would come to the other states from the transactions.

[5] Ironically, pumping by the Fort Huachua Military Reservation may be protected under federal reserve rights regulations, just as the San Pedro National Conservation Area would be. Other local and national environmental groups such as The Southwest Center for Biological Diversity, The Nature Conservancy, and Friends of the San Pedro are also involved in efforts to preserve this remnant vestige of riparian habitat in the American Southwest.

[6] Recent estimates indicate that newly imposed federal water quality rules will cost Nogales, Arizona an additional $3 million per year to meet the higher standards (Holub 2001).

[7] The maximum amount that MWD would have to forego, however, would be 500,000 af.

[8] Again, the maximum required reduction expected of MWD would be capped at 500,000 af per year. The obligation to reduce use would occur whenever the earliest of one of the following occurs: (a) the total amount foregone to benefit Arizona reaches 1 maf, (b) the Secretary makes a flood control release during any year in the 15-year interim period, or (c) MWD and ADWR agree on an alterative shortage reparation that explicitly terminates MWD's obligation.

[9] It is worth noting here that the new 30-year period for operational weather and climate forecasting reflects warmer temperatures than the temperatures used to determine climate averages at the time the Groundwater Code was written. Thus, assumptions used in developing water supply and demand estimates may be based on data that underestimate critical parameters such as evapotranspiration rates.

[10] Some, including former Secretary of the Interior and former governor of Arizona, Bruce Babbitt, have called for an AMA to be created in the Sierra Vista-area groundwater basin; local residents remain strongly opposed to this institutional change.

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