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ARTIFICIAL RECHARGE:
A Multi-Purpose Water Management Tool

The first flow of water reaches the New River - Agua Fria River Underground Storage Project, shown in proximity to the Cardinals' stadium and Coyotes' arena. After a week's worth of water delivery for recharge, only a quarter to a third of the basin was wetted. The seeping wetness shows as a ragged edge in bottom-left field. NAUSP, a Salt River Project facility in partnership with the cities of Avondale, Chandler, Glendale and Peoria, is the first recharge project in Arizona capable of storing water from the Salt, Verde, and Colorado rivers and reclaimed water from Glendale and Peoria. The picture was taken Oct. 10, 2006. Photo: Salt River Project Media Relations.

Overpumped, overdrafted and in various states of depletion, Arizona's aquifers have suffered the consequences of past failure to manage this vital resource. Meeting a rapidly growing demand for water in the desert southwest has never been easy; but advances in groundwater pumping technology in the first half of the 20th century made satisfying water demand easier than ever before. It is little wonder that the state of Arizona came to be addicted to groundwater. But with time, Arizona came to understand that unlimited groundwater use was indeed too good to be true. By the 1940s, statewide groundwater assessments were reporting gross overdrafts in many of the state's aquifers, resulting in rapidly falling water tables, reduced water quality, and subsidence of the land surface.

While the 1980 Groundwater Management Act was a critical step in the right direction, Arizona's groundwater addiction could not be curbed overnight, nor could the damage wrought on its aquifers be quickly undone. (Even today, groundwater accounts for roughly 40 percent of Arizona's water use.) But what the Act did do was provide a framework for innovative ideas developed since 1980 to more effectively manage Arizona's water supplies.

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Artificial recharge is one such idea that has emerged over the past 20 years as a major water management tool for meeting water supply challenges. The concept of artificial recharge is simple: return water to aquifers and increase groundwater supplies. Yet the benefits are many. Besides storing water underground in wet years for use during dry years, it is also used to manage problems of land subsidence, maintain base flow in streams, protect against salt water intrusion, treat wastewater, and abate rising costs of groundwater pumping. For Arizona, it also provides a way for the state to achieve its goal of full utilization of its annual entitlement to Colorado River Project water.

The State of Arizona has created a program to encourage and regulate the use of recharge as a water management tool. Administered by the Department of Water Resources in cooperation with the Department of Environmental Quality, this program already has had a significant impact on how water supplies are managed. The program provided the opportunity to experiment with new approaches and institutional structures, and in the process to discover new uses and benefits from this versatile tool. To understand the significance of Arizona's water recharge program and related activities, it is necessary to understand artificial recharge, how it works, and what it can and cannot do.

What is Artificial Recharge?

Recharge is simply the process of adding water to an aquifer. Natural recharge results from natural processes such as precipitation and streamflow. It occurs along mountain fronts, in and along stream channels, and anywhere water is able to seep down to the water table. The water table defines the top of the saturated part of an aquifer. The area of the aquifer above the water table is referred to as the unsaturated or vadose zone. A good recharge site has permeable materials such as unconsolidated sand and gravel and adequate depth to water, to allow large quantities of water to move downward to the water table and ample storage capacity for recharged water. The geology of central and southern Arizona provides large aquifers particularly well-suited for recharge.

Incidental recharge is water entering the aquifer after various human uses; examples are recharge of irrigation drainage, leakage from underground water lines, and treated wastewater discharges to channels. In other words, the recharge is incidental to the use. Artificial recharge involves direct human intervention to enhance or create conditions for recharge.

Artificial recharge facilities or projects are constructed to control the movement and rate of infiltration, with the purpose of adding water to the aquifer. Artificial recharge projects generally are divided into two categories: surface methods and subsurface methods. It is frequently described in the new hydrology literature as Managed Aquifer Recharge. Surface methods are further categorized into facilities that increase recharge in stream channels and projects built off-channel to which water is transported for recharge. Site-specific factors such as land use, geology, hydrology, and water quality determine which of these methods is most appropriate.

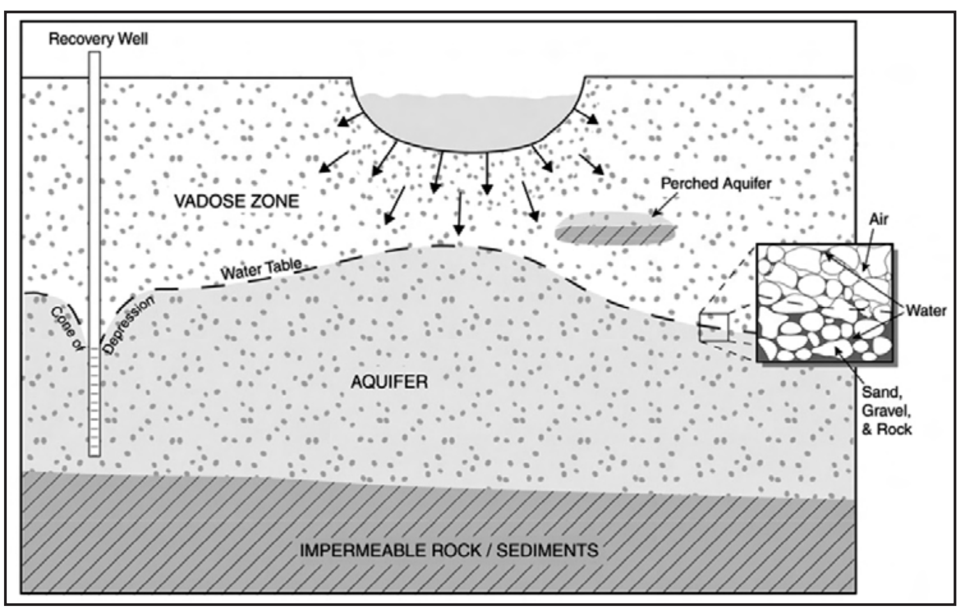
In-channel artificial recharge facilities typically are built into a river or streambed that is usually or mostly dry to retain water so that more will infiltrate or percolate into the underlying aquifer. Such areas generally have high infiltration rates. Inflatable dams, gated structures, and levees, or other devices are installed or constructed to impede water flow, allowing time for infiltration.

Surface off-channel recharge facilities include spreading basins, trenches, ditch systems, or constructed water bodies such

Goats eat on the job to eliminate weeds in CAP groundwater recharge basins. Photo: Philip Fortnam, Central Arizona Project

as wetlands, ponds, or lakes. For spreading basins, the top layers of soil are removed to reach more permeable layers sometimes as much as 20 feet below the surface. They are usually excavated, with the soils used to construct earthen berm walls. Surface spreading basins are by far the most common recharge method in Arizona. They are relatively simple to construct and maintain at high infiltration rates and are less costly than subsurface methods if sufficient land is available.

Deep basins or pits can be converted from other uses (such as gravel pits) for recharge and also can serve as decorative lakes. In such cases, water levels of about 10 feet typically are maintained during operation. Operating costs are usually low, since



Movement of recharged water underground basins are drained and maintained only once every year or two. Infiltration rates, however, are usually low due to build up of organic matter on the lake bottoms.

Subsurface recharge includes drywells, frequently referred to as vadose zone wells, of various designs and injection wells that inject water, often several hundred feet, into an aquifer. These methods are typically used if land needed for surface methods is unavailable and/or if an impermeable layer lies between the land surface and the aquifer. The well shaft penetrates the impermeable layer enabling the recharge water to reach the aquifer. Costs of construction, operation and water pre-treatment can make this an expensive method of recharge. In addition, recharge volumes are low compared with basins, making the unit cost of recharge more expensive. In Arizona, injection wells represent a very small percentage of the permitted recharge capacity.

Constructed recharge projects require maintenance to maintain infiltration rates and ensure smooth operations. For example, buildup of fine sediments and organic material can form a clogging layer, reducing recharge rates in surface spreading basins and trenches. Drying out a basin often solves the problem by allowing the clogging layer to dry and crack. A more intensive solution involves using tillers or scrapers to break up the clogging layer.

Because clogging of recharge wells is a more difficult problem to solve, subsurface projects usually are designed to prevent clogging. Injection wells installed into the aquifer can be rehabilitated by pumping out water and with it the clogging material in the borehole. In vadose zone wells or drywells, however, if clogging occurs, it is usually permanent.

Growth of weeds at recharge sites also is a problem. The flooding of spreading basins creates fertile seedbeds for weeds to take root and grow. The weeds increase evapotranspiration of water that otherwise would be available to replenish the aquifer. The weeds also attract pests such as midge flies. The Central Arizona Project has used goats at recharge facilities as a weed control strategy instead of chemicals; the goats are more ecologically friendly and their use is less expensive than applying chemicals. CAP has used goats at about half the cost of herbicides.

Tracking the Hidden Waters

The defining characteristic of groundwater is that it is underground and out of sight. To design, operate or regulate a recharge facility, a sufficient understanding of unseen subsurface conditions and water movement patterns is imperative. The effective management of such facilities requires answers to some important questions: Where does the recharged water go once underground? What water quality changes might occur to water that is recharged? What effect might recharged water have on its subsurface environment? Arizona recharge permit regulations require detailed investigation of these factors before a project is developed, as well as on-going monitoring throughout the life of the project.

Water managers often rely on sophisticated computer models to predict the movement of recharged water and to minimize off-site impacts as much as possible. For example, models have been used to discern if a proposed recharge project would release pollution from known sources such as landfills and dumps. The models, however, are only as good as the available data and the current scientific understanding of physical, biological, and chemical processes. Some degree of uncertainty must be accepted with any model of subsurface conditions.

This uncertainty is one reason groundwater monitoring is an important part of recharge projects. The Lower Santa Cruz Recharge Project provides a good example of using on-going monitoring to ensure the safety and effectiveness of a project (see LSCRP sidebar on following page). Water level rises under the Tangerine Road Landfill are carefully monitored. Recharge activities would be adjusted to prevent the water level from rising into the landfill liner and mobilizing potential contaminants.

Problem of Overdraft

The story of artificial recharge in Arizona begins with groundwater overdraft and the resulting depletion of many of the state's aquifers. Hand dug wells and windmills, with their shallow subterranean range, provided early settlers with rather limited groundwater supplies. Soon, however, steam powered pumps, in use by the end of the 19th century, allowed greater access to groundwater. In 1899, the Tucson Water Company's first steam driven pumping plant could pump 1,250 gallons per minute from a 40 foot well. Groundwater — the buried treasure once out of reach — now appeared to be an accessible and plentiful resource.

The 1920s were boon times for Arizona farmers. Not only were pumps becoming more efficient, but the power to work them was inexpensive. Low production costs and high market prices induced farmers to plant more cotton and, as a result, to pump more groundwater. Despite concerns raised during a drought in the 1930s, groundwater use increased. By the early 1940s, various proposals were made in the Arizona Legislature, for studying, writing and passing a groundwater code. Realizing it was to its benefit, the agricultural sector took a special interest in the passage of a groundwater code, with the Arizona Farm Bureau Federation calling for a code as early as 1942. Yet the pumping continued. After World War II, advances in pumping technology made it economically feasible to pump water from depths of as much as 500 feet to irrigate cotton, vegetables and citrus. The result was an increase in irrigated acreage, from 768,000 acres in 1945 to 1,279,000 acres in 1953, occurring mostly in areas of the state dependent on groundwater.

Despite continued overdraft, legislative efforts to manage groundwater pumping made little headway, and for all practical purposes, no effective regulation of groundwater pumping was in place until the passage of the Groundwater Management Act in 1980.

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Lower Santa Cruz Recharge Project Raises Groundwater Level

Developed by the Central Arizona Project and Pima County Department of Transportation and Flood Control, the Lower Santa Cruz Recharge Project has an annual permitted capacity is 50,000 acre-feet, with total recharge not to exceed 600,000 acre-feet. Its annual permitted capacity was increased from 30,000 acre-feet because the project performed better than initially expected. The

Above are the triangular-shaped basins of the Lower Santa Cruz Recharge Project. In the foreground are Avra Valley Recharge Project basins.

total cost of construction was $3.9 million, including $1.5 million of state demonstration project funds. The facility was built in conjunction with a flood control levee; 750,000 cubic yards of material removed to construct the project were placed on the banks of the river to provide flood protection to Marana. Operation began in 2000.

CAP has a water transportation agreement with BKW farms to use its irrigation canal system for water delivery to the recharge facility. The Arizona Water Banking Authority, Central Arizona Groundwater Replenishment District, Metropolitan Domestic Water Improvement District, the Town of Marana, Augusta Resources, and Robson Communities, Inc. all hold permits to store water at LSCRP.

Water is delivered to the three spreading basins, which range in size from 7.4 to 11.0 acres. Infiltration rates in the basins exceeded expectations by a wide margin. As a result, only two basins are needed to store the project's water deliveries while the third basin dries. Basins are rotated to minimize algae growth. In addition, calculated evaporation losses are low, amounting to less than one percent of the stored volume. Recharge has resulted in a water table rise of almost 100 feet since its construction.

LSCRP is within a quarter-mile from the Avra Valley Recharge Project, another State Demonstration Project, and the two have been permitted to share a monitoring system. The system consists of 14 piezometers, seven for each project, two on-site monitoring wells, one on each project, and seven off-site monitoring wells. Water quality samples are taken regularly at four of the monitoring wells.

The site is not bird-friendly. Its location within a 10,000-foot radius of the Marana Northwest Regional Airport means the project must comply with Federal Aviation Authority rules requiring the installation of special devices to scare away birds.

Meanwhile, people concerned about the water supply situation began to look at artificial recharge. Sponsored by the Salt River Project, the first Symposium on Artificial Recharge was held in Phoenix in November 1978. Artificial recharge at that time was viewed merely as a strategy to capture surface water that would otherwise flow beyond reach during floods. Recognition of its fuller potential as a groundwater management tool would come later.

Policy questions attracting attention at the symposium were related to the technical and economic feasibility of recharge, its environmental impacts and public acceptance. Unresolved legal questions, including ownership, financing, liability and water quality protection, were also raised. The symposium highlighted a growing awareness of the need for an Arizona recharge law to resolve these issues.

1980 Groundwater Management Act

After passage of the 1980 Groundwater Management Act, artificial recharge became an increasingly important tool in the management of Arizona's water supplies. Administered by the Arizona Department of Water Resources, the GMA established four Active Management Areas. AMAs are areas with severe overdraft problems, and originally included the metropolitan areas of Phoenix and Tucson, and the more agricultural areas of Prescott and Pinal counties. Later, the Tucson AMA was divided to form a Santa Cruz AMA. AMAs contain about 80 percent of the state's population, and 70 percent of the overdraft occurred in these areas. The primary management goal of the most populous AMAs — Phoenix, Tucson and Prescott — is to achieve safe yield by the year 2025. Safe yield was defined as a long-term balance between the amount of groundwater withdrawn annually and the annual amount of natural and artificial recharge in an AMA.

Most of the recharge occurring in Arizona takes place within the AMAs. As of December 2005, the AMAs had direct recharge facilities with a total permitted capacity of roughly 1 million acre-feet per year, the majority of which (almost 745,000 acre-feet) is in the Phoenix AMA.

The GMA mandated an Assured Water Supply program requiring that new development occur only if homebuyers could be assured of a continuous water supply (Although the 1980 Act mandated adoption of an assured water supply program, rules were not officially adopted until 1995). According to the AWS rules, every developer is required to demonstrate an assured water supply that will be physically, legally, and continuously available for the next

100 years before the developer can record plats or sell parcels. To receive an AWS certificate, the developer's water supply plan must be consistent with the management goal of its AMA; in safe-yield AMAs, this means it must make substantial use of renewable supplies, even if groundwater is physically available. Recharge has become a major strategy for meeting this requirement.

Recharge Legislation

The GMA's regulation of well development and groundwater pumping in AMAs resolved early concerns about the legal control and recovery of recharged water. To add further regulatory encouragement, the Legislature amended the GMA in 1986 to create a state administered program for recharge and recovery. The resulting Underground Storage and Recovery Program governs groundwater recharge projects using surface water or effluent. The Underground Water Storage, Savings, and Replenishment Act, passed in 1994, clarified rules on recharge and addressed the use of long term storage credits.

Although the benefits of recharge were recognized in 1986, technical and financial questions hindered recharge project development. In response, legislation was passed in 1990 establishing a program of state demonstration projects, with authority and funding granted to the Central Arizona Water Conservation District to construct recharge projects to hold excess CAP water "for future needs or use for replenishment purposes."

The intent of the projects was to demonstrate the feasibility of recharge projects, and thereby encourage their development. There are now six state demonstration projects in Arizona; three constructed in the Tucson AMA and three in the Phoenix AMA, plus a fourth in the design stage. All these projects use surface spreading basins to recharge water (See State Demonstration Projects sidebar on following page).

Funding for the demonstration projects was provided by the State Water Storage Fund and included appropriated funds along with the proceeds from a special property tax of 4 cents per $100 assessed valuation, collected from Maricopa and Pima counties between 1991 and 1995. The fund was to be used for capital, operational, and maintenance costs of projects. Maricopa and Pima counties have received $33.7 million and $8.5 million respectively for demonstration projects.

Arizona's Groundwater Recharge Program

Administered by ADWR, the Groundwater Recharge Program defines two types of facilities: Underground Storage Facilities and Groundwater Savings Facilities. USFs (sometimes called "direct recharge" facilities) include any of the surface or subsurface recharge methods, as well as "managed recharge" projects, which are simply stream channels equipped with monitoring installations.

Most of the USFs in Arizona are small facilities constructed by developers, towns and small cities to recharge effluent. However, CAP water accounts for the greatest amount of recharged water because CAP recharge projects tend to be much larger facilities. In 2005, for example, 23 recharge projects in the Phoenix AMA had permits to recharge effluent; only 12 were permitted to recharge CAP. The recharge capacity of the CAP projects, however, was almost triple that of the effluent projects.

The first permitted USF was the Granite Reef Underground Storage Project. Since it was permitted in 1994, more than 850,000 acre-feet of CAP water has been stored there. Cumulatively, USFs in the Phoenix and Tucson AMAs have recharged roughly 1.9 million acre-feet of water as of December 31, 2004.

By contrast, GSFs do not involve physical recharge. GSFs usually involve farms that agree to use "renewable" water rather than pump groundwater. GSFs have been referred to as "indirect" or "in lieu" recharge facilities because water is not recharged directly, instead renewable water is used in lieu of groundwater.

In a typical GSF arrangement, an entity such as a municipal water provider, sells water to a farm or irrigation district, usually at a price lower than what the farm would pay to pump groundwater. In return, the state grants credits to the municipal provider for the amount of groundwater that otherwise would have been used.

The municipal provider can then use these credits to meet AWS requirements or for other water management goals. As of December 2004, half of all the water

Recharge Also Occurs Outside AMAs

Outside of AMAs, towns are constructing recharge projects to solve local water resource problems. These projects most often use effluent from municipal treatment plants. For example, Kingman recharges effluent, with wastewater treated by a sequence of lagoons and wetlands before entering storage basins.

Payson's reliance on groundwater resulted in the water table dropping about 100 feet between 1986 and 1996. In response to the situation, the Green Valley Park was constructed in 1996 to recharge effluent, utilizing three lakes with a total surface area of 13.1 acres. The lakes are surrounded by 17.2 acres of landscaping (irrigated with effluent), walking paths, picnic tables, paved parking areas and boating facilities. The Arizona Game and Fish department stocks the lakes with rainbow trout. The town is assessing the effectiveness of the recharge project by monitoring wells located close to the park.

Sierra Vista recharges over 2,000 acre-feet of effluent annually at its Sierra Vista Water Reclamation Facility. Wastewater is treated using 50 acres of constructed wetlands that also serve as habitat for birds and wildlife. The 11 rapid infiltration basins are used in rotation, with each able to handle 24 to 36 hours of wastewater flows.

The city requires that all new subdivisions connect to the sewage system to ensure that all water used indoors is collected, treated and recharged. Plans are afoot to connect several unsewered areas in the vicinity of Sierra Vista to the reclamation facility. The most recent project is the Golden Acres Sewer Connection, completed in 2006.

stored in permitted recharge projects in Arizona occurred in GSFs.

Under its groundwater recharge program, Arizona has embarked on a program of recharge at an unprecedented scale. Particularly in central Arizona, the qualities of its aquifers, such as large storage capacity, areas of high permeability, and slow horizontal movement, provide conditions for secure, high-volume storage. As the growth in permitted recharge capacity and storage makes clear, the early period of restrained project development has been succeeded by rapid expansion.

Recharge Permitting

The Arizona Department of Water Resources issues three types of permits through the underground storage and recovery program: facilities permits, storage permits, and recovery well permits. In many instances, the facility permit holder and the storage permit holder are separate entities, but some entities hold both types of permits. Recovery well permits are issued only to entities with accrued storage credits obtained legally through the storage permit program.

Recharge Facilities Permits

The Arizona Department of Water Resources, in cooperation with the Arizona Department of Environmental Quality, permits all facilities operated under the water storage and recovery program. USFs and GSF have separate permitting requirements. In order to operate a USF, the permit applicant must prove that the project is technically and financially feasible; show that the facility will be closely monitored so that it does not degrade water quality; and ensure that the facility will not damage other land owners and water users. The applicant must

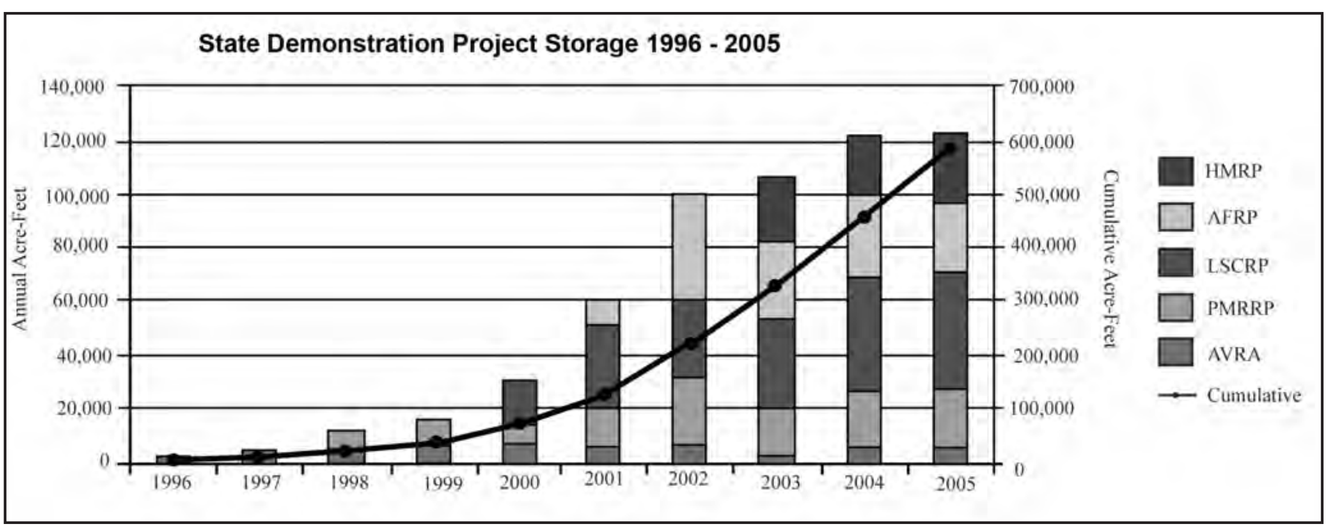
State Demonstration Projects Promote Recharge

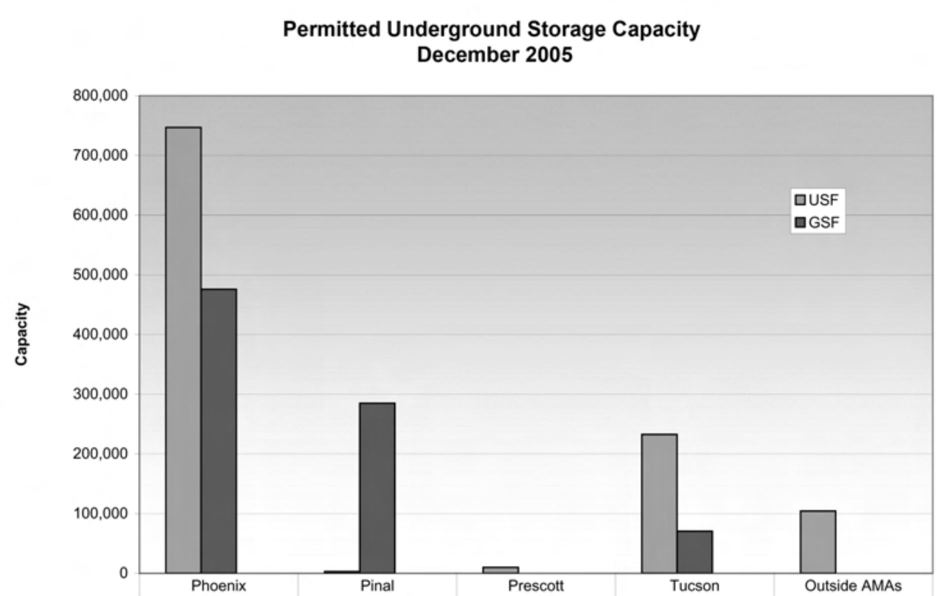
Legislation passed in 1990 recognized that recharge projects would be best promoted in the state by demonstrating their operations and effectiveness. Six demonstration projects were built by the Central Arizona Project, three in the Phoenix Active Management Area and three in the Tucson AMA. A seventh project has been designed and permitted: the Superstition Mountains. This project's East Salt River Valley site in the Phoenix AMA was chosen to offset groundwater use in an area where groundwater decline has resulted in land subsidence and fissures.

In the Phoenix AMA, water for the Hieroglyphic Mountain recharge project is pumped directly out of the CAP canal into a series of shallow basins. The Agua Fria Recharge Project is the only demonstration project to combine streambed recharge and infiltration basins in a single facility; a headworks structure captures streamflow at the end of the streambed recharge reach and directs it into a series of recharge basins. The recently completed Tonopah Desert Recharge Project pipes water from the CAP aqueduct directly to 19 spreading basins. In its first year of operation, 2006, it recharged more than 130,000 acre-feet.

The Avra Valley Recharge Project in Pima County was the first project built by the Central Arizona Water Conservation District and has operated since 1996. Both that project and the nearby Lower Santa Cruz Recharge Project have contractual arrangements with BKW Farms, a local irrigator, to carry water the short distance from the CAP canal to their basins through open irrigation canals. In contrast, the Pima Mine Road Recharge Project in Pima County uses a 2-mile long gravity flow pipeline to minimize transmission losses over that distance.

These demonstration projects have a combined capacity to receive 376,000 acre-feet of water each year. By the end of 2006 their combined cumulative recharge amounted to more than 824,000 acre-feet.





	Phoenix	Pinal	Prescott	Tucson	Outside AMAs
USF	746,871	3,056	10,081	232,647	104,299
GSF	475,840	285,000		70,472	
Total Capacity	1,222,711	288,056	10,081	303,119	104,299

also obtain a permit for floodplain use before beginning construction. For a GSF permit, the applicant must show technical and financial feasibility. In addition, the applicant must prove that he has the right and the ability to pump groundwater, but instead will substitute water from a renewable source, such as CAP.

The water quality section of Arizona's Environmental Quality Act requires that anyone planning a discharge that might reach the water table to apply for an Aquifer Protection Permit. Obtaining an APP requires monitoring and reporting and may require the adoption of best management practices or improved technology. Compliance is intended to "ensure protection of all current and reasonably foreseeable future uses of the aquifer."

Aquifer Protection Permits are required for effluent recharge projects but not for CAP projects or other surface water transferred to the recharge site through canals such as the Salt River Project canal system. Instead, the ADEQ certifies the Arizona Department of Water Resources' permit when the agency is satisfied that the project will not cause leaching of contaminants from the vadose zone or migration of a contaminant plume. ADEQ also reviews and approves the water quality monitoring plan for the recharge project. This process provides the water quality protection of both existing groundwater and the recharged water for future withdrawal and use.

Storage and Recovery Permits

The separate "storage permit" is granted to entities to store a specified amount of a specified type of water in a specified facility. Often multiple storage permits are issued for a single facility, so that the volume in storage permits can equal many times the permitted capacity of the facility. The permit does not require any storage; actual storage arrangements are negotiated between the facility owner/operator and the storage permit holder.

ADWR also permits recovery wells for recharged water. Generally, recharged water must be recovered within the same AMA where it was recharged. It may be recovered in the same area where it was originally stored, but recovery of water frequently occurs outside this "area of impact," particularly when the recharge facility is close to the CAP canal and the water use is many miles away. Recovery outside the area of impact is permissible if the recovery does not occur in areas with substantially declining groundwater levels, as defined by the recovery well regulations.

Granite Reef Underground Storage Project is First CAP Recharge Facility

When completed in 1994, the Granite Reef Underground Storage Project (GRUSP) was the first large-scale, direct recharge facility in Arizona intended for storage of CAP water. At 225 acres, it was one of the largest such facilities in the United States. Permitted to store 200,000 acre-feet annually, it has stored more than 870,000 acre-feet of water as of December 2006.

GRUSP was developed as a collaborative venture among the Salt River Project (SRP), Salt River-Pima-Maricopa Indian Community, and the cities of Chandler, Gilbert, Phoenix, Mesa, Scottsdale and Tempe to create storage for surplus CAP water in the Salt River Valley. It is operated by the SRP and stores water for the collaborating entities as well as for the CAP and the Arizona Water Banking Authority. Most of the water recharged to date has been stored for the AWBA.

The GRUSP facility was constructed in the bed of the Salt River, where the soil, sand and gravel allow for rapid percolation of water and minimal evaporation loss. In addition to CAP water, the facility recharges Salt and Verde River water. In 2007 reclaimed water from the City of Mesa will also be stored underground at GRUSP. Since 1994, the SRP has added three basins and plans further expansion as necessary.

Effluent Makes Up Big Share of State's Recharged Water Supplies

Effluent accounts for a significant amount of water recharged in Arizona. As of December 2005, 44 active Underground Storage Facility permits for effluent recharge were in effect in and around the Pinal, Prescott, Tucson, and Phoenix Active Management Areas. In addition, three active Groundwater Savings Facility permits for "indirect" effluent recharge had been issued, all in the Phoenix AMA, with a total annual capacity of 135,840 acre-feet.

Because the Prescott AMA lacks access to CAP water, projects there recharge only effluent and occasional flood flows from Granite and Willow creeks. The City of Prescott and the towns of Prescott Valley and Chino Valley all hold effluent recharge permits. Prescott has been recharging effluent from its wastewater treatment plant since 1996.

In the Phoenix AMA, the Town of Gilbert has a policy to reuse 100 percent of its wastewater. Three facilities annually recharge over 15,000 acre-feet of effluent. Wastewater also is used for golf course watering, artificial lakes, and landscape irrigation. The town's Riparian Preserve has 70 acres of recharge basins and marsh areas designed to attract wildlife and educate visitors about water and wildlife conservation.

Scottsdale's Water Campus underground storage facility has an annual capacity of 16,800 acre-feet for recharge of a combination of reclaimed wastewater and CAP water. The reclaimed water treated at the Water Campus is primarily used for golf course watering. However, during winter months, when golf courses require less water, it is recharged into the aquifer through vadose zone dry wells. The reclaimed water receives additional treatment through a process of microfiltration and reverse osmosis to meet Arizona Department of Environmental Quality standards for drinking water prior to recharge.

Glendale's Arrowhead Ranch Recharge Facility was the first in Arizona to use aquifer storage and recovery wells to recharge treated wastewater. The project stores effluent during times of water surplus for use during dry seasons. The recovered effluent is used mostly for golf courses and landscape irrigation. Glendale also accrues water storage credits from the West Area Water Reclamation Facility, which recharges almost 8,000 acre-feet of effluent each year.

In the Phoenix AMA, the town of Gilbert has a policy to reuse 100 percent of its wastewater.

In the Tucson AMA, Tucson's Sweetwater Recharge Facility was the AMA's first effluent recharge project. Begun as a demonstration project in 1986, the project became fully operational in 1991 and operates today with a permitted capacity of 6,500 acre-feet per year. Originally, effluent from Pima County's Roger Road Wastewater Treatment Plant, given tertiary treatment, was pumped to eight infiltration basins. A system of wet/dry cycles was adopted to resolve the problem of turbidity in the effluent that clogged the basins and reduced infiltration rates. Water table levels have risen in response to the recharge. In 1996, the Sweetwater Wetlands were constructed to treat the effluent before spreading in the recharge basins. The wetlands also provide habitat for wildlife, environmental education opportunities and an excellent place for bird-watching. Recovered water is served to reclaimed water customers. In anticipation of future needs, Tucson Water is considering expanding Sweetwater by installing a fourth extraction well, constructing additional basins and recharging effluent directly from the treatment plant.

Sweetwater Recharge Facility in Tucson, with eight recharge basins (RB-1to RB-8) and constructed wetlands

The Lower Santa Cruz River is being recharged by the Lower Santa Cruz River Managed Recharge Project. Permitted as an underground storage facility, the LSCRMRP has an annual capacity of 43,000 acre-feet of effluent. Nine separate entities hold the permit for this regional facility, eight more than most other recharge projects. The project provides streambed recharge over 16 miles of channel length. Because it is "managed" recharge, the storers receive credits for only 50 percent of the effluent delivered to the LSCRMRP in any year.

A water storage permit holder may choose to recover water in the same calendar year (annual storage and recovery) or to accumulate long term storage credits. ADWR maintains a long-term storage credit account for each storer. In most cases involving direct recharge of CAP water, storers get credits for 95 percent of the volume of water stored minus estimated evaporation. The state requires the other five percent to remain as a "cut to the aquifer". When water is recovered in the same calendar year it was recharged, the storer legally can recover 100 percent of the stored water.

Recharge and Water Quality

Water recharged in the state is either Colorado River water delivered via the Central Arizona Project, effluent, or other surface water, including stormwater. That the sources of recharged water are varied raises questions of water quality, especially when the recharge water is lower quality than the native groundwater. Recharge with effluent, for example, can introduce disease causing organisms and potentially harmful inorganic and organic chemicals into groundwater. In well designed effluent recharge projects, pretreatment can be an effective way to eliminate many of these water quality impacts.

It is also possible to improve the water quality of the recharge water through the recharge process. Soil Aquifer Treatment is a term used to identify processes (filtration, decomposition, adsorption, etc.) that improve the quality of recharge water as it seeps through the vadose zone. SAT typically reduces the concentration of many common pollutants such as microorganisms, biodegradable organic compounds, nitrogen, phosphorous, fluoride and heavy metals.

Recharge projects can be designed to solve specific water quality problems; for example, by enhancing conditions for denitrification to remove nitrates. However, SAT does not remove dissolved salts or minerals, such as calcium and magnesium. Recognizing these limitations, the Clearwater Renewable Resource Facility, Tucson Water's CAP water storage and recovery project, combines SAT, blending, and post-treatment to produce water of an acceptable quality for its customers.

Researchers at the U.S. Department of Agriculture's Water Conservation Laboratory in Phoenix have been leaders in SAT research for more than 30 years. Current research at the University of Arizona, Arizona State University, Stanford University, the University of Colorado at Boulder, and the County Sanitation Districts of Los Angeles County is investigating the use of SAT to reduce groundwater contamination and potentially increase water reuse.

Challenging water quality problems continue to arise. In recent years, one such problem has been synthetic organic compounds that are not removed by conventional wastewater treatment or SAT. Another growing area of concern is the presence of the byproducts of human birth control pills, other hormonally-active substances, and pharmaceuticals in wastewater. Effluent recharge projects, effluent discharges to water bodies, and irrigation with reclaimed water are ways for these substances to find their way into the environment, if only in trace amounts. Still, the underground fate, health significance, and environmental impacts of these substances are poorly understood.

Researchers at the University of Arizona's Office of Arid Lands Studies are investigating estrogenic activity in reclaimed water and storm water with funding from The University of Arizona's Technology and Research Initiative. Research is also increasing our understanding of subsurface biochemical and geochemical processes to answer questions about how recharge water reacts with native groundwater and the constituents of the soil and aquifer matrix.

The research has yielded some surprising results. For example, water pre-treated by reverse osmosis to a high level of purity before well-injection can aggressively leach chemicals from the aquifer. The chemicals may then pose a health risk when the water is recovered. Another counter-intuitive finding is that SAT can be more effective in removing harmful microorganisms when effluent has received less pre-treatment (primary rather than secondary or tertiary treatment).

Recharge and Subsidence

Artificial recharge is a tool with multiple uses in the water manager's toolbox. Not only can it be used to store water underground in times of surplus for use in times

CAVSARP Blends CAP, Groundwater

In 1995, Tucson voters passed a proposition that in effect prohibited direct delivery of treated Central Arizona Project water to the city. In response, the City of Tucson and a team of environmental engineering consultants together developed the Clearwater Renewable Resources Facility west of Tucson in the Avra Valley. As a component of the Clearwater program, the Central Avra Valley Storage and Recovery Project was constructed to blend Colorado River water with local groundwater via recharge and recovery facilities. As a large-scale storage and recovery project, CAVSARP is unique in Arizona. By design the project stores, blends and recovers water as needed, providing increased flexibility and reliability.

Initially, CAVSARP provided mainly groundwater since its screened wells pumped water from a depth below where recharged CAP water mixed with groundwater. As more CAP water is recharged, greater mixing with groundwater is expected, and hence a more balanced blend of CAP water and groundwater. Tucson Water officials estimate that at the end of 2005, the CAVSARP blend was 70 percent groundwater and 30 percent recharged CAP water. They anticipate a 50-50 blend in the near future.

Tucson benefits in several ways from CAVSARP and the Clearwater program. One key benefit is that the annual storage and recovery of large volumes of CAP water helps buffer water users from potential CAP water shortages and canal system outages. In addition, because the soil aquifer treatment filters out organic matter in the recharge process, the groundwater can be treated with chlorine rather than chloramines, thereby avoiding the public health concern associated with chloramines.

CAVSARP currently has a storage capacity of 80,000 acre-feet per year, and the facility may be expanded in the future. Recovery is expected to reach 70,000 acre-feet per year by 2008.

Subsidence near Eloy. Dates on the pole mark more than 15 feet of subsidence from groundwater pumping between 1952 and 1985. Photo: U.S. Geological Survey.

of shortage, it also is used to achieve other goals and control other water-related problems. For example, water recharged into an aquifer can mitigate land subsidence and earth fissure development. According to an Arizona Geological Survey publication, "subsidence is the downward movement or sinking of the earth's surface caused by removal of underlying support." A related phenomenon, fissures are land cracks or crevices in the earth's surface that can grow to considerable length.

In Arizona, subsidence usually results from pumping groundwater in excess of natural recharge. Groundwater fills any pore spaces between rock particles underground, creating what is known as "hydrostatic pressure" among the rock particles. As water is removed from these pore spaces by groundwater pumping, the elevation of the water table begins to drop. Without the hydrostatic pressure of the groundwater, the particles in unconsolidated aquifer sediments may compact and consolidate. As a result of this subsurface compaction, the land surface begins to lower, or subside.

Under the right conditions, artificial recharge prevents subsidence by replacing pumped groundwater. Because subsidence is typically "inelastic" however, recharge plays only a limited role in reversing subsidence. Furthermore, inelastic subsidence permanently reduces the water storage capacity of the aquifer.

While surface water recharge projects can help restore water table elevations, in some cases they may cause further subsidence, because the weight of the water applied at the surface can further compact underlying aquifer material. Well-injection recharge is likely to be more effective than other types of recharge in coping with subsidence because water can be directed to a specific location within an aquifer, close to the compacting layers.

Environmental restoration and preservation goals also may benefit from recharge activities. In the Upper San Pedro watershed, excessive groundwater pumping threatens the base flow of the San Pedro River. ADWR has determined that local recharge efforts are likely to reduce the groundwater overdraft that poses a threat to the river.

Underground Storage and Water Management

Recharging water for storage offers various water management opportunities. Annual storage and recovery has demonstrated its usefulness as a mechanism for water treatment, blending and delivery. Storing and recovering water seasonally through recharge can relieve seasonal strains on the water supply. For example, Scottsdale's Water Campus stores water in the winter for use during dry summer months. As the following sections show, water storage in Arizona's aquifers has allowed growth in AMAs without abandoning safe-yield goals. Long-term storage of CAP water has enabled full use of Arizona's entitlement and is providing a hedge against future declines or disruptions in supply. In addition, recharge program mechanisms for saving groundwater have enabled increased use of CAP water in agriculture. Even seemingly intractable problems among the states sharing the Colorado River have been mitigated through recharge.

Arizona Water Banking Authority

The Arizona Water Bank is in the business of long-term storage. It has provided new water management opportunities through its use of recharge.

The Arizona Legislature created the Arizona Water Banking Authority in 1996 because the state was not fully using its allotted CAP water, nor was it expecting to directly use its full allotment until 2030. Colorado River water that Arizona did not take was used by California, a situation that state leaders feared threatened Arizona's future right to the water. The AWBA was a strategy to keep the state's allocation within state as much as possible by recharging unused CAP water in Central Arizona to meet multiple objectives. Since its creation the bank has proved useful for implementing intrastate and interstate water transactions.

Arizona Banks Water for Nevada

In 2001, Arizona and Nevada entered into an agreement whereby the Arizona Water Banking Authority agreed to store 1.25 million acre-feet of water for the Southern Nevada Water Authority. Arizona agreed to store Colorado River water either by groundwater savings or by underground storage, up to a total of 1.25 million acre-feet. Because Nevada owns the credits, they may recover the long-term storage credits directly from the Colorado River, regardless of the physical location of credit accrual.

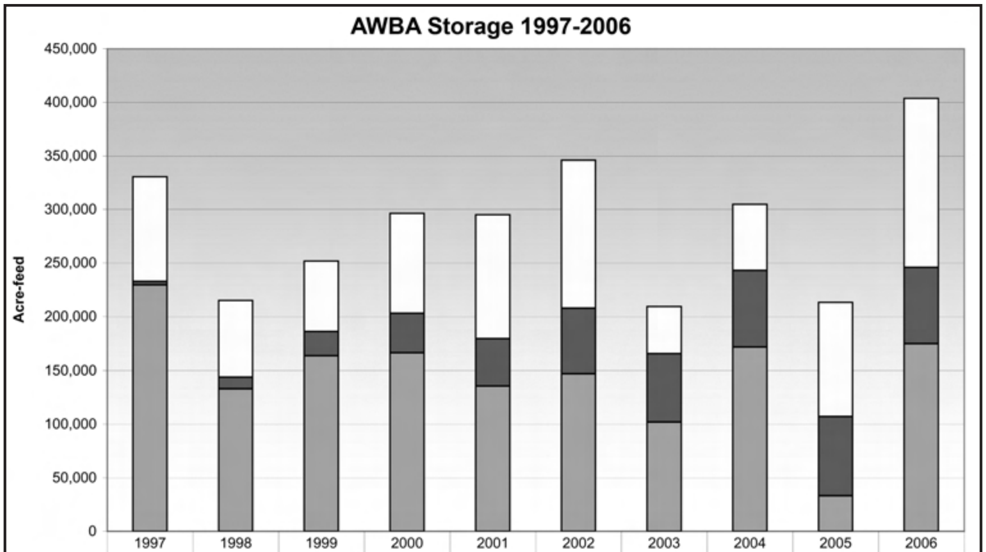
This arrangement benefits Arizona by providing financial resources to help develop alternative water supplies, providing revenues to aid Arizona's riparian protection program, helping to maximize Arizona's use of its Colorado River allotment, and most importantly, by strengthening the relationship between Arizona and Nevada. Strong interstate relationships are critical to achieving multi-state solutions to problems of drought and shortages on the Colorado River. Nevada also benefits because the agreement assures a firm water supply to the state for future use.

Between 2002 and the end of 2006, the AWBA banked over 386,000 acre-feet for interstate purposes, 80 percent of which occurred at GSFs in the Pinal AMA.

The AWBA is authorized to store water to meet specified goals. It stores water to protect municipal users from possible drought on the Colorado River or CAP delivery disruptions. Storage also helps meet Indian water rights claims. AWBA-stored water also can assist in meeting local water management objectives and in facilitating interstate water banking with California or Nevada (See sidebar on opposite page). Instead of constructing recharge facilities, the AWBA uses recharge facilities built by other entities, such as Tucson Water or CAWCD.

Funding for the AWBA has come from property taxes, groundwater withdrawal fees in AMAs with CAP water (Maricopa, Pinal and Pima counties) and, in some years, money from the state's general fund. The AWBA uses these funds to pay for CAP water and its delivery to storage facilities. The funds also pay the costs associated with recharge at USFs; the AWBA pays no facility charges for use of GSFs. Fees and taxes collected in the three CAP counties are used for the benefit of the AMA/county where they were collected.

The AWBA is also authorized to negotiate and enter into interstate water banking agreements with California and Nevada. Agreements are subject to approval of the ADWR director and must meet other conditions. Such agreements would allow California and/or Nevada to store or recharge unused Colorado River water in Arizona.



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Pinal	97,800	71,000	65,347	93,428	115,222	138,207	43,525	61,782	106,044	157,975
Tucson	3,200	11,000	22,470	36,325	44,276	60,659	63,805	70,898	74,088	70,643
Phoenix	229,600	133,000	164,057	166,696	135,637	147,117	102,086	172,127	33,141	175,160

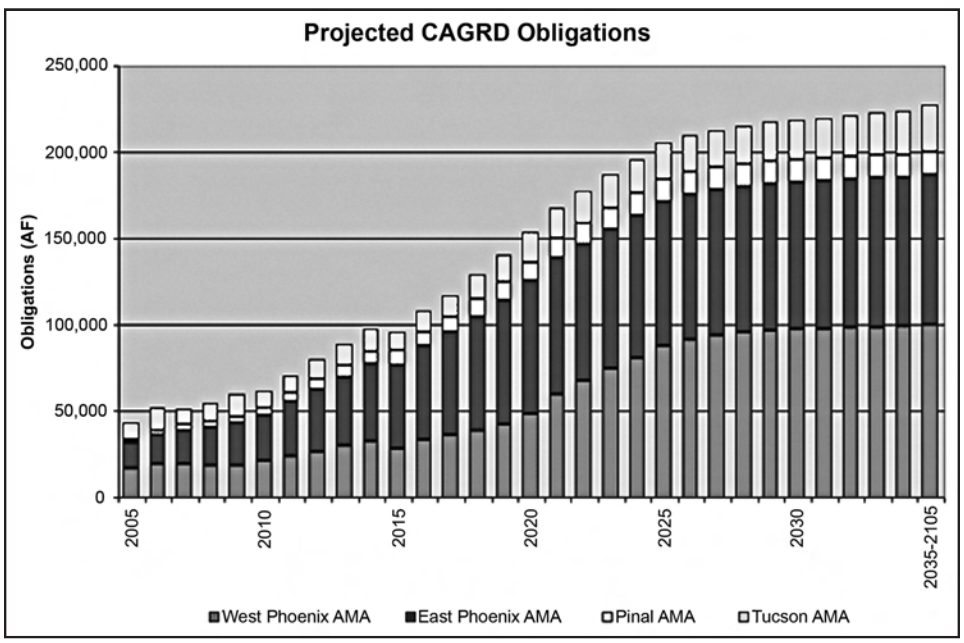
Even though the AWBA stands last in line for CAP water, it had stored more than 2.8 million acre-feet through 2006. Its storage potential has been proven, but a recovery plan for the stored water remains to be worked out, including cost estimates.

Central Arizona Groundwater Replenishment District

Recharge also figures prominently in the operation of the Central Arizona Groundwater Replenishment District. In 1993, the Arizona Legislature passed a law that provides a mechanism for subdivisions and water providers in Central Arizona AMAs to meet the Assured Water Supply requirement to use renewable water supplies. Under these rules, new subdivisions can not be developed unless they can show that the new homes will have enough water for the next 100 years. Some of this water must come from sources other than groundwater.

Entities that could not otherwise meet these requirements can pay a fee to the CAGRD for the "excess" groundwater served to the subdivision. The CAGRD then performs a checks-and-balance function, acquiring and recharging water to offset the mined groundwater. The recharge must occur in the same AMA as the groundwater was pumped. Because "replenished" water does not have to be recharged in the same location as the withdrawal, it may not check localized groundwater declines. Nevertheless, the overall management goal of AMA-wide safe yield is furthered.

Fees to the CAGRD are the same per unit volume for each of the participating "members" in an AMA but may differ across AMAs if the cost of operations differs. Members that are water providers pay the fee directly to CAGRD. When a subdivision is a member, each lot owner pays a portion of the annual fee in the form of an additional assessment on the property tax bill. One of the consequences of this arrangement is that the on-going costs associated with an assured water supply are not borne directly by developers, but are borne by the water user.



Critics of CAGRD are concerned that it allows developers to circumvent Assured Water Supply rules and may result in development of unsuitable areas. They question its reliance on recharge in the future for current groundwater pumping and ask where the agency will find the water to meet its replenishment obligation and how much it will cost. The seeds of this concern can be found in the very success of the agency.

The CAGRD has become a popular method of AWS compliance. By the end of 2003, 552 developments and 19 water providers had joined the CAGRD, with its cumulative replenishment obligation growing from less than 500 acre-feet in 2000 to almost 56,300 acre-feet in 2004. At that time the CAGRD had replenished 39,400 acre-feet of groundwater through direct recharge, groundwater savings, and purchasing and extinguishing groundwater credits. The CAGRD's annual replenishment obligation is expected to exceed 90,000 acre-feet by the year 2035 and possibly reach 225,000 acre-feet if membership continues to grow. If memberships and replenishment obligations do grow as anticipated, the CAGRD will become the largest recharge entity in the state.

Summary

In one sense, artificial recharge might be viewed as a relatively simple concept. Water is recharged into an aquifer to add to supplies depleted by groundwater pumping. In that regard, artificial recharge might be viewed as the reverse of groundwater overdraft, with water resources added rather than withdrawn.

In the 20th century Arizona faced the significant challenge of groundwater overdraft. In response to that challenge, the state made artificial groundwater recharge a key tool in its water management toolbox. The availability of excess CAP water created a unique opportunity to replace much of the mined ground water and at the same time achieve a number of related policy goals. A new recharge program and State Demonstration Projects legislation resolved fundamental questions and provided the means to start storing water on a large scale. It is in this context that Arizona is coming to understand and exploit the multiple facets and potential benefits of groundwater recharge as a management tool.

The AWBA, the CAGRD and the AWS program were brought into existence based on recharge and the flexibility it provides. The AWBA and the CAGRD are significant institutional innovations that depend on artificial recharge to fulfill their functions, and the success of the AWS program relies to a great extent on replenishment by the CAGRD. In addition, as the many examples show, jurisdictions around the state are looking to artificial recharge to solve local water resource problems.

Challenges remain. Overdraft, though diminished, is still a problem. For example, the AWS program may allow water levels in locally important aquifers to decline. Caution flags are waving over the unexpected growth in CAGRD membership and consequent replenishment obligation. The AWBA is struggling with the many factors that go into an acceptable recovery strategy.

Yet, through its recharge program and the recharge activities of individual communities, the state is in a better position to meet its water resource challenges. Undoubtedly, artificial recharge will remain an essential water management tool for Arizona into foreseeable future.

For additional information about recharge projects and activities discussed in this publication contact:

Arizona Department of Water Resources, http://www.adwr.state.az.us; **Central Arizona Project**, http://www.cap-az.gov; **Arizona Water Banking Authority**, http://www.awba.state.az.us; **Central Arizona Groundwater Replenishment District**, http://www.cagrd.com; **Arizona Water Resources Research Center**, http://ag.arizona.edu/AZWATER; **Arizona Water Institute**, http://www.azwaterinstitute.org