Managing for sustainability in an arid climate: lessons learned from 20 years of groundwater management in Arizona, USA

Katharine L. Jacobs · James M. Holway

Abstract Substantial progress has been made within central Arizona in moving towards a more sustainable water future, particularly in transitioning the urban demand from a primarily nonrenewable groundwater-based supply[1] to increasing dependence on the Colorado River, Salt River and effluent. Management efforts include a wide range of regulatory and voluntary programs which have had mixed success. The Department of Water Resources has learned a number of key lessons throughout the years, and this paper attempts to establish the water management context and identify those lessons for the benefit of others who may want to evaluate alternative approaches to groundwater management. Themes to be discussed include evaluating water management approaches in a public policy context, the effectiveness of alternative management approaches and the relative merits of regulatory vs. nonregulatory efforts, and the importance of high-quality data in making management decisions.

Résumé De nets progrès ont été faits dans le centre de l'Arizona pour aller vers une gestion plus durable de l'eau, en particulier en reportant la demande urbaine d'une alimentation basée sur l'eau souterraine primitivement non renouvelable sur une dépendance croissante des rivières Colorado et Salt et des effluents. Les efforts de gestion portent sur une large gamme de programmes de réglementation et d'actions volontaires qui ont réussi. Le Département des Ressources en Eau a appris un certain nombre de leçons clés au cours des années; cet article tente d'établir le contexte de gestion de l'eau et d'identifier ces leçons pour le bénéfice de ceux qui cherchent à évaluer des approches alternatives de gestion de l'eau souterraine. Les thèmes à discuter portent sur l'évaluation des approches de gestion de l'eau dans un contexte de politique publique, l'efficacité d'approches alternatives de gestion et les mérites relatifs d'efforts de réglementation par rapport à une absence de réglementation, et l'importance de données de haute qualité dans la prise de décisions de gestion.

Resumen Se ha logrado un progreso substancial en el centro de Arizona para conseguir un futuro más sustentable del agua, particularmente al trasladar la demanda urbana desde un suministro basado principalmente en aguas subterráneas no renovables hacia una mayor dependencia de las aguas superficiales de los ríos Colorado y Salado y de los efluentes de aguas depuradas. Los esfuerzos de gestión incluyen un amplio rango de programas legales y voluntarios que han tenido un éxito combinado. El Departamento de Recursos Hídricos ha aprendido diversas lecciones clave a lo largo de los años, y este artículo intenta establecer el contexto de la gestión del agua e identificar lo averiguado para beneficio de terceros que quieran evaluar enfoques alternativos para gestionar las aguas subterráneas. Entre los temas tratados, destaca la evaluación de los enfoques de gestión del agua en un contexto político público, la efectividad de enfoques alternativos de gestión y los méritos relativos de los esfuerzos regulativos y no regulativos, y la importancia de los datos de alta calidad para la toma de decisiones de gestión.

Keywords Groundwater management · Conjunctive management · Arizona water management · Water policy · Water conservation · Sustainability

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[1] Groundwater use in many areas of Arizona greatly exceeds the natural replenishment of the aquifer, so although a portion of the groundwater use is renewable, the majority is not.

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Introduction

More than 20 years ago, then-governor Bruce Babbitt signed one of the most important pieces of legislation in Arizona's history—the Groundwater Management Act (GMA). The 1980 GMA resolved legal disputes over rights to groundwater, established programs to reduce groundwater overdraft and the resulting water level declines, supported completion of a 330-mile-long canal to bring Colorado River water to central and southern Arizona (the Central Arizona Project), and created the Arizona Department of Water Resources and a faculty associate at Arizona State University.[2] The GMA set the framework for Arizona's water management, but focused most of the regulatory effort on parts of the state called active management areas (AMAs), which were experiencing particularly acute groundwater overdraft problems. Two decades later, it is clear that achieving the goals of the GMA is possible, but there are still obstacles to overcome.

The challenges to sustainable water use are numerous. By 2025, the year that key management goals of the GMA are to be achieved, the projected population of the state will exceed 6.0 million, within the AMAs and 1.8 million in the rest of the state. This is a 280% population increase from the 2.1 million living within AMAs when the 1980 GMA was adopted. Ensuring that there are adequate resources for all of those people, as well as for golf courses, agriculture, metal mining, and other industry will require a lasting commitment to responsible water management, considerable investments in conservation, and securing and using new renewable supplies.

Arizona's water supplies must also support several Indian Nations (Native American tribes are given nation status within the United States)[3] whose legal water rights are currently in the process of being quantified and negotiated; the conclusions of these water rights settlement negotiations will have a very significant impact on the water budget for the state. In addition to concerns about water availability for human use, protecting Arizona's remaining flowing rivers, riparian habitat and endangered species will also require water. Further challenges come from the water needs of others in the Colorado River basin who seek additional water supplies,[4] plans to protect endangered fish species in the mainstem of the Colorado, and increasing demand in Arizona's rural areas that lack renewable supplies. Changing climatic conditions will likely also affect water supply and energy availability from the Colorado River and within the state in the future.

[2] Additional information on the Department of Water Resources and its programs is available on the web site at: http://www.water.az.gov.

[3] Within the State of Arizona, there are 20 Native American (or Indian) reservations of varying size.

[4] Particularly Nevada, California and Mexico.

Hydrology of Arizona

Climate

The climate of Arizona varies dramatically with elevation, but is generally very dry and warm. Average annual temperatures range from 57–89°F; daytime summer temperatures are commonly above 100°F in the major developed areas. Average annual precipitation ranges from less than 3 in in the lowest deserts in the southwestern portion of the state to more than 38 in at Hawley Lake in the White Mountains. Annual precipitation averages 7 in per year in the Phoenix and ten in per year in the Tucson metropolitan areas. Rainfall is seasonal, occurring in the winter months from frontal storms and in the summer from thunderstorm or "monsoon" activity.

Geology

The State of Arizona has three main physiographic provinces: the Colorado Plateau to the north, the Central Highlands, and the Basin and Range province to the south (Fig. 1). The Colorado Plateau province is characterized by sedimentary rocks that have eroded into numerous canyons and plateaus. It contains several large but not especially productive groundwater basins, though most of the water uses in the area are supported by groundwater. The Little Colorado River and the Colorado River itself are the main surface water drainages in this province. The Central Highland area is characterized by a relatively narrow band of rugged mountains and generally high elevations, and a predominance of hardrock substrate. Groundwater availability is limited; the major watersheds, all tributary to the Gila River, supply water to the Phoenix area. The Basin and Range province is characterized by parallel ranges of uplifted mountains, separated by broad alluvial valleys, generally containing substantial groundwater supplies in aquifers thousands of feet deep with millions of acre-feet in storage (Arizona Department of Water Resources 1994). Most of the surface water is tributary to the Gila River. Four of the five AMAs are within the Basin and Range province; the Prescott AMA is in the Central Highland area.

Water Supply

Groundwater supplies nearly half the total annual demand of more than 7 million acre-feet in the state, with surface water, including diversions from the Colorado River, representing the other half. Approximately 70% of the water demand in the state is agricultural, though this percentage is expected to continue to decline over time. Groundwater overdraft in central Arizona has created significant problems such as increased well drilling and pumping costs, water quality problems and subsidence. In some areas of severe groundwater depletion (generally in areas with greater than 100 ft of groundwater declines) the earth's surface has subsided, causing cracks or fissures that have damaged roads, building foundations and other structures.

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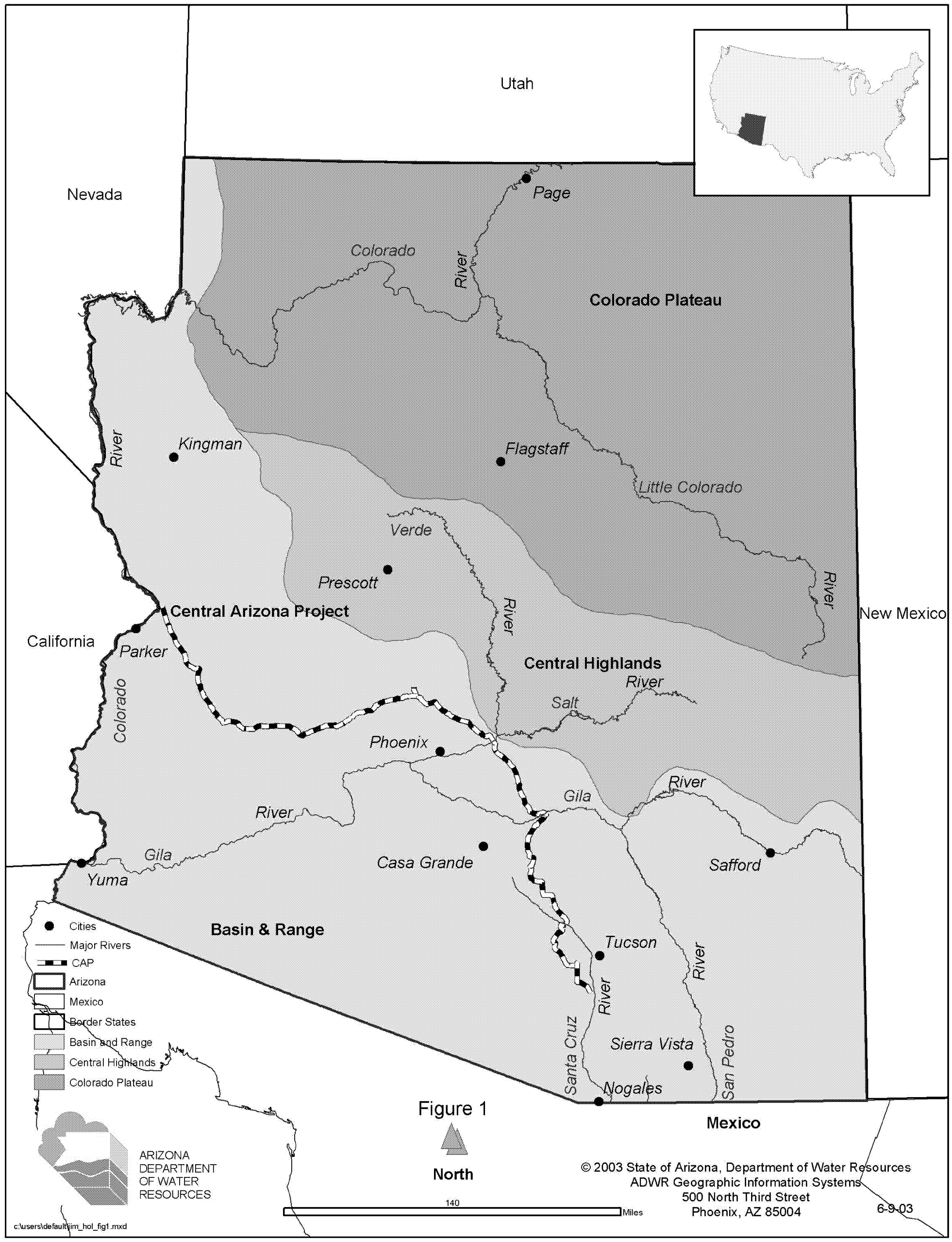

Fig. 1 Water resource map of Arizona

The Salt River Project[5] (SRP) has been delivering water to central Phoenix since 1903. It was the first multipurpose federal reclamation project, and currently delivers more than 1 million acre-feet of water to its water service area of 240,000 acres. SRP operates an electric utility as well as 6 dams, 260 wells, 131 miles of canals and 2 major recharge facilities.

The Central Arizona Project[6] (CAP) is the most significant addition to the State's renewable water supply system. The CAP is designed to bring 1.415 million acre-feet (MAF) of Arizona's 2.8 MAF Colorado River allocation into central and southern Arizona.[7] Deliveries to Phoenix were started in 1985, and to the Tucson area in 1992. The CAP system is interconnected with the SRP system, providing maximum flexibility for conjunctive management. However, the CAP has the lowest priority of the Lower Colorado allocations, and must curtail its usage first in a shortage year.

[5] Additional information available on the Salt River Project web site at: http://www.srpnet.com.

[6] Additional information available on the Central Arizona Project and the Central Arizona Water Conservation District, which operates the canal, at: http://www.cap-az.com.

[7] Under the Colorado Compact and subsequent international treaties, 7.5 MAF are allocated to the four Upper Basin states of Colorado, Utah, Wyoming and New Mexico, 7.5 MAF to the three Lower Basin states of Arizona (2.8 MAF), Nevada (0.3 MAF) and California (4.4 MAF), and 1.5 MAF to Mexico.

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Although use of municipal effluent does not currently provide a large percentage of the total water demand in urban areas, substantial investments have been made in advanced treatment and delivery systems to use reclaimed water for turf irrigation and aquifer recharge in all of the AMAs. Effluent availability increases with urban development, and its importance in meeting water needs will expand in the future. Effluent may ultimately become part of the potable supply in some areas.

Water Management in Arizona

Safe-yield

The statutory management goal for four of the five AMAs is safe-yield. "Safe-yield" means 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 annual amount of natural and artificial recharge in the active management area (A.R.S. § 45–561.12). The safe-yield goal, as defined in the GMA, does not account for potentially diminished surface water flows or localized areas of depletion. Thus safe-yield is not necessarily synonymous with sustainability, defined by the Brundtland Commission (1987) as the ability to "meet the needs of the present without compromising the ability of future generations to meet their own needs." Awareness of the impacts of subsidence on infrastructure, particularly within urban areas of Arizona, has caused concern about the need to manage groundwater levels rather than only focusing on a basin-wide water budget based balancing of groundwater pumping and recharge.

History and Basic Structure of Arizona's Water Management Programs

Arizonans have long noted the need for managing the state's groundwater resources. Water levels have been declining in some areas since the 1940s. The 1948 Critical Area Groundwater Code designated overdraft areas but was ineffective in controlling the ongoing overdraft. By the late 1970s there was growing recognition of the impacts of water level declines and resulting land subsidence in some areas. The U.S. Secretary of the Interior also declared that the long-desired Central Arizona Project would not be authorized unless Arizona took steps to reduce groundwater overdraft. A final catalyst to implementing an effective groundwater law was a lawsuit filed by an agricultural irrigator to prevent the cities and mines from transporting groundwater. These factors led to the adoption of the 1980 Groundwater Management Act (GMA), following a period of intense negotiation among a small group of stakeholders (Connall 1982).

The GMA focused almost exclusively on groundwater and did not affect the pre-existing surface water management code, which remains a separate body of law, despite the hydrologic connections between surface water and groundwater. Generally speaking, surface water in Arizona is allocated based on prior appropriation, "first in time first in right." Groundwater, on the other hand, is subject to beneficial use requirements and additional limitations within AMAs. Based on recent court rulings[8], water pumped from the saturated younger alluvium hydrologically connected to a stream would be considered surface water. Additionally, for wells near a stream, if the cone of depression around the well intercepts the saturated younger alluvium, then the intercepted water captured by the well would be surface water. The significance of this classification is that a senior surface water right holder could theoretically restrict a junior pumper from capturing the surface water. Any water pumped from the ground outside of these areas, whether or not the water would have eventually discharged to the stream, is considered groundwater and is not subject to the surface water laws (Leshy and Belanger 1988).

Although there are some technical or financial assistance and planning-based water management programs within the AMAs, the GMA uses a primarily regulatory approach to managing groundwater supplies. The three primary goals of the GMA are (1) to control the severe overdraft currently occurring in many parts of the state, (2) to provide a means to allocate the state's limited groundwater resources to most effectively meet the changing needs of the state, and (3) to augment Arizona's groundwater through water supply development. To accomplish these goals, the GMA set up a comprehensive management framework and established the Arizona Department of Water Resources (ADWR) to administer the GMA's provisions.

The GMA established three levels of water management to respond to different groundwater conditions. The statewide provisions are relatively limited, focusing on licensing of well drillers, well registration, notifications of supply adequacy for new residential developments and prohibitions on transportation of groundwater between most sub-basins in the state.[9] The next level of management applies to Irrigation Non-Expansion Areas (INAs), where no new land can be brought into agricultural production, but there are no limits on nonirrigation uses of water. The most extensive management provisions are applied to active management areas (AMAs) where groundwater overdraft was most severe.

The boundaries of AMAs and INAs (Fig. 2) are generally defined by groundwater basins and sub-basins rather than by the political lines of cities, towns or counties. The groundwater code created four AMAs—Phoenix, Pinal, Prescott, and Tucson. A fifth AMA, the Santa Cruz AMA, was formed from a portion of the

[8] See The Supreme Court of the State of Arizona (2000).

[9] The limitations on groundwater transfers resulted from efforts by cities within the AMAs to buy "water ranches" in rural Arizona during the 1980s. The rural areas were concerned that water transfers would limit their economic future, and the legislature passed the Groundwater Transportation Act in 1991. This Act, and subsequent legislation in 1993, prohibits any transfer of groundwater across groundwater basin boundaries that is not expressly grandfathered within the legislation.

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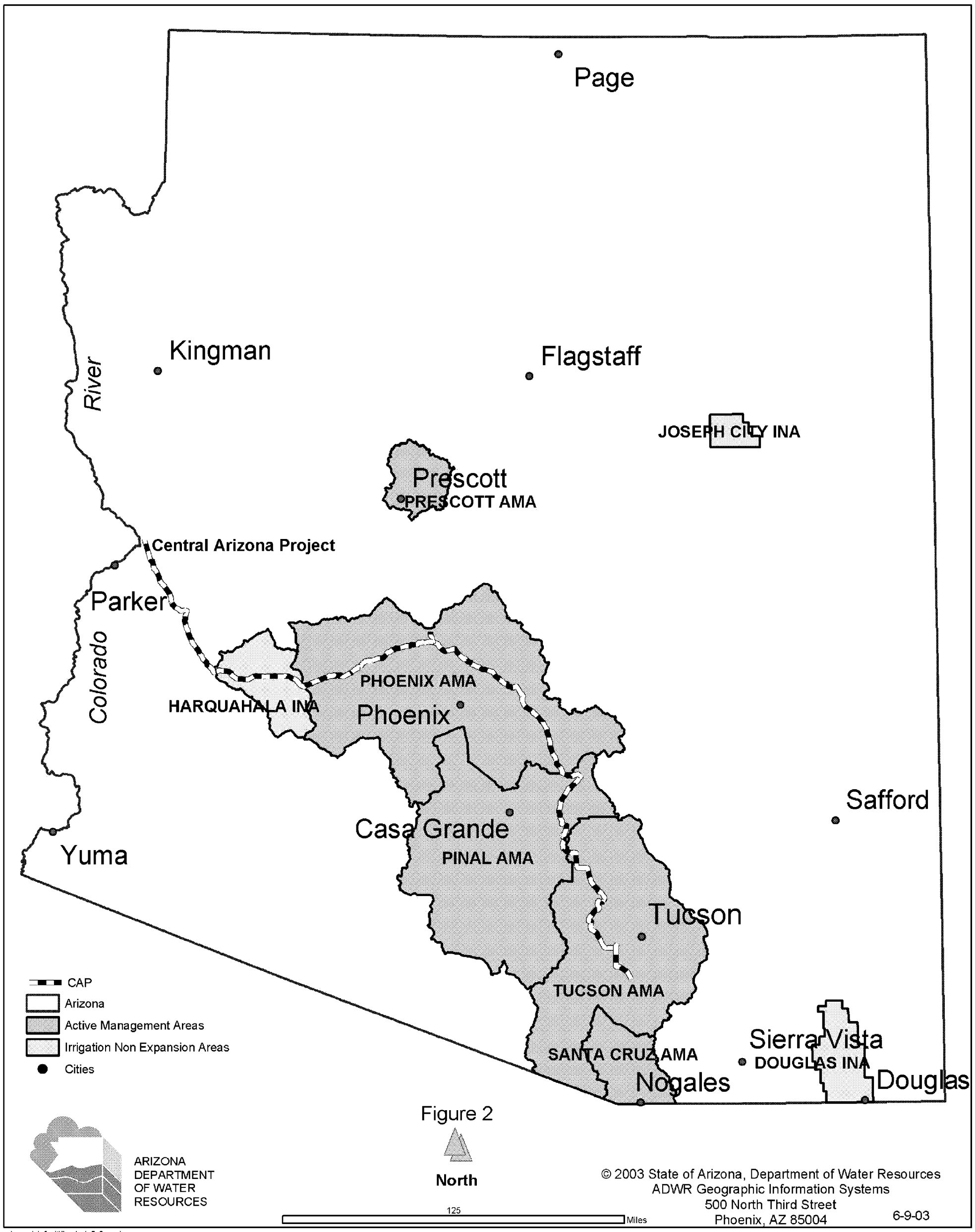

Fig. 2 Denotes active management areas and irrigation non-expansion areas

Tucson AMA in 1994. INAs were established in rural farming areas where the groundwater overdraft problem is less severe. Two INAs, Douglas and Joseph City, were created by the groundwater code; ADWR established the Harquahala INA in 1982. New AMAs and INAs can be designated by ADWR if necessary to protect the water supply or on the basis of an election held by local residents of an area.

The AMAs include over 80% of Arizona's population, over 50% of total water use in the state and 70% of the state's groundwater overdraft, but only 23% of the land area. Within the AMAs, total demand in 1998 was 3,718,600 acre-feet, of which 53% was used for agriculture. Overdraft in 1998 was estimated at 627,000 acre-feet. In the Phoenix, Prescott and Tucson AMAs, which include the large urban areas of the state, the primary management goal is safe-yield by the year 2025. In the Santa Cruz AMA, where significant international, riparian and groundwater/surface water issues exist, the goal is to maintain safe-yield and prevent local water tables from experiencing long-term declines. In the Pinal AMA, where a predominantly agricultural economy exists, the goal is to allow the development of nonirrigation water uses, extend the life of the agricultural economy for as long as feasible, and preserve water supplies for future nonagricultural uses.

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Arizona's Active Management Area Groundwater Management Programs

Arizona's groundwater management programs[10] focus on four different areas: the framework and structure of water rights, demand management programs, supply side programs, and water management planning and assistance. Key aspects of these programs are described below, and followed by a section briefly outlining how these programs are implemented.

Framework and structure of water rights and responsibilities in AMAs

1. A system of rights and permits grants the authority to withdraw groundwater, and provides a mechanism to protect most groundwater users that were in place prior to 1980 through grandfathered rights. New groundwater uses are permissible, but limited.[11]
2. Well permits and well impact analysis are required prior to drilling large wells.
3. Water pumped from all large wells (35 gallons per minute or larger) must be metered/measured and reported. Well owners must submit annual pumpage reports and pay a small withdrawal fee ($2–$3 acre-foot). The reports may be audited to ensure water-user compliance with the provisions of the groundwater code and management plans. Penalties may be assessed for noncompliance.

Demand side management programs in AMAs

1. No new agricultural irrigation is allowed within AMAs. This limitation ties all farming activities to acreage that was irrigated prior to 1980.
2. Mandatory conservation requirements are set for all large users. Agricultural groundwater-rights holders with greater than 10 acres of land are given an annual allotment based on historic crops grown and an assumption of 80% irrigation efficiency. Municipal water use is controlled through reductions in the average annual gallons per capita per day usage of all water companies serving more than 250 acre-feet. Industrial[12] users over 10 acre-feet are given allotments based on the use of the latest commercially available conservation technology. Alternative conservation programs based on use of approved best management practices are available for both agricultural and municipal water rights holders.

Supply-side management programs in AMAs

1. Demonstration of an assured water supply is required prior to platting all new subdivisions. This provision requires that all new subdivisions demonstrate a 100-year supply of water, primarily from renewable water supplies, before a plat can be approved. This program has forced major investments in the transition from overdrafted groundwater as the source of water supplies for urban areas towards the use of renewable water supplies.
2. The recharge and recovery program requires a permit prior to storing water underground or pumping the stored water. This program facilitates storage of surface water and effluent for future use, protection of rights to the stored water and water quality improvements through soil aquifer treatment. This program has proven to be an important tool for demonstrating a 100-year "assured water supply", and for the Arizona Water Banking Authority, which stores excess Colorado River water for future use.
   Three principal means of permitted recharge are (1) constructed facilities such as recharge basins, (2) managed facilities that allow the water to run down a dry streambed and passively recharge, and (3) groundwater savings facilities where a farmer reduces groundwater pumping and takes delivery of an alternative supply, generating "credits" for a municipal provider to pump the saved groundwater in the future. Recharge permits require consideration of hydrologic feasibility and prevention of unreasonable harm to other landowners and water users. [13]
3. Although the Central Arizona Water Conservation District, the Central Arizona Groundwater Replenishment District, and the Arizona Water Banking Authority[14] are separate water management entities from the Department of Water Resources, their water supply and recharge activities increase the water supplies available during normal years, and to enhance the reliability of municipal and industrial water supply deliveries to the AMAs during future shortages on the Colorado. Therefore, their activities contribute to the "supply side" of AMA management.

Water management planning, technical and financial assistance in AMAs

1. Grants and technical assistance in conservation, monitoring and augmentation are provided through a program that is funded by a portion of the withdrawal fees paid by groundwater users. Surface flows, groundwater levels and subsidence monitoring are key components of the data collection efforts. Conservation assistance is provided by AMA staff, and grants have been awarded to a wide variety of projects in every water-use sector. Augmentation assistance has focused on expanding recharge opportunities and effluent re-use.

[10] Additional information on these programs as well as copies of AMA management plans and rules are available through the agency web site at: http://www.water.az.gov.

[11] A very limited market has developed in Type II Non-Irrigation Grandfathered Rights, which can be severed from the land.

[12] Industrial users, for GMA purposes, are nonagricultural entities that have their own groundwater rights and do not receive service from municipal providers.

[13] A limited market also exists for acquiring recharge credits.

[14] A description of the Arizona Water Banking Authority is found on pages 17–18. Additional information is available on the AWBA web site at: http://www.water.az.gov/AWBA. Further information on the Central Arizona Groundwater Replenishment District, and the Central Arizona Water Conservation District, of which it is a part, is available through their website at: http://www.cap-az.com.

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2. Technical modeling and regional studies are performed by the Department of Water Resources' hydrology staff, including regional groundwater models for all of the AMAs. Department staff also assists in local planning activities relating to water availability, land use, recharge planning, etc.

Implementation in AMAs

1. The Department of Water Resources is required to prepare a series of water management plans for each AMA, containing enforceable conservation requirements for all large water users, a plan for augmentation of groundwater supplies, a conservation assistance program, and information regarding water quality. A series of five plans must be adopted at specified dates between 1980 and 2025, to move the AMAs incrementally towards their management goals through demand management and supply enhancement.
2. Through rule-making procedures, criteria have been specified that clarify the requirements of the GMA. Rules have been adopted for assured and adequate water supply, well-drilling construction and licensing, annual reports, water measuring devices, capping of open wells, fees, and well spacing and well impact.[15]

Recent Trends: Getting to Safe-yield and the Transition to Renewable Supplies

The last 20 years of Arizona's history has been a period of remarkable change and innovation. Due in part to Arizona's rapid rate of population growth and urbanization, and the dramatic diversification of the economy, Arizona has moved from a primarily resource-based economy (copper, cattle and cotton) to an urbanized state more dependent on technology production, construction and tourism. Nothing showcases the innovation and complexity better than the huge shifts in water management and water supply policy that have taken place.

Since the 1940s, the majority of water use in the AMAs was supported by groundwater, with the exception of large surface water delivery systems like the Salt River Project in the Phoenix area. The GMA charted a course for the municipal sector in the AMAs to move away from groundwater, and towards renewable water supplies. This focus on the use of renewable supplies for the municipal sector is based on the expectation that municipal and industrial demand would continue to grow, while the demand of agriculture and mining would diminish over time. The transition to renewable water supplies was expected to be gradual, although substantial policy changes have been needed to facilitate the transition.

The original expectation was that in the early years of the Central Arizona Project (CAP), agricultural entities would utilize all of the state's CAP allocation not yet needed by municipal, industrial and Native American users. It was also assumed that agricultural land would urbanize and agricultural use would phase out as the municipal, industrial and Native American demand increased over time. In fact, the costs associated with paying for the CAP water and the associated delivery systems made CAP water cost-prohibitive for agriculture initially, and major changes in pricing policy and water supply allocation have been made to respond to this problem. The majority of deliveries to agricultural interests are now subsidized either by municipal partners or the Water Banking Authority through the indirect recharge program, or through short-term pricing policies that are mutually beneficial to the agricultural and municipal customers of the Central Arizona Project (CAP). CAP deliveries have steadily increased since 1985 (see Fig. 3).

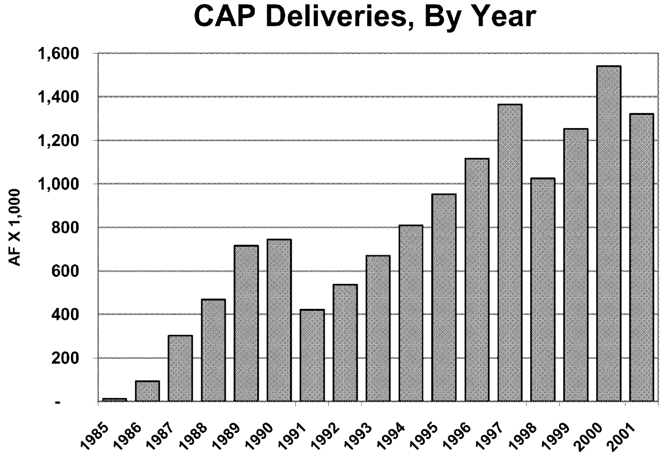

Fig. 3 CAP deliveries, by year

Municipal use of CAP water, although significant, also started slower than anticipated. Recharge of CAP water and recovery from the aquifer has also been utilized extensively along with direct delivery for municipal use of CAP.[16] With the creation of the Arizona Water Banking Authority in 1996 and the development of incentive pricing programs for agriculture and recharge, Arizona is now fully utilizing its Colorado River allocation, although annual utilization patterns are strongly affected by agricultural demand and availability of Colorado River water as well as other less expensive surface water supplies within the state.

Effluent is also a key resource for Arizona. Although there are current surpluses of effluent in the Phoenix and Tucson AMAs, water users in these AMAs have made substantial investments and are expected in the near future to more fully utilize the available effluent. Muni-

[15] The Department of Water Resources also has the authority to develop and publish substantive policies, in accordance with the State of Arizona Administrative Procedures, as necessary for additional guidance on regulatory program details not covered by statutes, rules or management plans.

[16] One contributing factor to a strong interest in recharge in the Tucson AMA is that initial direct potable deliveries of CAP water resulted in major technical and political problems, including brown water, bursting pipes and a resulting initiative that prohibited direct delivery of CAP water unless it was recharged and recovered first.

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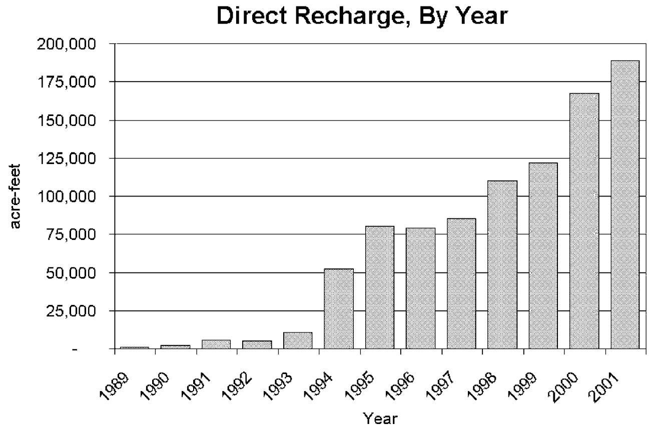

Fig. 4 Direct recharge, by year

cipal effluent (treated wastewater) is commonly considered to be a renewable water supply, but whether or not effluent is truly a new supply depends on whether it would return to the water system after discharge, either as streamflow or as groundwater recharge. Effluent will become a more and more important part of the state's total water resource budget in the future.

Soon after the adoption of the groundwater code it became clear that recharge would be a major component of storing and utilizing renewable water supplies, both CAP water and effluent. In 1986, legislation established the Underground Water Storage and Recovery Program. Since that time, there have been numerous refinements and additional components, culminating with a consolidation of the various recharge programs in 1994. This program has been very popular, resulting in the development of 65 storage facilities with a capacity to store up to 1.5 million acre-feet per year, and as of the end of 2001, actual storage of 3.1 million acre-feet of water in the AMAs. Of the 3.1 MAF of water recharged through 2001, approximately 70% is through subsidized use by agriculture in lieu of pumping groundwater, and the remainder is from direct recharge. Although the majority of this recharge is done with CAP water, over 200,000 acre-feet of effluent have also been recharged. Please note that the graph (Fig. 4) is for direct recharge only.

A key regulatory motivation for municipal investments in the use of renewable supplies is the Assured Water Supply (AWS) Program. The AWS rules clearly demonstrate Arizona's commitment to ensuring a long-term secure water supply for its citizens living in the AMAs, and to making the investments required for infrastructure, treatment and storage facilities.

The AWS Program is designed to sustain the state's economic health by preserving groundwater resources and promoting long-term water-supply planning within the state's five active management areas (AMAs). This is accomplished through regulations that mandate the demonstration of sufficient (primarily renewable) water supplies for 100 years for new subdivisions. The supplies must be physically and legally available, and of adequate quality; the developer or water provider must also show financial feasibility and compliance with the conservation requirements and the management goal for the AMA.

Institutional Changes Supporting the Transition to Renewable Supplies

One of the most innovative and controversial institutions that has been developed in response to the AWS rules is the Central Arizona Groundwater Replenishment District (CAGRD). The CAGRD was created to help provide access to renewable supplies for new developments that had no direct access to a CAP allocation. The CAGRD is required to replenish in perpetuity all groundwater that is pumped by its members that is in excess of the groundwater that is allowed to be pumped under the AWS rules. It has been very successful in attracting customers, perhaps more successful than anticipated. In part, the CAGRD is considered innovative because it is designed solely to support the AWS program by replenishing the groundwater use of its customers. The key controversies relate to the ability of the CAGRD to store water in locations that are distant from the place where it will be used (though it must be in a location where the water is available for future recovery) and to the fact that the CAGRD itself has more customers than were originally expected and does not currently have a permanent water supply; it is dependent on the availability of surplus water for recharge.

The Arizona water banking authority

A major concern for Arizonans has been protection of the state's allocation of Colorado River water from the other Lower Basin States. Although a lawsuit, Arizona vs. California (1963), quantified the rights to Colorado River water, California has been using more water than its 4.4 million acre-foot allocation for many years. In addition, Nevada's allocation of 300,000 acre-feet is fully committed. A conviction that Arizona needed to quickly utilize its full allocation developed during the 1980s and early 1990s. As a result, the Arizona Water Banking Authority was created in 1996. There are four primary objectives of the AWBA which include (1) to store current excess Colorado River water underground that can be recovered to ensure reliable municipal water deliveries during future shortages on the Colorado River or CAP system failures, (2) to support the management goals of the active management areas, (3) to support Native American water rights settlements, and (4) to provide for interstate banking of Colorado River water to assist Nevada and California in meeting their water supply requirements while protecting Arizona's entitlement. The AWBA uses a combination of property taxes, groundwater withdrawal fees, and state general funds to purchase excess CAP water and contract with recharge facilities to store the water underground in central Arizona. The AWBA has been hailed as a major innovation in water management, and it has changed the tenor of interstate negotiations substantially.

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The transition to full utilization of renewable water supplies is not yet complete, but enormous progress has been made. Interim uses for CAP water have been identified, and there is a clear path towards higher use by municipal and Native American entities. Although there are many concerns, it is generally recognized that Arizona has made major strides towards a secure water supply future.[17]

Lessons from Arizona's Water Management Experience

The evolution of groundwater management in Arizona has been affected by resource availability, economics, law and politics. Management approaches in the larger central Arizona active management areas (AMAs) have been shaped by access to deep, although overdrafted, aquifers and imported surface water supplies.[18] Many rural areas have limited groundwater and limited surface water rights. The high rate of population growth and the fast-paced changes in land and water uses throughout the state have resulted in unique management challenges. Arizona's approach has also been shaped by the state's politically conservative nature and resistance to government regulations and funding assistance.

The purpose of this section is to reflect on some of the policy choices and approaches taken by Arizona, in the context of a broader public policy framework. Obviously, there are some characteristics of Arizona's history and legal system that result in limited applicability of these approaches in other states or countries. However, it is hoped that this discussion will assist other regions with the design of their water management programs.

Before presenting our reflections on Arizona's water management experience we present a public policy framework. The purpose of this framework is to provide the reader with a way to categorize the different water management options in a manner that helps to understand the political implications and the appropriateness of the options in different contexts. Four different types of public policies and government programs are discussed below. They fall on two continuums (Lowi 1972). First, a "coercion continuum" considers the degree to which the government uses its authority to force a desired action. At one end of the continuum are highly coercive polices using police power to adopt regulations. At the other end of the continuum are very low levels of coercion where programs rely on use of government funds, incentives or education programs to encourage a voluntary action. A second continuum, "target of program", is used for classifying how government programs and policies are targeted. Do the programs directly impact individuals (or other entities) or do they have indirect effects by changing the environment in which decisions are made?

A progression sometimes evident in the evolution of public policies, including those on water resources is from (1) low coercion/indirect impact policies (constituent policies), to (2) low coercion/direct impact (distributive policies), to (3) high coercion/indirect impact (redistributive policies), to finally (4) high coercion/direct impact policies (regulatory policies). Examples of the four types of government water management policies include (1) constituent policies such as enforcement of private contracts and prior appropriation rights, and helping market mechanisms work through information provision, and technical assistance; (2) distributive policies such as public funds for building water supply structures, water treatment plants and flood control dams; (3) redistributive policies such as taxes on groundwater use to pay for programs and subsidized prices to encourage CAP use as well as disaster assistance funds; and (4) regulatory policies such as Arizona's groundwater code regulations, which include assured water supply requirements and limits on water allocations for individual farmers, as well as local zoning controls. The more intrusive redistributive and regulatory policies typically are a last resort because they generate opposition from those who are regulated or paying for the programs. A decision to implement more intrusive or expensive policies typically occurs when previous or current programs are insufficient to deal with the problem.

New programs and policies can move along the continuums in both directions in response to the magnitude of perceived public problems, and changes in the economy or political and social values. Additionally, if one level of government is unable to solve a problem, higher levels of government are frequently called upon for assistance. Control may or may not then be returned to the lower level of government, based on changing philosophies about the desirability of government intervention or increasing ability of local governments to address the problem. Comprehensive policies like Arizona's GMA involve multiple programs showing characteristics of most of these policy types.

Although government is generally viewed as slow to respond to changing social conditions and rarely if ever gives up authority, there has been ongoing flux in Arizona's water management programs, and budget constraints have forced the Department of Water Resources to prioritize its activities and deregulate or de-emphasize certain programs over time.

Lessons learned from Arizona's experience are organized in the next section in the context of (1) Arizona's framework for water management, (2) demand side programs, (3) supply side programs, and finally (4) Arizona's water planning and technical assistance efforts.

Lessons from Arizona: The State's Water Management Approach

Fundamental choices made by Arizona in setting up water management programs included establishing regulatory

[17] Portions of this section were excerpted from the Governor's Water Management Commission Interim Report (2001).

[18] In the Phoenix AMA, the ability of the Salt River Project to conjunctively manage and deliver approximately 1 million acre-feet of surface water, groundwater, and, more recently, CAP water, has shaped water management in that AMA.

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programs in state controlled active management areas (AMAs), maintaining a dichotomy between groundwater and surface water management, and establishing a water rights structure within AMAs which included grandfathering most existing groundwater uses. One assertion of the public policy framework above is that regulatory approaches are typically taken after less intrusive efforts. Given the politically conservative nature of Arizona, water managers from elsewhere are often surprised that Arizona has perhaps the most stringent and longest standing regulatory approach within the United States. The 1980 GMA was, in fact, the result of previous ineffective efforts and the threat of the federal government to not fund the Central Arizona Project.

In the United States, water rights and quantity management are generally the responsibility of states, not the federal government. Both surface water and groundwater are considered public resources subject to state law with rights and permits to use water granted to individuals and to water providers. Owners of water delivery and treatment infrastructure are typically not the states but are local governments or private water companies and irrigation districts[19] Although land use management decisions are often integrally related to water issues, in the United States, regulation of land use is generally the exclusive domain of local government (cities and towns, or the county if an unincorporated area) and actual land development investments are made by individual and corporate private property owners.

The majority of land in Arizona is state, federal or Native American lands with only 16% of the state in private ownership.[20] However, most water uses occur on these private lands and the rights of private property owners are vigorously defended in Arizona. It is the decisions and investments of these multiple water users and providers (cities, farmers, irrigation districts, private water companies, industries and individuals) that most strongly affect how water is used in Arizona. An effective approach for state programs is to influence the individual behaviors and investment decisions that collectively determine how water is actually managed. Different types of programs, both regulatory and nonregulatory, are needed depending on the decisions that need to be affected. By providing regulatory certainty, a clear water rights system and the grandfathering of existing users, the GMA has encouraged investments in conservation and use of renewable supplies. Establishment of a water rights structure is a type of "constituent" policy that protects existing users and assists private markets to function. Creation of such a water rights structure, though perhaps not essential for a regulatory program to operate, is fundamental to the operation of Arizona's regulatory demand and supply management programs discussed in the next two sections.

The state regulatory structure provides parity among AMAs, but also allows for local input and implementation to tailor the management system to local conditions. This model has been successful, as has defining management areas based on hydrologic boundaries. The individual AMA's management plans provide the opportunity to accommodate the unique character of each AMA, though to date this has been used in only a limited way

Lessons from Arizona: AMA demand management programs

The objective of Arizona's AMA demand management programs is to reduce overdraft by improving the efficiency with which all sources of water are used, and by prohibiting certain high water use activities. Effective conservation, in large part, depends on the behaviors and investment decisions of individual water users. For example, consider a conservation policy objective to increase the use of low water using landscapes and efficient irrigation systems in individual household yards.[21] The relevant decision-maker is the homeowner or building manager. In Arizona, it is not politically or administratively feasible for a state agency to regulate the landscape choices and irrigation practices of individual homeowners.

Arizona's approach is to regulate the municipal water provider (city, town, or private water company serving water) by setting conservation targets (per capita use rates) for the water providers or by requiring the water providers to adopt best management practices. This indirect regulatory approach hopefully leads the water providers, who are closer to their customers, to implement effective educational (constituent policies) and financial incentives (distributive and redistributive polices) to reach the decisions of individual homeowners. In a few cases, water providers have also worked with local governments to establish landscaping ordinances (regulatory policies) that are appropriate for their area to help achieve water conservation. Water providers have found that conservation behaviors are reinforced through multiple consistent conservation messages, including conservation-oriented rate structures.

Arizona's conservation approaches have evolved and additional regulatory options, as well as a grants program, have been added since passage of the GMA. Municipal conservation programs in the first management plan required providers to reduce per capita consumption over an 8-year period by a fixed percentage (0–11%) based on their per capita use. For the second

[19] Certain major infrastructure projects in the west, such as the Central Arizona Project, are federally owned and operated by either regional districts or the federal government. These projects are the result of federal "distributive policies" which use low levels of coercion but have a direct impact on individuals. These types of government investments are also very expensive. In fact, recognition by the federal government of the need for major investments in dam building in the early 1900s for flood control and water supply initiated one of the most significant expansions of the role of the United States federal government.

[20] Such a high percentage of federal public lands is common in only a few western states. In most of the states the vast majority of land is privately owned.

[21] Residential landscape water use comprises nearly 40% of total water use in the city of Phoenix.

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management plan a much more rigorous analysis was conducted and each provider was given a unique gallons-per-capita-per-day (GPCD) target based on the conservation potential in existing uses, model use rates for new development and population projections. The third management plan contains both the GPCD program and a best management practices (BMP) program. Interestingly, this movement from a performance-based program (GPCD) to a prescriptive program (BMPs) has occurred during a time when conventional theories on regulation identify performance based programs as superior for providing greater flexibility to regulated entities. Principal reasons for the trend in Arizona may include (1) the BMP program does not include a quantitative limit, thus allowing increases in per capita use; (2) the perception that the BMP program provides more regulatory certainty; and (3) long-standing complaints from some providers regarding the ability of providers to affect consumer demand.[22]

Arizona's regulatory conservation program for agriculture has created a significant administrative workload and has been only marginally effective. Irrigation rights were quantified on the basis of individual cropping patterns in the five years prior to the GMA, and the conservation program gradually reduced the allotments based on a statutory requirement to achieve maximum feasible conservation. However, historically the program has allocated more water than used by most individual farmers,[23] which has resulted in the accumulation of large flexibility account balances. These balances, which are uncapped and have some transferability, have largely undermined the conservation incentive through the periodic reduction of allocations. Additionally, since the adoption of the second management plan in 1988, farmers have contested the feasibility of basing the allotment on 85% irrigation efficiency (the Department of Water Resources determination of maximum feasible conservation) and historic rather than current crop choices.

Legislation passed in 2002 eliminated the requirement to achieve maximum feasible conservation and instead set the allotment on the basis of an assigned irrigation efficiency of 80%. This legislation also authorized a BMP program for agricultural water users. Just as with the municipal BMP program, this effort will require specific conservation practices to be implemented but will eliminate the quantitative limit on water use.[24] The effectiveness of the new agricultural BMP program will depend on the strength of the practices, both individually and in combination, and on the effectiveness of research, education and outreach in assisting farmers to effectively implement them.

Lessons from Arizona: AMA supply-side programs

Programs to encourage conversion from groundwater to renewable supplies and regulations requiring new growth to use renewable water supplies, are the cornerstone of Arizona's efforts to reduce overdraft in the active management areas. The earlier section on recent trends and the transition to renewable supplies summarized Arizona's efforts to increase utilization of renewable supplies through coordinated management of all sources of water. The earlier discussion of Arizona's transition to renewable supplies highlighted the use of distributive and redistributive programs (building the infrastructure and subsidizing certain uses of CAP water). A couple of key lessons to highlight from the supply-side programs include the decisions being targeted by the Assured water supply program, the institutional and ownership issues involved in recharge and the role of the Central Arizona Groundwater Replenishment District (CAGRD).

The AMAs' most effective regulatory tool, the Assured Water Supply program (AWS), illustrates additional program design points. The objective of the AWS program is to ensure new municipal development has a secure and renewable supply of water that will not exacerbate groundwater mining. The relevant decision-makers are developers who want to build, landowners who hold vacant land and local jurisdictions that approve new subdivisions. The AWS program features a strong regulatory approach, with control at the state level, to prohibit local governments from permitting the subdivision of land unless the requirement for a secure 100-year water supply is met.

Implementation of the AWS rules would not have been politically feasible in Arizona without providing a convenient mechanism for most residential developers, particularly those without ready access to renewable supplies, to continue building. The Central Arizona Groundwater Replenishment District, by committing to replenish groundwater used by its members, provided this mechanism and allowed adoption of the AWS rules. The AWS rules were also dependent on the passage of recharge and recovery statutes. These statutes provided the critical protection in that an entity storing water in the aquifer could retain access to that water and could recover the water anywhere in the same active management area and legally consider the water to be from the source recharged (surface water, CAP or effluent) rather than groundwa-

[22] The legality of the GPCD program is currently being challenged in court over a number of questions including whether GPCD targets can apply to all sources of water, whether nonresidential uses can be limited, and whether the state should directly regulate water users instead of requiring water providers to reduce use by its customers.

[23] This has occurred due to several factors including (1) improvements in irrigation efficiency, (2) low crop prices and high costs resulting in lower levels of production than the 1975–1979 historic period, (3) the allocation of water based on the maximum rather than average acres in production during the five-year period, (4) lands going out of production, and (5) the addition of flexibility credits which allowed limited marketing of unused allocations to individual farmers who did use more water than their allocations.

[24] Farmers in the BMP program are required to choose from a list of physical improvements and management practices in four separate categories. The BMP program does still limit irrigation to historically irrigated lands.

ter.[25] These provisions protecting ownership of recharge credits are a critical type of constituent policy that also facilitates some limited markets for recharge credits. The recharge statutes also put in place a regulatory structure for permitting recharge facilities. The recharge and recovery programs combine to allow aquifer space to be used for storage of excess waters and later recovery. The limitations on the transportation of groundwater from rural areas to AMAs also helped facilitate implementation of the AWS program, since without those protections the practice of "water ranching" would undoubtedly have caused additional friction and jeopardized the program.

Lessons from Arizona: water management planning and technical assistance

Arizona's water management programs include nonregulatory efforts. The objectives of these "constituent policy" based programs are to increase the effectiveness of water management and water use in the state through long-range planning, facilitating regional partnerships, research, education, technical and financial assistance. In some cases nonregulatory programs can be more effective than regulatory approaches, and can encourage collaboration among water users, providers and managers. Authority and legitimacy for involvement by any regional or state entity in water management can be established through regulatory programs or through less intrusive measures such as data collection and distribution, planning efforts, technical assistance, financial assistance, ownership of water rights and supplies, control or construction of water supply infrastructure, and authority to allocate available supplies.[26]

Arizona has successfully used technical assistance efforts to establish partnerships, facilitate regional coordination and contribute to sound water management investment decisions by water providers. One recent effort involved linking a basin-wide hydrologic model with future growth scenarios and alternative management practices. This work provided a revealing illustration of the hydrologic implications of various water management alternatives. The displays of future hydrologic conditions served to successfully alter public perceptions in the region and facilitated regional coordination. A second project brought together all interested parties to conduct technical studies and facilitate regional cooperation on planning and developing recharge projects. Projects such as these build cooperative relations with water providers and users, build staff expertise and perspective on real world water management needs and create a demand for the type of data and analysis necessary for effective water management.

[25] This is important because conservation requirements generally are not applied to effluent and AWS rules require use of nongroundwater supplies.

[26] Arizona makes recommendations to the U.S. Interior Secretary on the allocation of CAP supplies.

Other Observations from Arizona's Experience

The following list summarizes other suggestions that may benefit groundwater managers:

- A key component of Arizona's programs is significant enforcement authority. GMA violators can be fined up to $10,000 per day for illegal groundwater withdrawal or $200 per acre-foot of unauthorized groundwater used. Though financial penalties are rarely collected, they do provide significant authority. Violations of conservation requirements are typically dealt with through negotiated stipulations where the violator agrees to invest the resources necessary to correct the violation and in some cases pay a small fine.
- The requirement for water users within AMAs to report their water use and the maintenance of water use databases are critical for compliance efforts, but even more important for constituent policy type programs such as monitoring, long-range planning and information provision activities.
- Adoption of mandatory conservation measures was more acceptable because the required reductions did not threaten water users' groundwater rights. Water rights, particularly for surface water in western states, are frequently based on a "use it or lose it approach." By establishing quantified groundwater rights, Arizona ensured users that reducing their water use would not result in a reduction of their right.
- Regulations need to be sufficiently flexible so that they are reasonable in the context of changing climatic and economic conditions. Instituting limited multi-year averaging or flexibility credits for individual users in each sector can also provide an incentive to conserve water to use in times of higher demand. However, if provisions to earn "flexibility" credits or to trade the credits are too loose, this will render conservation regulations ineffective. Some observers believe this happened in Arizona's agricultural conservation program.
- Perceptions are very important when asking individual water-users to implement conservation practices. The average person needs to see the big water-users, farms, mines and cities also using water efficiently.

Concluding Thoughts on Implementation and Emerging Issues

Collaborating with water users and providers is important in designing any management program, whether regulatory or not. Alternative policy approaches lead to different economic and administrative costs, political pressures and relationships with the water using community. Regulations, for example, tend to lead to a confrontational political environment that creates winners and losers. However, regulations may also be cheaper to administer than comprehensive financial (distributive policies) or technical assistance (constituent policies) programs. This environment often makes elected or appointed officials

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unwilling to impose or enforce regulations. Regulatory approaches also make the water using community reluctant to share information and expertise with the regulator, for fear it will result in penalties or stricter regulations. In water resources, where building partnerships is critical for effective long-term management, there can be a significant cost to damaging these relationships. One option for state water managers is to separate regulatory and planning functions in different groups; see Lowi 1972 for a more detailed discussion of the types of political relationships associated with each of the four types of public policies.

Arizona took a strong regulatory approach to its groundwater management efforts, particularly within the AMAs. In the case of the assured water supply program, a strong state-level regulatory approach was essential. The standards for establishing a program like assured supply must be set at a level of government higher than the local governments that have the responsibility to approve or disapprove individual zoning and subdivision proposals. For conservation programs, however, a good case could be made for control at either a state, regional or local level. Equally good cases could also be made for the relative advantages of Arizona style regulatory or nonregulatory approaches[27] to conservation. By contrast, efforts to facilitate good water management through regional cooperation and technical assistance (constituent or distributive policies) are likely to be more effective when there is genuine responsibility at a regional (AMA, watershed, or even smaller sub-basin) level and the efforts can be kept separate from regulatory programs.

Future water management challenges in Arizona, where regional cooperation and technically sophisticated long-term planning efforts will be most critical include: efforts to identify and secure future supplies; sharing of infrastructure; optimizing the use of the aquifer for storage and recovery, drought protection, water quality management; negotiation of water rights settlements with Native American communities and dealing with interstate water issues. The authors believe these needs may be best addressed through nonregulatory programs.

Another major emerging issue for Arizona is water resources outside of AMAs. Current drought conditions have heightened awareness that water supply conditions in the largely rural non-AMA parts of Arizona are in many cases more acute than those within AMAs, yet little is known about the water supplies in some of these areas. There is substantial reluctance to adopt any of the AMA-type regulatory approaches, but those approaches have protected existing water users and enhanced stability of water supplies for the future within AMAs. Some of these non-AMA areas have insufficient supplies to meet current and projected demand. Importation of water from other basins is being considered, but current law prohibits most such transfers. Ironically, this issue will likely be reopened at the request of rural interests as they attempt to address their own long-term water needs.

The dichotomy in Arizona between surface water and groundwater laws will continue to create confusion and management challenges and has been described in multiple publications (see Glennon and Maddock 1977, Grant 1987, Tellman 1994, and Glennon 2002.) Although there are some protections available in Arizona for instream flows of surface water, the groundwater laws do not protect senior surface-water rights, surface-water flows or riparian habitat from groundwater pumping. The current bifurcated system is likely to be maintained by the state legislature and the courts because of the amount of investment and water development based on the current laws. However, for any region or state not already committed to a particular management scheme, areas with unified or coordinated management systems could provide more workable examples.

A final lesson from the Arizona experience comes from the recognition that comprehensive water-management programs grow and evolve over many years. The GMA, with the creation of a long-term goal and a series of ten-year management plans, put in place an incremental approach to reaching safe-yield and ensured an ability to respond to changing conditions.

Arizona's water management efforts within AMAs, although heavily regulatory, have largely been successful. The state is reducing its reliance on groundwater and increasing use of more expensive and sustainable surface-water supplies. The legal framework and management approaches in place provide the assurances of stable supplies and the certainty necessary to encourage investments in Arizona's future. Arizona's water managers have looked well into the future to secure new supplies, and although the different users and cities do compete for water supplies, they have been able to speak with one voice on interstate concerns over issues such as Colorado River management.

Navigating the hurdles of a regulatory approach to managing water supplies in the western U.S. has proven to be difficult, particularly in the context of Arizona's strong deference to private property rights and periodic budget cutbacks. However, the major tenets of the 1980 GMA are still in place, and if the findings of a recent Governor's Water Management Commission[28] are any indication, there is still strong support for the basic principles and most of the provisions of the carefully crafted compromises represented by the statutes, rules and management plans that guide water management in Arizona.

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[27] Nonregulatory approaches could include the less coercive and indirect influence "constituent policy" programs such as education and technical assistance or the more directly targeted "distributive policy" programs such as grants and other financial incentives.

[28] The Commission's final report is available on CD through the ADWR website, http://www.water.az.gov

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